The global CSP market - its industry, structure and decision mechanisms

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List of Abbreviations

CSP	Concentrating Solar Power
e.g.	(exempli gratia) for example
etc.	et cetera
EPC	Engineering, Procurement and Construction
EUR	Euro (currency)
GEF	Global Environment Facility
i.e.	id est
IPP	Independent Power Producer
ISCCS	Integrated Solar Combined Cycle System
HTF	Heat Transfer Fluid
kWh	Kilowatt-hour
LEC	Levelized Energy Cost
MWe	Megawatts-electrical
O&M	Operation and Maintenance
p.	page
pp.	pages
PPA	Power Purchase Agreement
PSA	Plataforma Solar de Almería
PV	Photovoltaics
R&D	Research and Development
RD&D	Research, Development and Demonstration
SEGS	Solar Eletric Generation Systems
USD	United States Dollar

1 Introduction

1.1 Objective

Concentrating solar power (CSP), also known as solar thermal power is a relatively unexploited form of renewable energy. The technology uses concentrated solar radiation for electricity generation and is most efficiently used for bulk power production in large-scale gird-connected power plants. This fact distinguishes CSP from many other renewable energy technologies.

Despite of the proven technology, the market development for CSP is very insufficient with crucial problems in the implementation of new projects. As a result, the CSP industry is still dormant industry.

Principally, most studies analyze the problems on the CSP market from a demand-side point of view and neglect the supply-side respectively the industry for solar thermal technology and services to a large extent. This thesis constitutes an attempt particularly at providing a characterization of the present CSP industry, their environment and potential markets. Therefore, the purpose and focus is to identify and characterize the main market player, the industry structure and market conditions, as well as the competitive environment in which the firms interact. Finally, the aim is to draw some conclusions as to which extent the industrial conditions could be held responsible for the weak market development.

Due to its limitations, it is not the aim of this study to provide a general justification for renewable energies or for CSP in particular.

1.2 Methodology and structure of the thesis

The thesis was carried out by collecting and reviewing available data and information on the market and industry conditions and preparing a final analysis in the end. In particular, the data collection includes sources such as expert interviews with key industry manufacturers, consultants and organization representatives.[1] The interviews have been carried out freely, which means that they

[1] A list of all interview partners is included in the appendix A.1.

did not follow a questionnaire, but were adapted to the specific knowledge of the interviewee. Another important source of data have been CSP publications by public institutions or international organizations, as well as information provided at the websites of the CSP companies, including annual reportings, press releases, etc.

During the analysis, comparisons are drawn frequently with photovoltaics (PV) and wind energy to get a benchmark to classify the present conditions in the CSP industry. About two decades ago both technologies were just as dormant as CSP is today, but have been very successful in developing markets and establishing competitive industries to date. Therefore, both could be considered as possible counterparts.

The thesis is organized into four parts: Technology overview, demand-side and supply-side considerations, industry and market analysis and final conclusions. First of all, chapter 2 starts with a brief description of the current state of CSP technologies. Chapter 3 provides a situation assessment and depicts descriptively market conditions and the present economic environment for CSP (demand-side), as well as the current project developer and provider of technology and engineering/consulting services (supply-side). The following chapter 4 is an industry analysis and attempts to develop probing, insightful answers to what kind of conditions characterize and shape the structure of the CSP industry. Finally, some conclusions are drawn.

Disclaimer

This thesis was prepared by Hajo Wenzlawski and supervised by Prof. Richard Tol (University of Hamburg), Dr. Dirk Aßmann (Wuppertal Institute, Germany) and Peter Hilliges (Global Environment Facility (GEF), Washington, D.C., USA / Kreditanstalt für Wiederaufbau (KfW), Germany). The views on the CSP industry and the market participants are those of the author and thus do not represent the Global Environment Facility or the Wuppertal Institute opinion. No warranty is expressed or implied about the usefulness of the information presented in this study.

2 CSP Technologies: Overview

2.1 General technology features

In contrast to photovoltaics (PV), concentrating solar power technologies are not producing electricity directly through solar radiation, but use concentrated solar energy to generate heat. This process heat is then used to generate steam and operate a turbine in a conventional power cycle.[2] Important features of most solar thermal technologies are their capacity for bulk power generation and their viability in a wide range of plant sizes from a few kilowatts to several hundreds of megawatts. For that reason, CSP has its place among the most cost-effective renewable power technologies and promises to become cost-competitive with conventional fossil fuel plants during the next decade if the introduction to the power markets will be successful in the end.

If approximately 1% of the world's desert area were covered by solar thermal power plants, sufficient energy would be generated to meet today's entire electricity demand [57]. Despite the few existing solar thermal power plants worldwide and the meagre public awareness, CSP is already a commercially proven and demonstrated technology. An intensified market penetration with accelerated grid-connected power plants is expected to lead to further technology improvements and cost reductions due to economies of scale and scope [4, p.2].[3]

The solar radiation is a large resource which is much more evenly distributed than many other natural resources and allows more facility locations globally than, for instance, hydroelectric or geothermal power stations. It can be collected by different types of concentrating solar power technologies: parabolic troughs,

[2] There is also a so-called *Concentrating PV* technology existing. A PV concentrating module uses optical elements (Fresnel lense) to increase the amount of solar radiation incident onto a PV cell. Therefore, it is similar to normal PV and has not the thermal nature of the CSP technologies discussed in this paper.

[3] Figure A.1 in the appendix provides a comparison of the current status and cost of different renewable energy technologies.

central receivers and dish/engines.[4] The basic principle of all CSP power plants is the concentration of sunlight through sun-tracking mirrors onto a small area to build up high-temperature heat and power. Because of the low energy density of the solar radiation, the collectors play a major role in this process. They have to be spread out over a wide area to capture enough solar energy to build up sufficient process heat. For parabolic trough and central receiver technology, the next steps of generating electricity are similar to conventional electricity production. The heat is transfered by a heat transfer fluid (HTF) in a heat exchanger which produces steam. The steam operates a turbine within a conventional power cycle to produce electricity. This kind of steam-based power plant with concentrated solar radiation as the main heat source is called Rankine-cycle system.[5] An additional fossil-fuel firing can be used whenever the solar radiation is not sufficient. These systems allow a high solar contribution (70-100%) but suffer from relatively low efficiencies, whether solar or fossil-fuel powered [54, pp.44].

Combined cycle systems powered with natural gas represent a more favorable type of plant with regard to efficiency, costs and emissions today [54, pp.47]. The combined cycle plant uses a gas combustion turbine as the first stage of electricity production. The hot flue gases from the turbine pass through a heat exchanger to generate steam which is used to drive a steam turbine in the second stage of the electricity generating process. To gain additional emission reductions, solar energy can be integrated into the second stage. These systems are called Integrated Solar Combined Cycle Systems (ISCCS).[6] The integration of a solar field must be well designed so that the efficiency of the combined-cycle does not decrease when solar heat is not available. Furthermore, the annual solar share is typically less than 10% in the ISCCS mode [79, pp.9]. However, the introduction of CSP is much easier than with solar only configurations, because the technology risks are much lower. Unaffected by the solar part of the plant, the large conventional part will be in reliable operation anyway.

In addition, the potential usage in a hybrid mode with fossil-fuels offers the opportunity to upgrade existing power plants. As mentioned above, this hybridization

[4]Furthermore, there are under development non-concentrating solar thermal technologies: *Solar Ponds* and *Solar Chimneys* ("Solar Tower"). Both use temperature differentials to generate electricity. At present there is a credible project in Australia promoted by the EnviroMission group to built a large 200 MW "Solar Tower" power station 600 km west of Sydney. This power station with an impressive tower almost 1000m heigh would meet the electricity demand of 200.000 homes. For further information see `www.enviromission.com.au`, or Parker (2002).

[5]A pattern of a Rankine-cycle plant configuration is provided in Figure A.2 in appendix.

