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INTERNATIONAL TECHNOLOGY COLLABORATION AND CLIMATE CHANGE MITIGATION

CASE STUDY 1: CONCENTRATING SOLAR POWER TECHNOLOGIES

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English - Or. English

FOREWORD

This document was prepared by the OECD and IEA Secretariats at the request of the Annex I Expert Group on the United Nations Framework Convention on Climate Change. The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

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Executive Summary

This case study reviews past and current experience in international collaboration in the field of concentrating solar technologies in order to identify lessons that may be relevant for more general climate-friendly technology collaboration. It presents concentrating solar technologies in their current status, recent achievements and development prospects. It analyses the present successes and failures of different forms of international collaboration in this field, and draws lessons for further elaboration of international technology collaboration in addressing climate change.

Concentrating solar technologies concentrate solar light to raise the temperature of a transfer fluid and run turbines and electric generators; they might also be used to produce hydrogen or other energy carriers. In regions with high direct solar insolation they can provide on-grid power at a lower cost than other solar technologies, though higher than fossil-fuelled plants. This power can be made dispatchable through heat storage of fossil-fuel back-up at a moderate cost, due to the use of turbines and electric generators. Though proven by more than 15 years of satisfactory experience in California, these technologies are still in their infancy; research and development efforts, combined with early deployment, may bring them to competitiveness in the power markets within one decade or so.

The IEA SolarPaces Implementing Agreement has been instrumental in organising international research and development efforts, sharing and dissemination information, promoting awareness and promoting cost-sharing of various experiments or scientific facilities. The Global Environment Facility has recognised the promises of these technologies to mitigate climate change, and is supporting projects in four developing countries: Egypt, India, Mexico and Morocco. It has not yet succeeded, though, in having any of these projects breaking grounds. Recently, several international organisations, national administrations and industry associations have joined forces to create a new form of international collaboration on concentrating solar technologies, the Global Market Initiative.

Four lessons emerge from this case study:

1. *International collaboration may help, but domestic policy decisions remain decisive*. International collaboration makes research and development efforts more productive and help keep momentum. However, the development of new climate-friendly technologies and industries require national or local governments to set up a policy framework providing the right set of incentives

2. *In technology transfer non-financial barriers must not be underestimated.* The Global Environmental Facilities uses financial contribution from industrialised countries to cover incremental costs of low-emitting technologies in developing countries. However, there are numerous other, non-financial barriers, that may impede such technologies transfers, and they deserve the highest attention from policy makers.

3. *Developing new technologies in developing countries only may not work.* The difficulties experienced in the GEF-supported concentrating solar projects in developing countries might be partly attributed to the lack of simultaneous similar activities in industrialised countries, preventing industry to benefit from experience in countries were risks are lower.

4. *Sharing the necessary "learning investments" might be a good idea.* To bring new technologies into the markets industries must benefit from research but also learn from doing. A certain amount of "learning investments" is thus needed. Coordinating national or local efforts to support early deployment may accelerate this process. However, R&D efforts remain necessary.

1. Introduction

1.1 Context and background

Mitigating climate change and achieving stabilisation of greenhouse gas atmospheric concentrations – the objective of the United Nations Framework Convention on Climate Change (UNFCCC) – will require deep reductions in global emissions of energy-related carbon dioxide emissions. Developing and disseminating new, low-carbon energy technology will thus be needed. Two previous AIXG papers have focused on possible drivers for such a profound technological change: *Technology Innovation, Development and Diffusion*, released in June 2003, and *International Energy Technology Collaboration and Climate Change Mitigation*, released in June 2004.

The first of these papers (Philibert 2003) assesses a broad range of technical options for reducing energy-related CO_2 emissions. It examines how technologies evolve and the role of research and development (R&D) efforts, alternative policies, and short-term investment decisions in making long-term options available. It considers various policy tools that may induce technological change, some very specific (e.g. R&D subsidies), and others with broader expected effects (e.g. taxes or cap-and-trade systems). Its overall conclusion is that policies specifically designed to promote technical change, or "technology push", could play a critical role in making available and affordable new energy technologies. However, such policies would not be sufficient to achieve the Convention's objective in the absence of broader policies. First, because there is a large potential for cuts that could be achieved in the short run with existing technologies; and second, the development of new technologies requires a market pull as much as a technology push.

The second paper (Philibert 2004) considers the potential advantages and disadvantages of international energy technology collaboration and transfer for promoting technological change. Advantages of collaboration may consist of lowering R&D costs and stimulating other countries to invest in R&D; disadvantage may include free-riding and the inefficiency of reaching agreement between many actors. This paper sets the context for further discussion on the role of international collaboration by describing the globalisation of the economy and current efforts of technology collaboration and transfer. Finally it considers various ways to strengthen international energy technology collaboration.

This paper is one of six case-studies designed in an effort to provide practical insights on the role international technology collaboration could play to achieve the objectives of the UNFCCC. They will all consider the past achievements of international technology collaboration, and the role it could play in helping to develop and disseminate new technologies in the future: what worked, what did not work and why, and what lessons might be drawn from past experiences.

Most case studies consider energy technologies that could help mitigate greenhouse gas emissions. A few others consider areas not directly related to greenhouse gas emissions but where international technology collaboration has proven particularly successful in the past.

1.2 A case study on renewables

Renewable energy sources offer a great potential for satisfying mankind's energy needs with negligible atmospheric CO_2 emissions. They are also inexhaustible, contrary to fossil fuels, and more widely spread over the Earth's surface.

There is a great contrast, however, between the theoretical potential – sun energy reaching the Earth's surface is about 9,000 times current total primary energy supply (TPES) – and industrial realities. If biomass and hydraulics represent significant shares of world's TPES of about 12% and 6%, other renewable energy forms do not.

Clearly, renewable energies are one area where technology development and dissemination in the coming decades can make a significant difference in global energy supply, and global CO_2 emissions. Therefore, it makes sense to devote one of our international technology collaboration case studies to renewables.