[6]Figure A.3 in the appendix provides a pattern of an ISCCS plant configuration.

increases the value of CSP technology dramatically by reducing introduction barriers, decreasing cost by falling back upon standard power plant equipment and making a more effective use of it. Moreover, ISCCS configurations could be seen as stepping stones to solar only plants. Another advantage of CSP power plants is their capability to employ storage systems for bridging periods of low solar radiation. Both options reduce dispatch problems by allowing plants to generate electricity on demand, even when the sun is not shining like during cloudy weather, or in the early evening hours after sunset [75, p.5].

2.2 Parabolic Trough

According to the way of concentration different CSP concepts turned out for different applications and market segments. By far the most mature and prominent technology are parabolic troughs. They use large fields of linear trough-shaped collectors with a parabolic curvature to focus the sun rays onto thermal receiver tubes running towards their focal line (see Figure 2.1). A solar field consists of many parallel rows of solar collectors tracking the sun usually along on a north-south horizontal axis. This ensures that the sun is continuously concentrated on the linear absorber tube. The solar energy heats a heat transfer fluid (HTF), typically thermo-oil, which is circulating through the tubes. The HTF transports the heat to a heat exchanger in a power conversion system. Thereafter, the steam runs a steam turbine for generating electricity [38, pp.217].

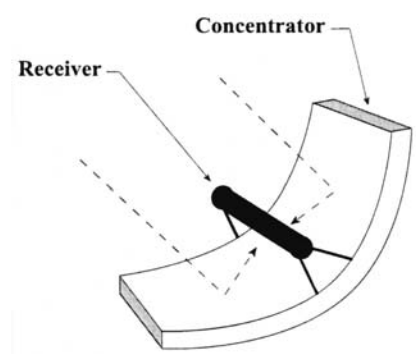

Figure 2.1: Parabolic Trough Principle [12, p.2]

The only commercially operated CSP power plants are the Solar Electric Generation Systems (SEGS) in the California Mojave Desert, approximately 160 kilometers northeast of Los Angeles. Based on parabolic trough technology nine

Rankine-cycle plants with a total capacity of 354 MWe generate about 90% of the world's commercial solar electricity today. This is enough power for about 100.000 homes [13, p.7]. The facilities were built between 1984 and 1991 by the Israeli-American company LUZ Industries Limited, the first commercial developer of private CSP projects. Owing to tax incentives for investment in renewable energy, an on-peak rate for electricity in summer afternoons (e.g. due to air conditioning), and high fossil fuel prices it was possible for LUZ to negotiate a long-term power purchase agreement (PPA) for solar generated power with the local power utility Southern California Edison (SCE). LUZ was not only the project developer of the plants but works also as planning and construction firm. In addition, the company managed to finance the power stations by bringing together a large number of investors. The construction of SEGS I and SEGS II began in 1984. This was the first time that sunlight was commercially converted into electricity on a large scale. Seven further plants with an electric capacity between 30 and 80 MWe have been added every year until 1992, which led to continuous technology progresses and the opening of significant cost reduction potentials. Similarly, experience of the ongoing operation and maintenance (O&M) of the facilities lead to further cost reductions. As a result of changes in taxation and financial incentives, LUZ went bankrupt during the construction of the tenth plant [23, pp.33]. But the SEGS I-IX, property of different private investment groups and managed by private operating companies, are successfully operating grid-connected until the present day. Parabolic troughs are presently the most economical option for solar thermal power generation. Consequently, also the Global Environment Facility (GEF) has been supporting the trough technology under its Operational Program Number 7 [7] since 1995. Because of its maturity, a parabolic trough plant could technically be built immediately today, but not as a business venture. Reality proves that currently non-technical problems persist.

2.3 Central Receiver

Central Receiver (or Power Tower)-systems consists of a fixed receiver located on top of a tower. Figure 2.2 shows a pattern of a power tower plant system. The tower is surrounded by an array of large individual sun-tracking mirrors called heliostats which reflect and concentrate the solar radiation onto the elevated receiver. The receiver absorbs the concentrated sunlight and transfers its energy

[7]"Reducing the Long-Term Costs of Low Greenhouse Gas-Emitting Energy Technologies"

to a circulating thermal transfer medium, usually molten nitrate salt. This heat transfer fluid is then used to make steam to generate electricity within the conventional power conversion system or could be pumped into a *hot* tank for storage. The molten-salt storage system retains heat very efficiently. Consequently, it is possible to store the contained energy for hours. Apart from this fact, the central receiver system collects solar energy very efficiently by optical means transferring the highly concentrated sunlight only to a single receiver unit. This minimizes thermal-energy transport requirements and generates higher process temperatures compared to parabolic troughs. Central receiver systems operate at temperatures of up to 1200 degrees Centigrade, which meet the demand of power-conversion systems in an optimal manner and offer favorable conditions for integrating highly efficient gas and steam units (ISCCS). This will reduce the levelized energy cost (LEC)[8] of this technology in the end which are presently expected to be a little bit higher than for parabolic troughs [38, pp.219].

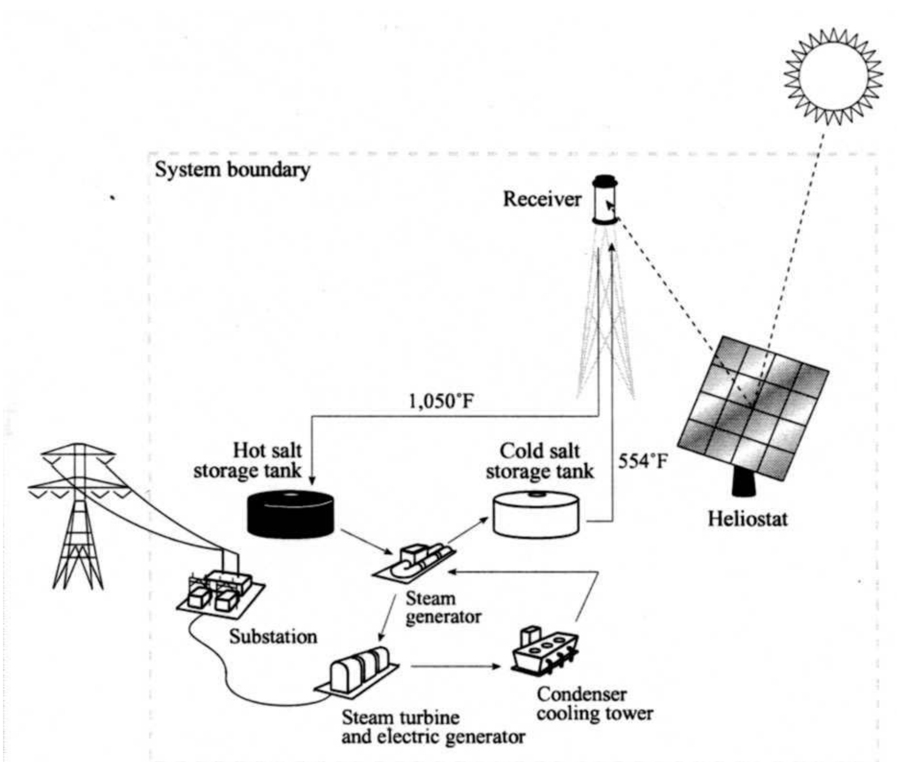

Figure 2.2: Central Receiver System [12, p.4]

After more than 20 years of experiments worldwide, the technical feasibility of central receiver tower plants has been proven in various demonstration projects

[8]Power plants are most frequently compared on the basis of their LEC, which relates the capital cost of the facility, its annual O&M cost and fuel prices to the annual electricity production [66].

in the USA and Europe for instance using different types of heat transfer media or heliostat designs. Beside a few demonstration facilities in Europe and Israel, the well-known plants are *Solar One* and *Solar Two* in the USA. The 10 MWe pilot demonstration plant Solar One operated successfully from 1982 through 1988 at Barstow, California, connected to the Southern Californian grid. Also the subsequent 10 MWe Solar Two plant, upgraded from Solar One with a molten-salt storage technology, met its demonstration objectives and helped to identify additional technology issues during its operation from 1990 through 1999. Furthermore, it proved the feasibility of delivering utility-scale power to the grid on a regular basis. [75, p.8].