Renewables encompass a wide number of technologies and sources: biomass, hydraulics, ocean thermal energy, ocean tides and waves, solar heating and cooling, solar photovoltaics, solar thermal electricity, wind. For this case study solar thermal electricity – and more precisely concentrating solar technologies (CSP) – was chosen. Concentrating solar holds great possibilities with relatively little realities to date – a perfect example for renewable energies. CSP is already the subject of various types of international technology collaboration, with varying successes and this is what makes it particularly interesting. They are the following:

- IEA technology "implementing agreement": CSP is the main topic of IEA's so-called *SolarPACES* implementing agreement gathering private and public partners from both industrialized and developing countries

- GEF: CSP is also one the technologies selected by the Global Environment Facility for its "Operating Programme n°7" which aims at bringing new promising climate-friendly technologies to competitiveness through learning-by-doing processes.

- Global Market Initiative: CSP is the main topic of the so-called *Global Market Initiative* that has been endorsed by various environment ministers at the Bonn renewable energy conference in June 2004.

The combination of great potential, little realisation and diverse array of international collaboration forms makes concentrating solar an attractive area for further investigating international energy technology collaboration and climate change mitigation.

2. The Technology and its Potential

2.1 Basic features

While other solar technologies can use diffuse sunlight, concentrating solar power technologies (CSP) only use direct sunlight, concentrating it several times to reach higher energy densities – and thus higher temperatures when the light is absorbed by some material surface. CSP constitute the bulk of solar thermal power technologies – the only other technology in this family being the intriguing, but yet largely unproven, solar chimney concept (Schlaich 1995; Bonnelle 2003).

CSP provide electricity partly as most technologies relying on fossil or nuclear fuels do. They generate medium to high temperature heat, which is then used to operate a conventional power cycle, for example through a steam or gas turbine or a Stirling engine, which drives a generator.

These two basic features have two important consequences. First, CSP are best suited in areas with high direct solar radiation. These areas are widespread, but not universally found over the globe (see Figure 2 on page 12).

Second, because it uses a thermal phase, CSP technologies can easily make power production firm and even dispatchable, either by storing the heat in various forms, or by backing its production by some fossil fuel burning – in both cases using the same steam generators, turbines and generators. This characteristic allows alleviating almost entirely the intermittence problem, which may limit the expansion of various other renewable energy sources for producing power, such as wind or solar PV. Storage or back-up by fuels is also possible with the latter, but the necessary additional investments will be much more important than for concentrating solar. CSP plants displace capacities, not only energy, from other sources.

Back-up from fossil fuel or heat storage also gives a greater value to the electricity produced by moving it over time to better match the peaking load. Heat storage may also open up the possibility of continuous, solar only operations. There is no single, one-fits-all optimum design and operating mode: it will more likely depend on the needs of the utility.

CSP technologies are usually categorised in three different concepts: troughs, towers and dishes (see figure 1 below). Their main characteristics are as follows:

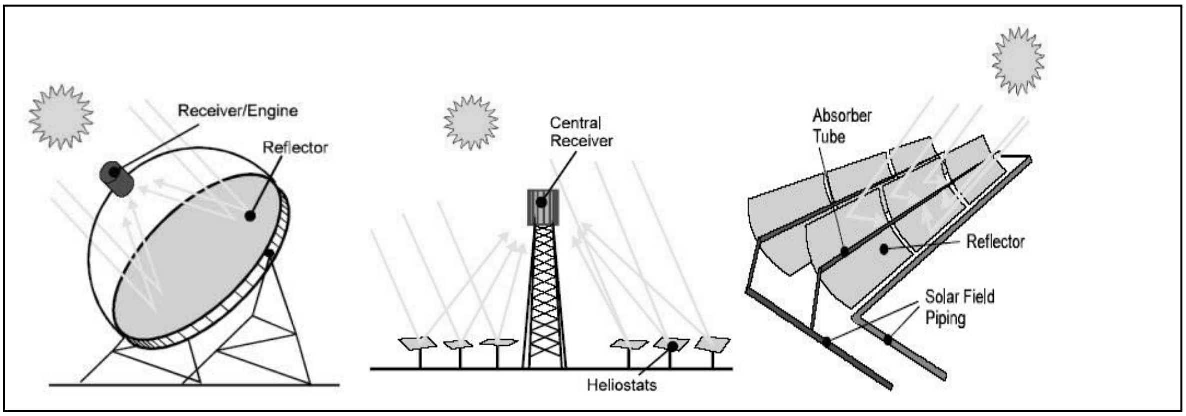
- *Troughs:* parabolic trough-shaped mirror reflectors linearly concentrate sunlight on to receiver tubes, heating a thermal transfer fluid which is then used to produce superheated steam. This is currently the most mature concentrating solar technology, benefiting from the accumulated experience of the 354 MWe of capacity built since the mid 1980s.

- *Towers:* Central receivers use numerous heliostats to concentrate sunlight on to a central receiver on the top of a tower. With two dimensions of concentration solar towers can reach higher temperature and may offer higher Carnot conversion efficiencies.

- *Dishes*: Parabolic dish-shaped reflectors perfectly concentrate sunlight in two dimensions, reaching the highest concentration ratios. They can run a small engine or turbine at the focal point. They are best suited for decentralised power supply and remote systems.

Apart from producing electricity, concentrating solar technologies have a broad range of other current or potential uses. Closest to power-only generation is the co-generation of power and heat, which may be used for warming and cooling buildings, providing heated water or process heat. Another option of interest for climate change mitigation is the production of hydrogen or other energy carriers (such as metals). Other applications include water detoxification, and the production of small amounts of clean high temperature heat for various research and development purposes (such as material testing). Only straight energy applications are considered in this paper.

Figure 1: Dishes, towers and troughs



Source: SolarPACES web site

2.2 Achievements to date

2.2.1 Luz success story

From 1984 to 1990 Luz International Ltd built a series of nine solar electric generating systems (SEGS) in the Californian Mojave desert, ranging from 14 to 80 MWe unit capacities and totalling 354 MWe of grid electricity. The $1.2 billion raised for these plants were from private risk capital investors and institutional investors (notably subsidiaries of East Cost utilities). These ventures were significantly aided by federal and State tax incentives (from 35% in 1984-1986 to 10% in 1989) as well as attractive long term power purchase contracts (Mariyappan, 2001).