Although, two to three projects for power technology are announced presently, no commercial plant has been built yet. One of the present project opportunities is PS 10, planned by a European consortium in Spain. Another major project is developed by an American technology consortium and the South African public power utility Eskom in South Africa. The African project can probably be seen as the successor of the recently given up, or at least dormant project Solar Tres in Spain, which is also based on the American Technology (Solar One and Solar Two) of Boeing/Rocketdyne and Nexant (Bechtel) [27]. Therefore, it might also include the molten-salt technology used in Solar Two, but scaled up by a factor of three to gain sufficient economies of scale.

In opposite to parabolic troughs plants, the central receiver technology has not been used commercially until today. The same is true for the storage system technology. One reason might be their still unproven costs and performance characteristics. It has to be taken into consideration that besides all promising future prospects this technology needs still more research and development efforts as well as bigger demonstration plants to come up to commercial use [4, pp.6].

2.4 Dish/Stirling

The third type of CSP system, the solar dish/engine, is a point-focus collector in the shape of a dish, concentrating the sunlight onto a receiver located at its focal point (see Figure 2.3 below). The receiver absorbs the solar energy and converts it into thermal energy in a heat-transfer fluid. The working fluid transfers the contained energy to a power conversion unit. This can either be a Stirling engine generator[9], located in one unit together with the receiver, or a central power conversion system at the ground if several dishes operate as part of a larger plant system. [38, pp.219]. Basically, dishes are in a position to deliver thermal energy for electricity generation, process heating, or other uses such as water pumping due to the mechanical energy of the Stirling engine. Because of its ideal optical parabolic shape and the two axes flexibility to track the sun, dish collectors achieve the highest efficiency of all concentrator types. They typically measure between 5 to 15m in diameter with a power generation capacity of some 10 kWe [4, pp.6].

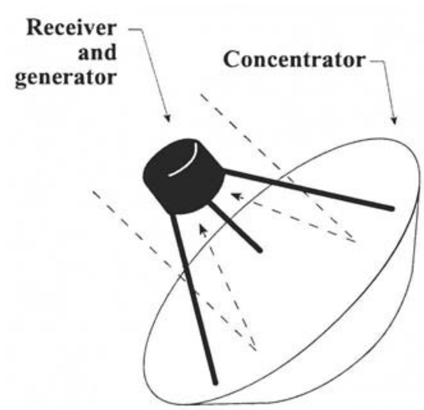

Figure 2.3: Solar Dish/Engine Principle [12, p.3]

Whereas both parabolic trough and central receiver technologies are typical concepts for grid-connected bulk power generation, dishes are very suitable for off-grid power production. In principle, utility-grid connection is possible as well by arranging independent dishes to a single power plant of any size to produce electricity up to the MWe range. But this solution is much more expensive compared to parabolic troughs and central receiver systems. Therefore, the important markets and fields of applications differ from those of the other CSP technologies. Dishes mainly have to be seen as decentralized power suppliers in remote areas, islands or rural regions of developing countries. For these specific applications dish/engines compete more with PV or conventional Diesel engines. This study, however, aims at examining the industry and market for CSP as means of bulk power generation. From this point of view the dish technology is excluded from further discussion.

[9]This type of engine converts the thermal energy into mechanical energy, which can be converted into electricity or other applications afterwards. The Stirling engine is named after the Scottish vicar Robert Stirling who already invented this principle in 1816.

3 Principal Markets and the CSP Industry

3.1 Demand-side

3.1.1 Principal markets and market potential

The most important requirement for CSP technologies is the availability of sufficient direct solar radiation.[10] Only direct solar radiation can be concentrated by concentrating solar collectors, such as parabolic troughs and central receivers. The annual solar radiation values should be at least 1700 kWh per square meter. The most desirable locations to meet this requirement are found in the arid or semi-arid regions of the world.

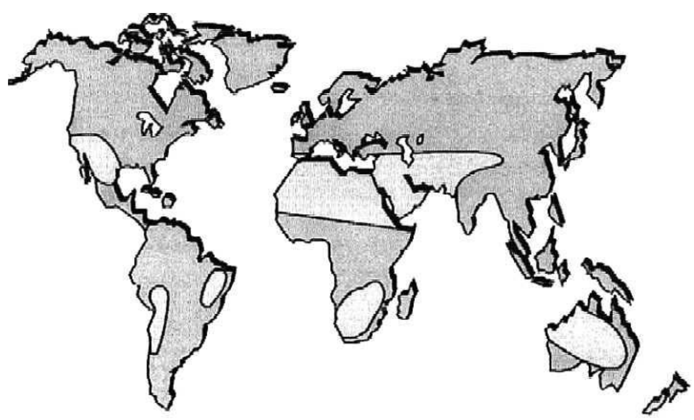

Figure 3.1: Global Solar Resources [54, p.15]

Figure 3.1 shows that the degree of direct solar radiation is high enough in many regions. These geographic areas are [79, p.16]:

➢ Mediterranean countries (including Southern Europe, North Africa and the Middle East)

[10]This is the share of solar radiation which passes the atmosphere without scattering and refraction. The total radiation in tropical regions is pretty high too, for instance, but the share of direct radiation is low due to haze and rainy seasons. Therefore, these regions are not suitable for CSP applications in general.

- Mexico and southwest USA
- Parts of India and Pakistan
- South Africa
- Australia
- Parts of Brazil and Chile

Despite the fact that the best conditions are mostly found in developing countries, the short term implementation of CSP facilities in industrialized countries is much more likely. These countries have the means and, due to accelerated public awareness of environmental problems, the political will to introduce renewable energies in their electricity markets. However, market barriers such as higher initial investment costs than for conventional power plants, or technological and regulatory risks prevented the commercial realization of CSP projects also in industrialized countries during more than one decade. At the same time, the focus was on other renewables like wind energy, PV or biomass. But especially in developing countries the electricity demand is growing at a fast pace due to population and economic growth. This makes solar thermal power even more suitable for many of these nations which are often located in the sunbelt regions of the earth [53]. In addition the authorities of these nations, which have expressed their interest in implementing CSP plants in their national energy sector, hope for various benefits. The expected advantages vary from increasing the independence on fuel imports, or the hope for technology spill over to significant positive impacts on the national labor markets. But developing countries are a difficult environment for investments. In addition to the general market barriers for CSP projects, they face high country risks which make it considerably more difficult to attract investors. The specific country risks vary between those countries but may include political instability, insufficient legal and administrative structures, economic vulnerability, lack of infrastructure and many more. Nevertheless, it is to be expected that the main future markets for solar thermal power will emerge in developing countries because of their outstanding solar resource.

Another incentive or advantage for industrialized countries to promote the CSP technology are not only future technology export opportunities to economies in transition and developing countries, but also electricity imports from the sunbelt regions to their own national power markets. The idea of a cooperation between northern Europe, in particular Germany, and the northern African countries in the field of solar thermal power plants have been raised in the 1980s. This is an interesting aspect especially for Europe - where clean and CO_2-free power are subject of increasing public concern - and the Mediterranean countries, which have very suitable conditions for CSP. An electrical interconnection might be beneficial to both regions, but it is not proven if an economic cooperation would really lead to welfare gains in the developing countries [78, pp.238].

The technical market potential worldwide is estimated at about 600 GWe over the next 20 years [54, pp.9]. However, due to the high cost of CSP and the competition with other forms of electricity generation, only a small share of this potential is likely to be exploited. The near term market penetration is probably to be with niche markets of high fuel costs or restricted access to fuel. Assuming a penetration rate of just 7,5%, which is dependent on further cost reductions, support from the public sector and energy prices, the market could possibly reach an annual installation rate of 2000 MWe [28, p.3].

The usage of CSP could not only create jobs, boost economies and might help to reduce the risks of energy related conflicts [73, p.5]. Moreover, this technology could play a major role in combating climate change by means of flexible instruments defined in the Kyoto Protocol. Those instruments may also help to reduce the higher capital costs in the long run [3].

The average current generating costs, or levelized energy cost (LEC) from hybrid parabolic trough plants of about 0,10 - 0,15 USD per kWh are much too high to compete in Europe's and North America's bulk power markets. This is also true for all kinds of renewable energies. However, the industry expect cost reductions to approximately 0,05 to 0,06 USD per kWh in the medium term after a successful penetration of the electricity market. This would be competitive with the typical fossil-fuel generation cost of 0,04 to 0,06 USD per kWh [13, p.7], [61]. In the meantime, electricity from CSP plants can compete in certain high-value and niche markets such as be the demand for peak power and correspondingly high-priced periods[11] and green marketing, for instance. The *green marketing* niche market refers to the possibility to market electricity from CSP projects directly to the customers by labelling the solar electricity as environmentally friendly. This can also be done by adding other renewable energies to such a power package. Many customers purchasing green marketing products are willing to pay slightly higher prices if they could be sure that the electricity were generated from

[11] The additional power for air conditioning in the afternoon when CSP plants are most efficient, for instance.

renewable sources [68, p.2]. However, it is doubtful that the share of customers for green marketing will be high enough to have significant effects on the market penetration of renewable energies.

In sum, high-value and niche markets can definitely help to lower the obstacles for introducing CSP in the power markets. But for the success in the long run it is absolutely necessary to achieve cost-competitiveness of CSP generated electricity compared to conventional generated energy. On the one hand, this aim can be achieved by stimulating further technological advance and gains of economies of scale and scope due to new commercial projects. The industry needs real investments and real projects even if in the beginning they are just on a small scale of only a few megawatts [62]. But on the other hand, cost-competitiveness can also be reached by simultaneously increasing fossil-fuel prices or internalizing of external costs of pollution. Thus, cost-competitiveness could be helped to reach from both sides [3].

3.1.2 Market barriers

Common barriers for the commercialization of CSP are high initial capital costs, financial risks, technology and regulatory risks, including the lack of present reference plants, cheap competing fuels, a dormant industry, the demise of LUZ, the liberalization of the energy markets (e.g. decreasing depreciation times of power plant investments), additional barriers in developing countries and high transaction costs, for instance. Basically, all barriers are known and manageable [47]. But there can be probably observed a cumulative effect of the single barriers.

Many of those obstacles will be mentioned in the following sections of this paper. The most important barriers capital cost, finance and risks are briefly depicted below. As a further barrier for CSP, transaction-costs are often just mentioned in passing in publications. But they might play a crucial role as well. Therefore, they are also briefly discussed in this section.

- Capital cost and finance. According to most CSP publications and to what almost all interviewed CSP experts indicate, the largest barrier for the commercial introduction of CSP is the high capital cost relative to conventional fossil-fuel plants. In the short term, the capital cost are approximately 2,5 to 3,5 times higher than for conventional plants. The higher initial capital cost is expected to be compensated by the savings in fuel costs and credits for carbon reductions during the operation [79, p.62]. High cost in comparison to conventional forms of electricity generation are a barrier themselves but are exacerbated by additional financial barriers. Because, other thing being equal, investors prefer safer assets and a riskier investment must have to offer a higher return in order to compensate for undesirable risks. Thus, the estimation about the project risk is crucial for the feasibility of financing. [17, p.341]. As a result, innovative financing is definitively another key to successful CSP market introduction [1].

- RISKS. In the context of a renewable energy technology, risks can be divided into *Technology risks* and *Regulatory risks*. Uncertainties are a result of those risks. The revenues from the operation of a CSP facility are at risk due to technology performance uncertainties. With any new technology there is a risk of failure or performing under the expectations. Customers will also experience one time start-up costs associated with system design, O&M, training, grid integration, etc. Hence, even if CSP would be equal in cost to conventional plants, there would be be some resistance to switch to the new technology as well [79, p.62].

  Regulatory risks can be fundamentally examined by instruments of the *political economy*. In the context of CSP, regulatory risks could refer to the problem of governmental incentives and their dependence on the uncertainty of the availability in future years due to possible political changes or government budget cutbacks, for instance. A famous example in this context is the refused extension of the investment tax credits in the USA in the early 1990s, which among other reasons lead to the bankruptcy of LUZ during the construction of the tenth SEGS.[12] But also policy distortions in favor of other energy sources or subsidies for conventional electricity sources fit in this context.

- TRANSACTION COSTS. Besides the higher technology and construction cost of a CSP plant, there are a lot of hidden additional cost, which arise by implementing large projects like CSP plants. In the recent economic literature there is a strong emphasis on the costs of market transactions, or in short transaction-costs. They include all costs connected with exchange relations, particularly contracting in a market. It is common to divide transaction-costs into five types:

[12] For further information about the economical and policy factors leading to the initial success of the LUZ's SEGS as well as the reasons and barriers which contributed to its demise please see Lotker (1991).

→ Cost of initiation

→ Cost of contracting

→ Cost of dealing

→ Cost of control

→ Cost of adaptation

The cost of transactions are fixed by certain characteristics of the required work, the economic behavior of individuals and firms, or the form of organizations [52, p.41]. Transaction-costs may also play an important role in the CSP market due to the long project implementation process and the unique character of every single plant project, at least in the beginning of the market development.

3.1.3 Customers

Having outlined the potential and principal markets, as well as possible market barriers, the following question should be answered: Who are the potential customers, respectively investors of such CSP plants?

The investors differ between CSP and PV or wind, for instance. Private homeowners are an important target group for PV due to its typical small scale applications. In Germany, the biggest market for wind energy at present, farmers still account for a significant market for newly installed wind capacity [24]. Because of the large scale nature of CSP, investors in this technology are only private investors groups, such as Independent Power Producer (IPP) and power utility companies due to the fact that the volume of a CSP investment ranges of some 100 million USD.

Until now, the few existing CSP plants are owned by private investor groups. All SEGS in California were created as limited partnerships each. The nine single IPPs merged into larger companies at the different sites today. Utilities are presently not the owners, but the entities who buy the solar generated electricity via long term Power Purchase Agreements (PPA), with the exception of the FPL group, a power utility from Florida and co-owner of two SEGS [19]. Anyway, there has not been much commitment by utilities to CSP until the present day.

However, the most favorable investors for CSP plant projects are large private or state-owned utilities. On the one hand, because of their experiences in the power markets and their financial possibilities. On the other hand, because the solar generated megawatts would only constitute a small part in the power portfolio of such a utility [47]. Thus, the investment risks would be much smaller due to diversification compared to IPPs, who rely completely on the single power station with its uncertain performance. However, utilities with a long-term, strategic interest in CSP were facing deregulation and market liberalization, which lead to decreasing depreciation rates for new investments. The companies are forced to concentrate on their core business and defend their market share. As a result, they do not take the risks to invest in uncertain CSP projects [1]. These problems are underlined by the electricity shortages in California and the major blackouts in the northeast of the USA due to general low investments in the electricity infrastructure.

Because of the deregulated electricity markets in most industrialized countries the utilities are usually under private ownership nowadays. In the developing countries, where the GEF projects are located, the utilities are mostly state-owned and additionally under serious financial trouble. Nevertheless, it might have been a mistake, that the GEF insisted on IPPs instead of allowing state owned utilities for the supported projects, because the financial environment in developing countries is often not sufficient to emerge strong IPPs who could handle such cost-intensive projects [27].