Luz became bankrupt in 1991, after falling fossil fuel prices coincided with the withdrawal of tax credits and a change in the mandatory purchase contracts. However, all nine SEGS plants are still in profitable commercial operation with a history of increased efficiency and output as the operators improved their procedures (Mariyappan, 2001). SEGS-I and II (14 and 30 MWe) are run by the Dagget Leasing Corporation; SEGS-III to SEGS-VII (30 MWe each) are operated by the Kramer Junction Company, while SEGS-VIII and IX are operated by the Harper Lake Company.

The essential component of a SEGS plant is the field of parabolic-trough collectors, aligned north to south. Their basic element is the solar collector assembly module, with its own parabolic collector, sun-tracking and local control systems. The collector is a glass reflector (of typical aperture of 5 meters) which focuses the solar radiation directly onto a receiving metal tube enclosed in a vacuum with a glass envelope. A mineral oil is circulated as heat transfer fluid within this receiver. Working temperatures were raised from about 300°C to about 400°C from the first to the last SEGS plants.

These plants benefit from an average annual insolation of over 2700 kWh/m^2. They have generated more than 10 billion kWh, with a highest annual plant efficiency of 14% and a peak solar-to-electricity of about 21% having been reached. For most 30 MW plants, investment costs was about $3.9 per watt, while levelised electricity cost went from 24 US¢/kWh for SEGS-1 to 12 US¢/kWh for SEGS-VIII & IX (80 MWe each). However, the solar only power cost of these plants would be higher, close to 16 US¢/kWh.

A legal condition for benefiting from attractive purchase contracts was to limit back-up from fossil fuels to 25% of annual primary energy supply. Nevertheless, this back-up proved instrumental in lowering generation costs to 12 US¢/kWh. More importantly, it helps guaranteeing the capacity in peak and mid-peak hours (partly after sun set), which provides the bulk of the plants' financial revenues (Pharabod & Philibert, 1991). Except for SEGS-1, no heat storage had been installed on the plants.

The 150 MWe Kramer Junction solar power park achieved a 37% reduction in operation and maintenance costs between 1992 and 1997, and averaged 105% of rated capacity during the four-month summer on-peak period (12 noon-6pm, weekdays).

2.2.2 Other Achievements

There are a wide number of past and ongoing demonstration projects using parabolic dishes, mostly in Europe or in the US. Capital costs are currently estimated above 10 US$/W but might fall drastically with mass production.

There have been a dozen of solar towers built in the 80s as research and demonstration projects around the world, with capacities ranging from 0.5 to 10 MW (see table 1 below). None is still under operation. The most recent has been Solar Two, built in California in 1996. This 10-MWe was operated from 1997 to 1999, successfully demonstrating advanced molten-salt power technology. 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 (Mariyappan, 2001).

Heliostats represent the largest single capital investment in a central receiver plant. Capital costs for a 10 MWe plant are estimated US$70 million (i.e., 7$/W) but would be lower for a 100 to 200 MWe plant, the size that most experts believe would be optimal.

Table 1: Solar towers

Name	*Location*	*MWe*	*Mirrors (m^2)*	*Transfer fluid*	*Date*
Eurelios	Adrano, Sicily	1	6,200	Water steam	1981
SSPS/CRS	Almeria, Spain	0.5	3,700	Sodium	1981
Sunshine	Nio, Japan	1	12,900	Water steam	1981
Solar One	Barstow, USA	10	71,500	Water steam	1982
Themis	Targasonne, France	2.5	11,800	Molten salts	1983
CESA	Almeria, Spain	1.2	11,900	Water seam	1983
SPP5	Shchelkino, Ukraine	5	40,000	Water steam	1985
Solar Two	Barstow, USA	10	71,500	Molten salts	1996

2.3 Technology development prospects and economic potential

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. For example, today's parabolic trough developers state that their new collectors are 20% more efficient than those of the most recent SEGS – and some have demonstrated such improvements in fields.

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

- *Integrated Solar Combined Cycle Systems* would integrate a parabolic trough (or a solar tower) with a gas turbine combined-cycle plant, the solar heat supplementing the waste heat from a gas turbine to augment power generation in the steam Rankine bottoming cycle. This would reduce costs mainly by increasing the solar to electricity efficiency.

- *Direct solar steam*, where steam is generated at high pressure and temperature directly in the parabolic troughs (or Fresnel reflectors). This would reduce costs by eliminating the need for costly mineral oil and heat exchangers and reduce efficiency losses. This option might, however, make storage more complex.

- *Linear Fresnel reflectors* would approximate parabolic shape with fragmented mirrors. This could drastically reduce capital costs thanks to a low cost structure, a low cost fixed receiver which is composed of mild steel pipe, and exceptionally low reflector costs.

- *Molten salts use in trough field,* an option under investigation by the Italian ENEA (2003) would allow raising temperature and efficiency, thus reducing costs. The challenge seems to protect molten salts from freezing in the solar field at cold nights.

The potential for improvements is probably even greater with the less mature dish and tower technologies. However, their possible applications might differ significantly, with trough and tower technologies likely being used for grid-production, while dishes are more likely to find their niche market in remote applications or smaller isolated grids – where it could compete in sunny areas with the more expensive photovoltaic electricity.

While there remains a large potential for cost reductions from research and development on all elements of this technology, from global concepts to almost all elements, this potential could only be reached if there is an active marketplace for these technologies and entrepreneurs capable of integrating lessons from experience as well as concepts and materials from laboratories. The costs reductions experienced in only seven years by the Luz Company seem to offer a clear case for learning by doing improvements.