3.1.4 CSP promoters

This section attempts to provide an overview of the most important public as well as semi- and non-public institutions and organizations which are supporting the market development to a large extent. The criterion for this selection is, that these organizations invest in CSP technology by spending money either for technology R&D or the creation of market incentives. Figure 3.2 depicts all major supportive organizations which have a great deal of influence on the market demand and the industry participants. It could be argued that some of the mentioned organizations would also fit into the supply-side and not necessarily into the demand-side only. This is certainly true. For instance, the research institutions assist the industry in the development of new products, or the activities of the Development Financing Institutions (DFI) could lead to new projects by stimulating the demand, which also would have a big impact on the industry. In fact, many CSP promoters often act as mediators between the supply-side and potential customers (investors) and influence the market from the outside. Therefore, the CSP promoters could be considered as a third group being outside of the demand and supply categories as well.

However, the first and foremost task of all mentioned organizations is, or at least could be, the stimulation of the demand for solar power. In particular this is true for the governmental institutions such as the key ministries.

Organization / Institution	Objective	Country
EIB (European Investment Bank)	DFI (Development Finance Institution)	Europe
EU - Commission	DFI (Development Finance Institution)	Europe
GEF	DFI (Development Finance Institution)	International
KfW (Kreditanstalt für Wiederaufbau)	DFI (Development Finance Institution)	Germany
World Bank	DFI (Development Finance Institution)	International
BMU (Federal Ministry for the Environment, Nature Conservation and Nucl. Safety)	Gov. Ministry	Germany
DOE (Department of Energy)	Gov. Ministry	USA
Ministry of Economy	Gov. Ministry	Spain
Ministry of National Infrastructures	Gov. Ministry	Israel
CIEMAT (Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas)	Research Organization	Spain
DLR (Deutsches Luft- und Raumfahrzentrum)	Research Organization	Germany
Frauenhofer Institute for Solar Energy Systems	Research Organization	Germany
NREL (National Renewable Energy Laboratory) [Sunlab]	Research Organization	USA
Sandia National Laboratories [Sunlab]	Research Organization	USA
Weizmann Institute of Science	Research Organization	Israel
ESTIA (European Solar Thermal Power Generation Industry Association)	Advocacy Group	Europe
IEA/SolarPACES	Advocacy Group	International
SEIA (Solar Energy Industries Association)	Advocacy Group	USA

Figure 3.2: Global CSP Promoters

Four different types of CSP advocates and public support institutions can be identified:

- ➢ Development Finance Institutions (DFI)
- ➢ Government ministries
- ➢ Public Research Institutions
- ➢ Advocacy groups.

The Development Finance Institutions could provide money and grants to cover the incremental costs of new projects and equalize possibly weaker financial capabilities of countries suitable for projects. Governmental ministries become more evident on the national level. The essential ministries are located in the four countries which are promoting CSP the most: Spain, Germany, USA and Israel. Their aim is to support the development of a CSP market by implementing market incentives, financing R&D programs and supporting public private partnerships between research laboratories and the industry.

The research institutions assist the industry by developing and commercializing solar thermal power technologies. They provide scientific know-how and resources as well as demonstration facilities. In the USA, the Department of Energy (DOE) administers its CSP Program through SunLab, a virtual laboratory that combines the expertise from the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories. In Europe these are the German Aerospace Center (DLR) and the Frauenhofer Institute for Solar Energy Systems also located in Germany, together with the Spanish Center for Energy, Environment and Technological Research (CIEMAT). The major part of CSP research in Israel is done by the Weizmann Institute of Science.

Besides the USA, Australia has the most extensive solar resources of all industrialized countries and is also doing research on solar thermal power technology. Especially the research activities of the University of Sydney together with industrial partners (e.g. Solar Heat and Power Pty Ltd.) regarding Linear Fresnel Systems could be mentioned. However, there are currently only little institutions respectively industry participants which are committed to parabolic trough or central receiver technology development. Due to the vast coal resources (Australia did not sign the Kyoto Protocol) it is hardly possible for CSP to compete with the low domestic energy prices. As a result, it is very difficult to gain domestic investment capital for CSP projects [25]. In this context, the outcome of the solar chimney project, which is admittedly a non-concentrating solar technology, has to be awaited.

The advocacy groups mentioned in Figure 3.2 are committed to CSP anyway. To operate as advocacy groups, they need funds and also spend money on their promotions. They attempt to influence political decisions and support the view of its members. Apart from the biggest groups ESTIA (European Solar Thermal Power Generation Industry Association) and the American SEIA (Solar Energy Industries Association) there are some other national industry associations worldwide with only little influence. IEA/SolarPACES (International Energy Agency's Solar Power and Chemical Energy Systems) is an international cooperative organization trying to coordinate efforts on the development and marketing of CSP systems. It is managed under the patronage of the International Energy Agency (IEA) helping to find solutions to worldwide energy problems.

Certainly, there are other national ministries or associations existing worldwide who have expressed their interest and potential support for CSP development. This includes mainly institutions in countries which declared themselves willing to host CSP projects in their country, but did not make any remarkable efforts in the way of financing, or actively promoting CSP development yet. An example are the governments and ministries which are hosting the GEF supported projects.

3.1.5 The role of the public sector

3.1.5.1 Policy mechanisms

As a result of the existing barriers and combined with other distortions in the power market, it is not possible that a market for solar thermal technology emerge without public support. But if there is no market, no further cost decrease for the technology is expected to happen. Therefore, special policies to create incentives have been and continue to be necessary for CSP to penetrate the electricity markets. This is true not only for CSP, since long term and stable incentive programs are needed to attract financiers to invest in renewable energy technologies in general [49, p.6]. Thus, the main role of the public sector, respectively of the government is to act as a regulator. From an economic theory point of view, however, the primary reason for considering public policy interventions in the power market are the existence of market failures and barriers that inhibit socially optimal levels of investments in renewable energies [20, pp.375]. In fact, there are various reasons and justifications for the public sector to intervene in the power market and it is unclear if these are always cases of market failure. It is argued that the government should do something to halt the negative external effects of pollution (e.g. to combat climate change), protect scarce resources, support future technologies or diversify the energy sector to obtain an energy-mix. Especially a well-balanced energy-mix, where conventional and renewable generating systems are not in conflict would help to maintain the supply security. The major blackouts in the northeast of the United States in August 2003, as well as in London two weeks later emphasize that massive deregulation of the energy sector do not necessarily lead to efficiency gains in the energy supply [18, pp.106].

Markets with a long term perspective are not emerging necessarily on their own, because markets often follow a short-term view only. Hence, to stimulate the demand for CSP the motivation has to be of another nature than purely financial. From this point of view, a collaboration with the public sector is absolutely necessary for the CSP industry [10]. It is obvious, that the public sector as a market regulator plays a major role with profound impacts on the emerging industries. There would not be any markets for renewable energies, if the public sector had not helped to establish them by creating and using different policy mechanisms. Some policy instruments, like environmental taxation, aim at correcting market failure by taxing different environmental impacts accordingly. Other instruments, like investment subsidies, aim to expand the market size and thereby stimulate the technological advance and economies of scale. The following selection of policy mechanisms have been used to promote renewable energies in general and are also important for CSP in particular [59, pp.168].

- Investment incentives. They aim to reduce the capital costs and induce financiers and developers to invest in projects. This could be investment subsidies, investment tax credits, or other investment tax incentives, such as accelerated equipment depreciation, property tax reductions, and so on.
- Production incentives. These are subsidies to reduce the cost of electricity production from renewable energies and are paid per generated kWh. They could be paid either as a direct cash subsidy or could be provided as tax credits per produced electricity unit.
- Renewable Portfolio Standards (RPS). In the ongoing deregulation process of the energy sectors in many countries mandates have been developed ensuring that at least a certain percentage of the total generated electricity come from renewable sources. RPS are considered to be the most important driver for renewable energies in North America over the next 10 years [49, p.34]
- Research, development and demonstration grants. The public goods character of R&D can be underlined by direct government funding. Many governments provide research, development and demonstration (RD&D) grants and industry-government alliances to improve the technological and knowledge base [9, p.1204].
- Power Purchase Agreements (PPA). The majority of all renewable energy projects have been implemented by IPPs with no relations to utilities. Thus, the only possibility for renewable energy facilities to sell the generated electricity is to get access to the utility's distribution and transmission channels. Therefore, contracts have to be negotiated

which arrange the purchasing of the power by the utility to gain stable revenues. Because such projects are generally considered risky by financial intermediaries, reliable, long term and sufficient PPAs are the single most criterion for the development of a significant installed solar thermal power capacity in the near future [59, pp.168] [25]. Those long term contracts could be either individually negotiated with the local power utility by the IPP, or ordered/mandated by national power purchase agreements. The latter are more preferable, because in general they are more reliable and the transaction costs are much lower.

A very good example of the way those mechanisms work underlines the experience with the economic environment in California in the middle of the 1980s. A sufficient power purchase agreement with the local utility Southern California Edison combined with tax and investment incentives allowed the construction of the SEGS within a few years. This dynamic was interrupted due to the sudden deterioration of the favorable Californian conditions. The demise of LUZ shows that stable and reliable incentive programs are absolutely necessary to support new kinds of technologies and industries. Any *stop and go* conditions are poison for emerging industries. In the case of LUZ, it was a failure of the political environment in California and not of the technology [36].

Wind energy is a positive example showing that long term policies can create markets. Due to the stable conditions in Germany and Spain it was possible for wind energy markets to emerge significantly during the last decade [77].

To sum up the policy implications of the public sector it has to be emphasized that a long term government commitment to guarantee the incentives is crucial for a successful market development. Furthermore, the type of incentives applied need to reflect the different development stages of the promoted technologies. Such a policy could lead to significant additional shares of renewable energy as a result[49, p.6].

Germany and Spain are the most prominent and significant examples for countries with a PPA on the national level, which regulates the supply of electricity in the grid. The governmental justification for these subsidies are, besides environmental aspects and the security and diversification of the energy supply, investments in future technologies.[13] Germany established the *Renewable Energy Sources Act (EEG)* and Spain the *Royal Decree* to generally support the development and implementation of renewable energies. Until today, both countries gained socio-economic benefits, such as many new jobs in the wind technology industry.[14] Particularly the recent modification of the Decree in Spain will most likely contribute significantly to the implementation of the next CSP projects. Therefore, a more detailed look at the Decree is given in the next section.

3.1.5.2 Royal Decree in Spain.

The modification of the "Real Decreto 2818" in August 2002 is very important for the development of CSP in Spain. The Royal Decree established tariffs to promote the production of electricity from renewable energy sources and supported mainly the development of local wind energy applications during the last years. This was a very successful strategy and lead to a well emerged high-technology industry with impacts on the domestic labor market. Spain achieved an installed total wind capacity of 4,830 MWe by the end of 2002, which takes the country to number two in the world behind Germany (12,000 MWe) [48]. Now the present modification of the decree grants incentive premiums of 0,12 EUR/kWh also for larger power generating facilities, such as solar thermal power plants with a maximum power unit of 50 MWe. At a current market price for electricity of 0,03 to 0,04 EUR/kWh this premium leads to an entire remuneration of 0,15 to 0,16 EUR/kWh. The premium is restricted to CSP plants fueled by solar radiation only. A hybrid mode with fossil fuels is just permissible for frost protection, i.e. for molten-salt storage systems [58, pp.55].

As mentioned in section 3.1.1, the costs of parabolic trough generated electricity is often estimated between 0,10 to 0,15 USD/kWh which corresponds to about the same amount in EUR. Despite the entire remuneration of 0,15 to 0,16 EUR/kWh granted by the Royal Decree it seems to be difficult to attract financiers and make an economic calculation over the years of operation. Perhaps this could be

[13] In addition, the import of CSP generated electricity from North Africa as a part of the future energy supply has been discussed in Germany for many years. From this point of view and beside environmental considerations and future technology support, it is explicable why German public institutions and industries are so strongly committed to CSP technology despite the fact, that the German solar resources are completely unsuitable for the domestic commercial usage.

[14] In Germany, more than 35.000 jobs have been created within the wind industry and about 130.000 employees have been working within the whole renewable energy industries in the year 2002 [31]

an indicator that the current costs are more likely about 0,15 EUR/kWh than further down [30].

Every four years, an adjustment of the premium is made possible by the Spain government. This is a very short period to base investment decisions on that fact which run for more than 20 years. As a consequence, it is possible that this uncertainty may raise the additional risk bonus for the interest rates which would make it even harder to run the plants profitably [8]. But Spanish bankers seem to be quite relaxed as it is a similar procedure as for the domestic wind energy support. Hence, there is a great trust within the financial organizations in Spain that the procedure for CSP will be the same. In the beginning, up to a total capacity of 200 MWe, the premiums are guaranteed anyway [22]. One has to adopt an attitude of wait and see how the financial institutions will value this specific uncertainty. On the other hand, it must be kept in mind that the Spanish government pursues the aim of archiving certain tasks by modifying the decree for CSP requirements. So it is unlikely that the decree will be skipped at the next opportunity.

A minor limitation to guarantee the success of the Royal Degree might be that the projects should be carried out as Spanish as possible. This includes the involvement of Spanish companies, the Spanish banking sector, or Spanish facility operation for instance. Otherwise, a continuous subsidy of foreign countries with little benefits for the domestic economy might leave a sense of annoyance in the Spanish authorities [25].

3.1.6 Present project opportunities

Despite the ongoing full operation of the nine SEGS in California, no new commercial CSP plants have been built since 1991. Nevertheless, several project developments are announced for commercial parabolic trough or power tower plants in many different parts of the world at present. A short summary of the most credible projects is as follows:

- India, Egypt, Morocco and Mexico. The Global Environment Facility (GEF) has identified the parabolic trough technology as one of their renewable energy options within the Operational Program Number 7. This program envisages that these technologies will achieve near-commercial levels due to learning effects, economies of scale and market dynamics.

Thus, the GEF has approved grants to cover the incremental costs for CSP plants in India, Egypt, Morocco, and Mexico of up to 50 million USD each. The main objective is to demonstrate the technical and commercial feasibility of the technology under developing country conditions. These projects are at various stages of development, but showed only little progress during the last years. The reasons are many and diverse, such as financial restrictions, vulnerability to political changes and decisions within these countries, vaguely formulated terms of the GEF itself, etc.[15] The most advanced of these four projects is probably India. An ISCCS configuration is planned for all plants with a solar share of just 5-10%, which was suggested to reduce the barriers of implementation. But even this strategy did not lead to the expected success yet.

➢ SPAIN. Due to the modification of the Royal Decree (see 3.1.5.2) the Spanish government provides a substantial incentive for the construction of CSP plants. But despite the additional granted premiums it is only possible to realize very tightly calculated projects, because the revenues of new solar facilities are very uncertain and might be lower than expected due to technological risks. The most advanced projects in the country are the 10 MWe power tower *Planta Solar (PS10)* and the parabolic trough plants *AndaSol*. Probably mainly based on European technology the power tower PS10 is planned to be located near Sevilla. After the recent interruption of the Solar Tres project near Cordoba, based on the experiences of Solar One and Solar Two, supported by EU grants and pursued by the American companies Boeing, Nexant (Bechtel) and the Spanish company Ghersa (Abengoa Group), PS10 is the only central receiver project in Spain. The leader of the technology consortium and main promoter is the Spanish Abengoa Group through the Inabensa (Instalaciones Abengoa, S.A.) company and the IPP Sanlúcar Solar, S.A. The expected total costs of this facility are 27,5 Mio. EUR including a subsidy of 5 Mio. EUR from the European Union within the 5th framework program [58, pp.55].