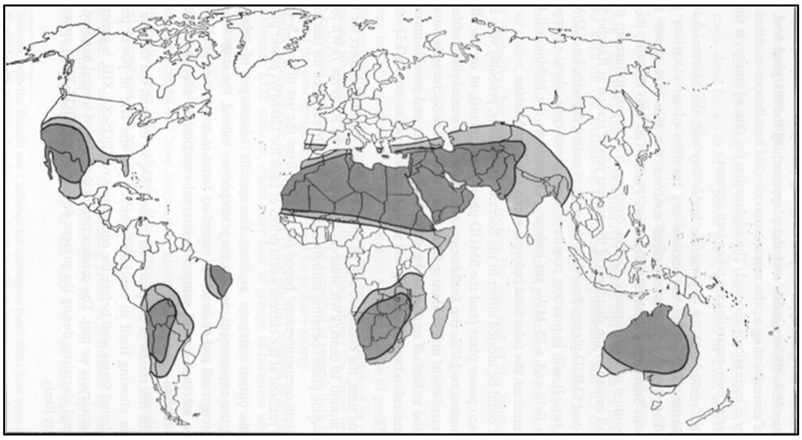
An active market place could also presumably reduce costs by mass production, economies of scale, reduction of risk premium and risk mitigation costs as the market develops, learning by doing of suppliers of parts and assemblers. In-depth studies suggest that full competitiveness could be reached for trough technology after the installation of 5,000 MW of capacity (see below the *Global Market Initiative*).

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

There exists no reliable map of the world indicating normal direct solar radiation. Estimates must be made on the basis of global solar radiation crossed with data relative to annual duration of sunlight (defined as hours when the sun is directly visible) and maps of climate and vegetation to take into account atmospheric humidity and interference. Ultimately, suitable areas are likely to be found in arid and semi-arid conditions in tropical areas. Figure 2 below provides one such attempt to map worldwide suitable resources for concentrating solar resources (Pharabod & Philibert, 1991). Some other maps are somewhat more optimistic with respect to the resource, especially in larger parts of Russia, China, the US, Latin America and central Africa.

Amongst the most promising areas are the South-Western United States, some areas of Southern America, the Middle East, central Asian countries from Turkey to parts of India and China, North Africa, South Africa, and parts of Australia. Even the sunniest European countries can only be rated a second choice for the quality of their direct solar radiation resource.

Figure 2: Suitable areas



Source: Pharabod & Philibert 1991

A striking example of the importance of the high quality of the solar resource is the proposal of the Italian ENEA to build concentrating solar power plants in North-Africa, rather than in Italy, and to import the power for satisfying the EU directive on renewable share of electricity production. The difference in costs arising from the difference in solar resource is likely to more than offset the costs of transmissions (ENEA 2003).

Although only a part of the world population lives in suitable areas for concentrating solar technologies, it is far from negligible. Suitable areas count no less than 70 multi-million inhabited cities, and gather populations with fast-growing energy needs, with relatively high time coincidence between peak load and sunlight. Exports to neighbouring countries – in particular when they accept to pay a higher price for green electricity – would further increase the potential market. Other resource constraints may arise from limited water availability.

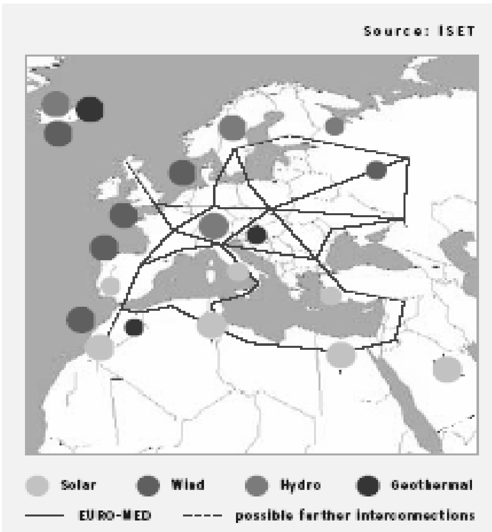
According to the US Department of Energy (DOE 2002), CSP plants on about three percent of the available land located within regions of premium solar resources could produce over 1,000 TWh of electricity each year, almost equalling the 1999 Western States' consumption. Perhaps even more strikingly, enough electric power for the entire US economy could be generated by covering about 9 percent of Nevada—a plot of land 100 miles on a side—with parabolic trough systems.

A scenario set up by the European Solar Thermal Power Industry Association (ESTIA) in cooperation with Greenpeace (Aringhof et al. 2003) envisages a world capacity of 21,450 MW of concentrating solar power, producing 54.6 TWh in 2020. Because CSP uses conventional technologies and materials (glass, concrete, steel, and standard utility-scale turbines), production capacity can be rapidly scaled to several hundred megawatts/year, using existing industrial infrastructure.

Such a scenario may not represent an ultimate limit for CSP technologies. According to the IEA (2003), before 2030 some 4,700 GW of total power capacity is expected to be built worldwide, either as additional capacity or in replacement of existing capacity. The Greenpeace-ESTIA scenario considers that in 2040, CSP plants could total 630 GW. This would probably represent a significant market share of power investments in sunny regions, as well as some exports to neighbouring areas (see, e.g., figure 3 below) – which, assuming a world with relatively high oil, gas and coal prices and CO_2 pricing might not be unrealistic.

For concentrating solar technologies to further expand its market share would likely require either unforeseeable progress in techniques for power transport, possibly from superconductivity. It is also possible that some energy-intensive industries shift production to areas with lower electricity costs – assuming other production factors can be provided as well. Another remote possibility is to produce hydrogen for future transport needs and decentralised power production.

Figure 3: Vision of a Euro-Mediterranean grid with large renewable resources



Source: Institut für Solare Energieversorgungstechnik, Germany

2.4 Current projects

The capability of solar thermal power plants to generate the lowest cost commercial scale bulk electricity and their ability to dispatch power as needed during peak demand periods have motivated several national and/or local governments to revive support the large-scale implementation of this technology. Among them Spain and the US state of Nevada have implemented in 2004 the most favourable regulatory and tariff framework for concentrating solar plants. A dozen other countries have projects in development or consideration.

In Spain, a Royal Decree established in March 2004 the same incentive premiums in the order of 0.18Euro/kWh for photovoltaic and concentrating solar plants up to 50MW capacity each, for the first 200

MW to be built. This incentive immediately attracted commercial developers. The forerunners are the Abengoa Group, who has broken ground for a 10MW tower plant PS10 in July 2004 and the Solar Millennium Group together with the ACS Cobra Group, who will break ground for its first 50MW AndaSol plant in Andalusia end of 2004. This trough plant of 500,000 m^2 mirrors will store heat for hours to closely follow power peak loads.

In Nevada, the state renewable portfolio standards initiated the first long term power purchase agreement of concentrating solar electricity signed between the public utility companies Nevada Power and Sierra Pacific and the US developer Solargenix. A 50 MWe trough plant will be built by the end of 2005, with 300,000 m^2 mirrors and storage of less than one hour to guarantee the capacity. In June 2004, the Governors of seven South-Western US States (New Mexico, Arizona, Nevada, California, Utah, Texas and Colorado) voted a resolution calling for the development of 30 GW of clean energy in the West by 2015, of which 1 GW would be of solar concentrating power technologies. In November 2004 the US Department of Energy decided to back this plan and to contribute to its financing.

With the financial support of the Global Environmental Facility (GEF - see below) Egypt, India, Mexico and Morocco are planning to build large combined –cycled power plants integrating solar trough fields in the range of 35 MWe. In India, the Rajasthan State Power Corporation Ltd. (RSPCL) has announced to publish a revised Request for Proposal before the end of 2004. In Morocco, the national electric utility ONE has published in May the request for prequalification. In Egypt, the New and Renewable Energy Agency (NREA) has announced to publish the request for prequalification before the end of 2004.

Algeria has become in February 2004 the first North African Country to implement national incentive premiums for the market introduction of integrated solar combined cycle plants (ISCC). The agency New Energy Algeria (NEAL) will develop and tender a first 160MW plant for domestic supply. Algeria wants to produce 5% of its electricity from renewable energy sources (mostly solar) by 2010 and to export electricity from ISCC plants to Europe.

The Government of Israel decided on November 2002 to introduce to its electricity market until 2005 the CSP as a strategic ingredient, with a minimal power unit of 100 MWe. The project is carried forward by the Ministry of National Infrastructures.

In Italy, the ENEA is developing a trough plant concept based on molten salts as heat transfer fluid. It aims at building large scale plants in North-Africa and import the power, to benefit from the green electricity price arising from the implementation of the EU directive on renewable in electricity production.

Australia intends to add a “coal saver” of CLFR 4 MWe (14 MW th) to an existing 1440 MWe coal plant at Stanwell in Queensland to demonstrate the Compact Linear Fresnel Reflector concept. The project, estimated to cost $7 million, received a technology commercialisation grant of A$2 million from the Australian Greenhouse Office.

In South-Africa, Eskom is considering the building of 100 MWe solar-only tower plant at Northen Cape. Other projects have been considered in Brazil, Greece, Iran and Jordan, and may surface again (Octobre & Garrigues 2004).

As both Luz’ success in the eighties and current project developments suggest, a favourable domestic investment environment appears to be a major driver for dissemination of concentrating solar power technologies at this stage.

3. International Technology Collaboration

3.1 Origins

As early as 1912 in Meadi, 25 km south of Cairo, a remarkable solar installation was built. Five 60m long parabolic, mirror-equipped troughs with an aperture of 4m, automatically tracking the sun at daytime, concentrated the solar radiation onto a tube in the focal line – like modern parabolic trough collectors – and in this way heated the circulating water inside almost to the boiling point. This installation as well had a hot water storage tank for the night. This hot water storage system operated a low pressure steam engine, which transported 24,000 litres of Nile water per minute to the fields for irrigation by means of a pump with a capacity of 40 kW.

The usefulness in practice already at that time impressed internationally. The members of the German Parliament then allowed 200.000 German Reich marks for such a solar plant in the German Southwest Africa colony, today Namibia. The First World War and the death of the American engineer, Frank Shuman, stopped further realizations and let the existing installation fall into decay. This was not only an early demonstration of international collaboration in this technology at the time of the so-called first globalization, but also an early demonstration of the strong interest from German authorities for concentrating solar techniques, currently expressed by the Federal Minister for the Environment and the state-owned bank group kFw, although German land does not offer the suitable solar resource.

3.2 The IEA SolarPACES Implementing Agreement

The IEA Solar Power and Chemical Energy Systems (SolarPACES) implementing agreement was initiated in 1977 as a cost-shared collaboration under the former name Small Solar Power Systems (SSPS). Current membership includes Algeria, Australia, Brazil, Egypt, European Commission, France, Germany, Israel, Mexico, Russian Federation, South Africa, Spain, Switzerland, United Kingdom, and the United States. From 1996 on, the European Commission contributed to the revival of European CSP developments, like the DISS, EuroTrough, EuroDish, Solgate and Solair Projects. Through SolarPACES, all these projects have led to share information with non EU countries.

The SolarPACES Executive Committee gathers delegates from national CST (concentrating solar technology) programs with a composite budget of 40-50 Million USD per year. SolarPACES is the only international, multilateral umbrella for CST cooperation. Three task annexes were formed:

- Solar Electric Power Systems
- Solar Chemistry Research
- Solar Technology and Applications.

A fourth Task on "Solar Heat for Industrial Processes" has been recently established in cooperation with the IEA Solar Heating and Cooling Implementing Agreements.

In 1997 the Strategic Plan for IEA SolarPACES was published. It expanded the role of this implementing agreement from one that has been focused largely on technology development to one addressing the full range of activities necessary to overcome barriers to large-scale adoption of concentrating solar technology. Its prime objectives were: support technology development, support market development and expand awareness of the technology.

An example of activities undertaken in this respect are the START (Solar Thermal Analysis, Review, and Training) Missions to provide technical input to countries interested in, but unfamiliar with, CSP technology. Start missions have been conducted in Egypt (1996), Jordan, Brazil, Mexico and Algeria (2002).