Both 50 MWe parabolic trough plants, AndaSol-1 and AndaSol-2, are developed and planned by the German companies Solar Millennium AG (respectively by their Spanish subsidiary Milenio Solar S.A.) and its strategic partner Flagsol GmbH, as well as the Spanish Solúcar S.A., also part of the Abengoa Group. The collector to be used is the EuroThough, the only

[15] For a more detailed description of the current status of the GEF-financed projects see Mariyappan and Anderson (2002)

collector of new type construction since the development of the LUZ LS-3 collectors. The construction will be carried out by the Spanish company Cobra, a huge construction company specialized in turn-key facility projects. To improve the commercial usage, a molten-salt storage system should be included in the AndaSol plants. The total costs for the facilities are about 200 Mio. EUR each, also including a promise of 5 Mio. EUR by the EU. Up to now the project is in good progress. The construction site was purchased, planning permission and building regulations clearance was approved and it was applied for grid connection, which required a high deposit. Further negotiations with banks and equity investors are going on. It is expected to put the plants in commission in 2005 [22].

Another project in Spain is the parabolic trough plant *EuroSEGS*, a co-operation between the Spanish EHN group (mostly engaged to PV) and Solargenix Energy, USA. The major problem is that the plant was developed for hybrid operation, which is now refused through the revision of the Royal Decree. Therefore, the finance of this plant might become very difficult, and the project is dormant right now [58, pp.55].

- USA. The South western states Nevada, California, Arizona and New Mexico seem to be very interested in the implementation up to 1000 MWe of CSP. The potential project opportunities differ in their size in a range from 80 MWe to small scale 1 MWe Rankine-cycle projects. This aim was also expressed by the Western Governors Association in a letter directed to senators, as well as by Congress trough a requested Department of Energy (DOE) report which was evaluating the "Feasibility of 1,000 Megawatts of Solar Power in the Southwest by 2006".[16] Currently, it appears that the strongest progress takes places for a 50 MWe plant project in Eldorado Valley, Nevada. Solargenix, the leader of the American parabolic trough industry, was able to negotiate a power purchase agreement (PPA) with the local utility Sierra Pacific Resources. But only little details about the content or further project features became public at present. In addition, a 1 MWe parabolic trough plant is under design for Arizona Public Service at present [61, p.3-2], [67].

- South Africa. The national power utility Eskom generates over half the electricity produced in all of Africa and aims to extend its transmission grid into neighboring countries. With a generating capacity of over 40,000

[16] see DOE (2002)

megawatts, it is one of the largest utilities in the world.[17] The company has been evaluated the opportunities to build a CSP plant in South Africa recently. It performed a substantial study to compare the technologies and decided in September 2002 to proceed with the tower technology only. The 100 MWe central receiver power station with molten-salt thermal storage is developed by Boeing and Nexant based on the technology used in Solar One and Solar Two. Eskom might become a good example for the commitment of a huge utility company to CSP.

- Israel. The Israeli Ministry of National Infrastructures decided to implement CSP in the national electricity market as a strategic means of diversification. The minimal plant size was suggested to be 100 MWe including an option to scale-up the capacity up to 500 MWe. But a final decision has not been taken yet.

- Other. Finally, the CSP efforts of Iran, Algeria and Jordan should be mentioned. Particularly Iran shows credible interest in the large scale exploitation of its abundant solar resource mainly because of the rapidly increasing population, the need to increase and diversify the power production basis and finally to spare the fossil resources, which could be sold on the world markets [3]. The objective is to upgrade an existing gas turbine power plant to an Integrated Solar Combined Cycle System power plant (ISCCS).[18] The combined cycle plant is in operation near the city of Yazd since 1999 [32]. Iran ministries also applied for GEF grant to cover the incremental cost occurring in this kind of projects, but the GEF's policy is not to approve any further CSP projects until the first four are sufficiently progressed. In addition, it might be difficult for the Iranian government to get enough foreign support for the implementation because of political reasons.

  Also Jordan authorities had expressed their interest and support of a solar thermal plant already more than 10 years ago. At the time an European-based consortium known as PHOEBUS performed feasibility studies, data collection and evaluated financing possibilities for the construction of a

[17] At present, Eskom produces 90% of the South Africa's electricity and is the monopoly domestic public power utility. Eskom also owns and operates the national transmission system, a power line network measuring over 316,000 kilometers which transports electricity throughout South and Southern Africa. Furthermore, Eskom operates 13 coal-fired power stations, a 1,930-megawatt nuclear power plant, two gas turbine facilities, two conventional hydroelectric plants, and two pumped-storage stations in the Drakensberg and the Western Cape [2].

[18] For further information see `www.yazd.com`

central receiver plant. However, the outbreak of the first Gulf War in 1991 postponed further project development with little progress until today [21].

Besides Iran and Jordan, also the Algerian authorities take efforts to investigate possibilities for market development and exploitation of renewable energies for domestic use and export to the European Union. At present, evaluations concerning the feasibility of a 140 MWe hybrid solar/gas ISCCS plant takes place.

It appears that the demand for solar thermal power plants overcomes the lean period even though the progress is slow. Most CSP experts expressed their confidence that at least some of these projects will be implemented during the next few years. It is hard to make a forecast which of the above mentioned projects has the biggest chance of success in the near future. In particular, the projects in Spain are very advanced due to the good economical conditions and the project in Nevada is on top of the list as well. However, it is not possible that one of these CSP opportunities will be implemented within the next 2 years. Especially the negotiations for power purchase agreements, the bidding-process, and the search for financial resources require a long time period. After finishing the legal and contracting processes it will take at least another year to construct a plant. The next large scale CSP plant will therefore not be in service before 2005 and it will most likely use parabolic trough technology.

It is also an important factor to get new state-of-the-art reference facilities for potential investors. In opposite to other renewable energies like wind for instance, current commercial reference facilities are missing for CSP. Wind mills on the other hand can be inspected everywhere. Of course, it is possible to travel to California and visit the SEGS there. But these facilities are at least 10 to 20 years old, and also the integration of a solar field into an ISCCS is not available as commercial facility [3].

3.2 Supply-side

3.2.1 CSP industry overview

Having looked at the environment and demand-side for solar thermal power technology, the present CSP industry involved in the supply of parabolic trough and central receiver technology shall be described in the following paragraphs. In general, the term *industry* refers to a group of firms that produce a well-defined product or closely related products and sell them in a particular market [39, p.211]. How does the industry for CSP technology look like and which are the important participants?

The global CSP industry is still very small today. In fact, no plants have been built for a long time and no industry can emerge and survive only by producing spare parts or research modules for demonstration sites. Thus, there are only little independent companies within the industry whose corporate activities rely chiefly on CSP. Otherwise the companies are subsidiaries and have the financial resources of a corporate group. Due to the different CSP technologies as well, the single industry participants are very inhomogeneous, ranging from some small and specialized CSP project developers, to large corporate groups which supply some certain components or services through some of their subdivisions. Figure 3.3 on the next page provides an CSP industry overview.

In fact it is definitively hard to find an accurate selection and define which firm is part of the small industry and which firm may actually not belong to it. For example, many companies are represented at the large test sites at Plataforma Solar de Almería, Spain (PSA), the USA, or Israel, doing research and testing new components and technologies. But most of them do neither have a marketable product nor gained important patents yet. A trough collector consists of a large number of quite conventional components, which can be obtained from various suppliers. Therefore the borderline to exclude companies is drawn for providers of standard equipment for a CSP system, because those components are usually neither licensed nor protected by patents nor require certain knowledge and sophisticated production facilities. This means that these parts are not unique and might easily be substituted. As a result, many components could be produced locally by the host country of the plant project. Only some core components for the solar field are provided solely by a few companies worldwide. For example, it is one of the goals of the South African project, promoted by the utility Eskom, to manufacture most parts of the planned power tower plant locally [27]. Consequently, the description that follows refers only to key suppliers and global pacesetters.