IEA SolarPACES' Membership, though it does not include all countries currently showing interest into CSP technologies, reflects the fact that the bulk of the potential is in developing countries, Australia and the USA. With six non-IEA member countries participating, and one out of four countries being represented by industries, it exemplifies the willingness of the IEA member countries to open its technology research and development implementing agreement to both non-member and industry participation.

One of the important assets of the SolarPACES agreement is the Plataforma Solar de Almeria (PSA), which was initiated as an IEA project (SSPS) and therefore was originally pursued with international contributions from Europe as well as from the US. Since 1988 financial support of the PSA has been taken over by Germany and Spain. A wide range of solar thermal facilities have been established and tested at PSA. The main components are two central receiver systems (CRS) of 0.5 MW (SSPS-CRS) and 1 MW (CESA 1), a parabolic trough system of 500 kW and three dish/stirling systems of a total capacity of 27 kW. PSA also has facilities for materials research. Direct steam generation, the Euro Trough and Euro Dish concepts have been tested at PSA.

Cooperation with industry is a key element in the SolarPACES cooperation. Over a fourth of the contracting governments designated industrial or utility partners as SolarPACES participants and Delegates to the Executive Committee.. Industry and utility partners are actively participating in the Tasks and their technical meetings and seminars, as reported in detail in the SolarPACES Annual Reports.

In task- and information shared cooperation, it is difficult to quantify the added value of the SolarPACES Implementing Agreement to the national projects. It is mostly the networking and catalysation effects of the joint meetings, workshops and symposia that give the communication basis and forum for initiating new projects, coordinating their methodologies and objectives, and sharing their results. SolarPACES has helped to strengthen national R&D capabilities for many of the participants through improved access to personnel exchanges, training, information, technology or equipment.

In almost 25 years of SSPS and follow-up SolarPACES cooperation, a strong and efficient network has been established within two generations of CSP experts from research, industry and utilities, who regularly meet at the biannual international CSP symposia and in subgroups at the Task meetings and workshop. There is no other academic network in the field of concentrating solar technologies.

In sum, SolarPACES seems to have been effective in achieving its purposes: maintaining alive the CSP community throughout the world, before, during and after the SEGS experience in California; facilitating exchange of information and experience, and cost-sharing experiments; and promoting awareness of CSP technology and potential. The launch of the CSP "Global Market Initiative" (see below) can largely be credited to SolarPACES, and may represent its ultimate success in achieving its stated objectives.

3.3 The GEF OPn°7

The Global Environment Facility (GEF) is recognised as the main financial mechanism of the UNFCCC and offers an entirely different form of technology cooperation – technology transfer. It covers "incremental costs"of projects in developing countries that mitigate greenhouse gas emissions. However, its Operating Programme n°7 aims more specifically at taking advantage of learning by doing processes to drive new technologies to competitiveness. It has identified CSP technologies as one of the most promising options for renewable bulk power production. The current CSP project GEF portfolio comprises four projects, in India, Egypt, Morocco and Mexico. These four projects were conceived as a group, and no more than four were envisioned before the next stage of market development would be reached, i.e. before a significant number of them would touch ground. They are briefly considered in turn.

- ***India***. As early as 1990, a feasibility study for a 30 MW CSP plant to be built at Mathania village near Jodhpur in Rajasthan was carried out by German engineering consultants, Fichtner, with assistance from the KfW bank. In 1995 a new feasibility study evaluated the option of integrating a concentrating solar field of 35 – 40 MW with a liquid fossil-fuel based combined-cycle power plant of 140 MW. The project entered the GEF work program in 1999 with a grant of $49 million. KfW committed the equivalent of $150 million loan. However, in September 2003, the Rajasthan Renewable Energy Corporation came to the end of an 18-month long bidding process, without receiving any proposals, after the International Competitive Bidding for the project Engineer-Procure-Construct (EPC) had already been postponed four times at the request of potential bidders. The RFP is currently being revised with the objective to attract new bidders.

- ***Morocco*****.** Pre-feasibility studies were performed by Pilkington Solar international with funding from the European Commission in the late 1990s. The study analysed solar only and hybrid integrated solar combined cycle (ISCC) stations of ranging from 30 to 140MW for several sites in Morocco. Based on these findings, the national electric utility ONE selected Ain Beni Mathar, in the north-eastern Jerada province**,** close to the new gas pipeline from Algeria to Spain for the implementation of a 240MW ISCC plant. The project includes a trough solar field with a natural gas-fired combined cycle. The Morocco project entered the GEF work program in May 1999 with a grant of $44 million. The project is now being developed on an EPC basis with an operation and maintenance (O&M) contract, while the legal framework in Morocco is being reformed to attract private Independent Power Projects in future. A Request for Prequalification has been published in May this year.

- ***Egypt***. The project at Kuraymat would be of a 120-140 MWe hybrid solar-gas combined cycle plant, with solar field producing 95 MW of thermal output, equivalent to 35 MWe. A GEF grant has been awarded to the Egyptian New and Renewable Energy Authority (NREA). Though specified in the concept stage as an IPP, the project has been modified to an EPC approach with an O&M contract for the first 5 years of operation. This changed concept is subject to securing public financing.

- ***Mexico***. The Mexico solar thermal hybrid project entered the GEF work program with a grant of $49 million in December 1999 as an IPP project at a specific site in Mexicali. Government of Mexico is now proposing a public sector solar-thermal hybrid under a build-transfer scheme under which the turn-key contractor is responsible for securing construction finance. Support from the GEF may take an innovative form, as the government of Mexico is seeking to directly stimulate renewable energy through a GEF-supported financial mechanism that will deliver incentive (tariff) support to jump-start the market.

In sum, none of the GEF-supported projects has been brought to the construction stage thus far, despite years of work and commitment. These projects are still alive, but the World Bank (2004), as the implementing agency for these GEF projects, is considering to deliver a firm timetable for the steps needed to complete the preparation and appraisal of the projects, with the understanding that if any milestones are significantly delayed, consideration would be given to dropping the project.

What lessons might be drawn from these mixed results? There is no single explanation to the delays, but rather a tangle of explanations. Each project has its specific history and context. For example, in the case of Mexico, there is a constitutional least-cost requirement prohibiting ex-ante commitment to procuring a solar-thermal hybrid, and incompatibilities between the bidding procedures of the *Corporación Federal de Electricidad* and the Bank procurement guidelines.

More generally, the lack of success of the IPP approach is attributed by the World Bank (2004) to be the result of risk aversion to this new technology, requiring relatively high investment for the hybrid projects, in the private-sector, coupled with the general global decline in IPP interest in developing countries. On the other hand, projects involving government owned utilities are vulnerable to changes in government, leading to the delay or termination of various energy projects. (Mariyappan 2001)

For the developers the country risks are perceived much higher than technology risks. They include permitting risks, but also fuel and water supply risks when specific infrastructures have to be built. Since the construction of the last SEGS plant in California in 1992, no plants have been constructed and the industrial teams of that time have disappeared. For today's bidders, these are first-of-their-kind projects with the corresponding risk surcharge on the project price. This is especially true for the integration of CSP into large combined cycles, which is a new concept that gives a leading role to companies that have no experience of solar fields. While the technology suppliers of combined cycles are economically strong companies, ready to fully guarantee all risks of their part, the surviving solar technology suppliers are comparatively very small companies, with little financial background. Since the publication of the attractive feed-in-law for CSP electricity in Spain, the situation is improving: much larger companies have been attracted and are willing to takeover the wrap around guarantees for the entire solar plant, including the solar part and the conventional part. Some of these newcomers have expressed their interest, to also bid for the GEF projects in India, Egypt, Morocco and Mexico.

By showing support for CSP 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. Overall, the GEF can take a lot of credit for giving life to an industry that was in danger. (Mariyappan 2001)

The four GEF projects have, however, not only suffered from the various bureaucratic difficulties that may have arisen from both the World Bank and the GEF, and the host country administrations, but also from the fact, that before 2004 their has been no market perspective for CSP plants in the developed countries. With this lack of a general market perspective, the four isolated GEF projects presented too little incentives to the power plant bidders, whose market expectations are Gigawatts and not Megawatts. To overcome this problem, all involved players had concurred in joining forces for a "CSP Global Market Initiative", described in the following. With the clear commitment of Spain as the first OECD country, to put attractive incentives for CSP market introduction in March 2004, this situation as changed. Upcoming Request for Proposals from the GEF solar thermal projects will clearly benefit from this.

A general conclusion might be that GEF efforts to develop new technologies in financing buy-down costs (or learning investments) must be better coordinated with similar efforts within industrialised countries themselves – for two reasons. The first is that suitable areas gathers some industrialised and many developing countries, and the larger is the participation to the global effort the more effective it will be; the second is that industrialised countries are more likely to have the institutional and technical abilities to assume the risk for new technologies. While the GEF provides industrial country money to fulfil the financial gap in developing countries, this does not necessarily overcome all the barriers to such innovative investments.

These examples also suggest that project driven approaches are less likely to succeed than country driven approaches. Bringing together all relevant stakeholders, including internal and external financing sources, at the earliest possible stage would help to avoid wasteful project development expenses. Further, these examples illustrate the ever present technology and political risks that must be addressed before there will be significant flows of private capital.

3.4 The Global Market Initiatives

In the CSP Global Market Initiative, the following organizations have joined forces in early 2002 to aggregate their individual efforts to promote, develop and implement Concentrating Solar Power projects:

- The German Ministry for Environment
- The Global Environmental Facility
- the United Nations Environment Programme
- the German State-owned bank group Kreditanstalt für Wiederaufbau
- the Solar Energy Industries Association (SEIA) of the U.S.
- the European Solar Thermal Industry Association (ESTIA), and
- The IEA SolarPACES Implementing Agreement.

The Global Market Initiative (GMI) aims at facilitating CSP uptake in markets that offer the most favourable conditions. Its purpose is to facilitate and expedite the building of 5,000 MW of CSP power worldwide over the next ten years – a global investment of about   10 billion.

Therein the CSP industry declared that solar power generation cost could be reduced by 20 %, once 400 MWe of new solar capacity have been implemented. Upon reaching 5.000 MWe of new solar capacity, solar generation cost shall be fully competitive with fossil-based grid connected power generation cost. In-depth studies such as Sargent & Lundy (2003) have given credit to such claims. Cost reductions would come from technology improvements, but also volume production and plant scale-up. As notes the Department of Energy (DOE 2002), parabolic trough technology has demonstrated a reduction in the cost of electricity of 15 percent with every doubling of cumulative installed capacity – and similar cost reductions have been demonstrated for other power technologies.

The GMI requests from participating countries or states to adopt specific target for CSP capacities, either in absolute numbers or percentage of CSP in newly built capacities; to ensure adequate level of revenue for CSP projects and provide a stable investment climate; to ensure that the project-based flexible Kyoto instruments become applicable to CSP; and to remove limitations on CSP plant capacity or operating strategies. It distinguishes three regions as follows:

- Region I countries and states have already partially implemented the policy measures recommended by the CSP GMI or will do so in the near term (e.g. southern Europe, south-western United States and Israel).

- Region II countries are or will soon be connected to Region I countries for trans-national power exchange (e.g. Algeria, Morocco and Mexico). Solar power from CSP plants in these countries could be exported to Region I countries and supported essentially by ratepayers as in region I countries.

- Region III countries are developing countries not interconnected to the grid of Region I countries (e.g. Brazil, Egypt, India, Iran, Jordan, South Africa). Subsidies from industrial countries are required to help these countries develop CSP plants.

The GMI was accepted as a World Summit on Sustainable Development (WSSD) "type II partnership" in Johannesburg in September 2002. At a follow-up conference in California in October 2003 a GMI Interim Management Team was set up and the IEA SolarPACES Implementing agreement mandated to act as its coordinating Secretariat. The GMI was then presented at the Renewables 2004 conference in Bonn and endorsed by the energy ministers of Algeria, Egypt, Jordan and Morocco and the environment ministers of Germany, Italy and Spain and the Israeli minister for national infrastructures.

4. Lessons Learned

4.1 Lesson 1: *International collaboration may help, but domestic policy decisions remain decisive*

Since the implementation of the Meadi parabolic trough plant near Cairo in the beginning of the last century, development of CSP technologies has been to a large extent an international collaborative effort. Several IEA countries joined forces in 1977 in the IEA Implementing Agreement on Small Solar Power Systems (SSPS), sharing the cost and the effort for the demonstration of tower, trough and dish technologies at the Plataforma Solar de Almería in Spain. In the success of the SEGS projects in the United States, the State policy was decisive in providing sufficient incentives but the international cooperation also played its role The parabolic mirror technology had just be proven at the SSPS project in Spain, the absorber tube, plant concept and collector design was developed in Israel, the financing was engineered in California, the steel structures were manufactured in Mexico, Brazil and Turkey, the absorber tubes in Israel, the mirrors in Germany, and the construction, operation and maintenance provided employment for US engineers and workers.

During the long years between 1992 and 2004, when oil prices were too low to motivate national governments to support CSP market introduction, the national R&D programmes on CSP were often reduced, sometimes close to be extinguished, had it not been for the commitments of international collaboration within the IEA SolarPACES Implementing Agreement.

However, the main factor explaining the building and successful exploitation of the SEGS plants in California was the legal and economic framework created at the federal level by the Public Utility Regulatory Policy Act (PURPA) of 1978, combined with various tax credits at federal and state levels. Under PURPA, utilities were required to purchase a portion of their power from so-called qualifying facilities, which were small, independent power producers, including many renewable energy companies. Similarly, the current revival of the technology seems to be driven by the new policies of Spain and the South-Western US States.

If it cannot substitute for domestic policies, international energy technology collaboration has nevertheless played a very important role in CSP technologies in reducing costs and multiplying benefits of many R&D efforts thanks to cost-sharing collaboration and information exchanges (Geyer et al. 2004). It has also played a very important role in raising awareness of the possibilities of CSP technologies and giving it credibility. It is well possible that in absence of international collaboration, the Luz success would be a unique experience with no follow-up. There are strong indications now that this will not be the case. The IEA SolarPACES Implementing Agreement, but also the GEF, can be both commended for this.

4.2 Lessons 2 & 3: *In technology transfer non-financial barriers must not be underestimated; developing new, large-scale technologies in developing countries only may not work*

The limited success that the GEF has had thus far with implementing four CSP projects in four developing countries suggests that non-financial barriers play an important role in preventing new technologies from making their way in developing countries. Policy framework, in particular, has tremendous importance. Even when more mature technologies are involved, many investment projects in developing countries never materialise for a wide variety of reasons.

Although integration of solar fields in larger combined cycle plants is an interesting concept, it requires institutional and industrial innovations beyond those achieved in California with the SEGS plants. Maybe the developing countries were not the most appropriate place for testing such new concepts in the difficult environment for foreign investment just described. International collaboration cannot be expected to overcome all barriers to investment and innovation.

A key for innovation and development of innovative technologies (including innovative industrial or institutional schemes to incorporating young technologies) is the direct involvement of industrialised countries and the existence of an active market on their own territories. Efforts under the GEF Operating Programme 7 to bring down costs of innovative technologies through market development in developing countries would be made more effective through explicit linkage with similar efforts undertaken in industrialised countries – what the Global Market Initiative is aiming at in case of CSP technologies.

In the case of CSP technologies, Australia, the US and, to a more limited extent, the European Union, are decisive because only they enjoy the necessary solar resource as well as the technological capabilities. A direct collaboration between the EU countries with less direct insolation and the technology-deprived North-African countries, as is currently developing, will be a major component of a global effort.

As the bulk of potential resources for CSP technologies rest in countries that are not bound by quantitative commitments on their GHG emissions by the Kyoto Protocol – Australia, the US and developing countries – the Protocol is unlikely to be a major driver for new CSP developments. Climate change mitigation, however, is not limited to the Kyoto protocol, and there are other drivers for these technologies, including the more efficient use of natural resources, improved local air quality, and energy security and development benefits.

4.3 Lesson 4: *Sharing the necessary "learning investments" might be a good idea*

For CSP technologies to provide significant contribution to greenhouse gas mitigation they will need to be fully competitive with other energy sources – at least if CO_2 emissions are duly priced one way or another. For this to occur, the building of new capacity totalling a few thousand megawatts may be as effective as more research and development efforts, so as to take advantage of learning-by-doing processes. This, of course, requires that someone pays the bill – the extra costs of using not-yet-competitive technology. If there are good prospects for reaching full competitiveness through learning-by-doing processes, these extra costs might be considered "learning investments".

Policy-makers may have numerous reasons to set up a policy framework that makes utilities pay for renewable power, from energy security improvements to contribution to climate change mitigation to strengthening national industries; international co-ordination of such efforts could reinforce their determination so long as participants see mutual benefit in such coordination. This would facilitate competition between industries on wider markets and speeding the learning-by-doing processes. The return on investment for each contributor will be greatly enhanced as the number of contributors increases. It should be noted, however, that what makes for mutually beneficial outcomes is creating an atmosphere that allows each entity to exploit its own comparative advantage, not having governments prescribe pre-determined technology and policy approaches. The recent decisions by the Spanish government and the seven US South-Western governors to facilitate the building of 1,2 GW in the coming years could be important steps.

However, even if trough technology is a proven technology, many technological improvements are still expected to contribute to the bulk of the cost reductions, along with plant scale-up and mass production.

This makes the next plants as much “demonstration projects” than strictly speaking “market deployment”. There might be a risk associated with financing such projects through market incentives: raising expectations that all projects will succeed, while technology failures or difficulties might not be ruled out. Other CSP technologies are less mature, and it would perhaps be safer, for example for large tower projects, to be supported from research and development funding – provided the current level of R&D spending on CSP technologies were increased.

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