Company	Main Activities	Country
PARABOLIC TROUGHS / CONSULTING		
Solargenix Energy, LLC	Turn-key producer (formerly Duke Solar)	USA
Solel Solar Systems Ltd.	Turn-key producer, spare parts for SEGS (absorber tubes)	Israel
Solar Millennium AG	Turn-key producer, investor group, project developer	Germany
Solarmundo N.V.	Potential turn-key producer in future (Fresnel technology)	Belgium
Flabeg Group	Supplyer of curved refelctors	Germany
FlagSol GmbH	engineering and project development (strategic partner of Solar Millennium)	Germany
Fichtner Solar GmbH	Consulting and engineering; feasibility studies, etc.	Germany
Schlaich, Bergermann und Partner (SBP)	Company of Engineers, EuroTrough, (strategic partner of Solar Millennium)	Germany
Solucar S.A. (Abengoa)	Manufacturing and assembly of solar field equipment at PSA and AndaSol	Spain
Schott-Rohrglas GmbH	Glass tubes/ Receiver tubes in near future (subsidiary Schott Glas GmbH)	Germany
Lahmeyer International	Consulting and engineering; feasibility studies, etc.	Germany
Industrial Solar Technology	Supplier of small-scale parabolic through systems (e.g. water heating)	USA
Nagel Pumps	Pumps	USA
KJC Operating Company (KJC CO)	O & M of SEGS in California (Kramer Junction Company)	USA
FPL Energy (FPL Group)	Utility; Co-owner of SEGS VIII and IX	USA
FPL Operating Services	O&M of SEGS VIII and IX, Harper Lake	USA
Sunray Energy	Owner and O&M of SEGS I and II, Daggett	USA
Other Grid-Utilities	Southern Edison, SMUD (Sacramento Municipal Uitlity District)	USA
Kearney & Associates	Consulting	USA
Morse & Associates, Inc.	Consulting	USA
Sargent & Lundy	Consulting	USA
CENTRAL RECEIVERS		
The Boeing Company / Rocketdyne	Molten-salt receiver technology	USA
Nexant, Inc. (Bechtel)	Consulting (especially power tower and storage systems)	USA
Eskom	Uitlity; Substantial efforts to realize a CSP project at the Northern Cape	South Africa
Abengoa Group	Engineering and Construction company	Spain
Instalaciones Abengoa, S.A. (INABENSA)	Heliostat design	Spain
Sanlucar Solar S.A. (Abengoa)	IPP for PS10	Spain
Ghersa (Abengoa)	IPP for Solar Tres	Spain
Kraftanlagen München (KAM)	Volumetric air receiver technology (technology successor of Steinmüller, Germany)	Germany
Advanced Thermal Systems	Heliostat design	USA
Science Appliacations International Corporatrion (SAIC)	Heliostat design	USA

Figure 3.3: CSP Supply-side Overview

Concerning the different roles of the companies, the industry could be roughly divided into a few major groups. These are turn-key developer and producer of parabolic trough solar fields, respectively for central receiver systems. Furthermore, there are suppliers of core components, providers of strategic engineering and consultant services, as well as commercial plant operators. However, it will turn out that the dividing line, particularly between the turn-key developer and core component supplier, is blurred.

3.2.2 Parabolic trough technology

3.2.2.1 Turn-key project developer and technology supplier

Apart from Spain where the regulations of the Royal Decree do not allow a hybrid mode, almost all current plant projects are Integrated Solar Combined Cycle Systems. Usually, an ISCCS is a conventional gas plant with an additional solar firing. For the implementation of a CSP plant project different consortia are formed and apply for the engineering, procurement and construction (EPC) contract. A consortium for a parabolic trough plant ideally consists of a domestic construction company, a supplier of the conventional power block (such as ABB, General Electric, Siemens, etc.), a provider of the solar field, and an experienced engineering company. The consortium is under the leadership of the so called EPC-contractor company, usually a large domestic construction company, which must be large enough to provide guarantees for the entire plant [54, p.58]. Hence, all CSP turn-key developers and manufacturers are dependent on the EPC-contractor, who is in charge for the completion of the plant project as a whole. Most CSP industry participants are currently of a small size, which is not unusual for companies within a new industry. Therefore, they are not in a position to take over the role of a EPC-contractor company. As a result, the possible ability of a turn-key offer for CSP technology in this context refers to the solar field and in addition to the integration of the solar heat in the combined cycle process of such a plant. To date there are about three to four companies in the market which fit into this requirement scheme for parabolic trough technology: Solel Solar Systems Ltd. (Israel), Solargenix Energy, LCC (USA), Solar Millennium AG (Germany) and perhaps Solarmundo N.V. from Belgium. These companies have the ability to design and develop a CSP plant project.

3.2.2.1.1 The heritage of LUZ Industries, Ltd. The rise of the most successful Israeli-U.S. solar thermal electric power developer LUZ can be considered as the *big bang* of the CSP technology. Because of the successful development and construction of all SEGS in California this company accumulated a huge amount of experience and knowledge. After its bankruptcy, the brain power spread all over the world. But naturally the question arises as to who got the major share of the solar thermal electric brain trust, and most important: Who is the holder of the proven technology? At first glance it is the Israeli *Solel Solar Systems Ltd.*, the successors of LUZ, which bought the assets. But Solel is not the complete legal successor, because it took over only the production facilities from the bankrupt's assets, but not the debts. The legal situation is unclear. In addition, also the American company *Solargenix Energy, LLC* (formerly Duke Solar) claims to continue the intellectual know-how and the experiences gained from LUZ, because this company consists of some key personnel from LUZ. Within the industry, little interest exists to resolve the issue because legal proceedings would probably send all companies into bankruptcy. Anyway, it can be assumed that both companies do have the ability to design, manufacture and construct a CSP plant to a greater or lesser extent [8], [22], [30].

Solel was established in 1992 by former LUZ employees in Israel with financing from the investors group Pixy Investments, Luxembourg. Based in Jerusalem the company purchased most of the LUZ assets, which makes it one of the most important companies in the CSP industry. Until today, Solel is the manufacturer of vacuum absorber tubes, one of the core parts of a solar field. Therefore, the company has become the major supplier of spare parts for the existing plants in California. But generally the company has the capability of project development, providing engineering services and the supply of collectors for new large scale CSP plants. In addition Solel offers a range of smaller modular solar collectors suited for different kinds of applications, such as household, institutional and commercial uses. Solel's unique core technologies are glass and metal tube connections and selective coating processes, which are combined to manufacture the absorber tubes. For the support of their development and research activities, the company has a good relation to the Weizmann Institute of Science [60].

Founded in 1997 with key personnel from LUZ, Solargenix Energy (formerly Duke Solar) is the leading provider in the design, manufacturing and construction of future CSP plants in the USA. With its 25 employees and own production facilities, Solargenix is cost-sharing with the National Renewable Energy Lab in its efforts to develop the next generation of trough technologies for commercial use. Whereas Solel demonstrably manufactures absorber tubes, the actual CSP product of Solargenix is the structure of a trough collector system. But the company has not built any collector suitable for a utility-scale CSP plant yet. Solargenix currently designs a 1 MWe parabolic trough plant in Arizona. The entire corporate activities are divided into the CSP Division, the Energy Buildings Division and the Solar Water Heating Division. Basically, the company currently earns money with small scale solar thermal water heating and has experience in designing and constructing sustainable buildings. However, a significant share of the activities relies on CSP projects. At present, the main business to be highlighted is the construction of the concentrating solar thermal *Power Roof* system for sustainable building concepts. Solargenix can design, install and maintain these systems, which underlines its solar competence and technological capabilities.

3.2.2.1.2 Solar Millennium AG The German joint-stock company *Solar Millennium AG*, established 1998 in Erlangen, was created with the objective to overcome one of the big obstacle for CSP during the last decade: the insufficient supply of qualified organizations to take turn-key responsibility for the implementation of a plant project. To reach this task, the company raised several million EUR of venture capital solely for solar thermal power project development, specialized in parabolic troughs and solar chimneys. In addition, the company formed alliances with a group of competent cooperation partners, who are jointly able to realize plant projects [65, p.2]. The partners are the solar field company *Flagsol GmbH* and *Schlaich, Bergermann & Partner GmbH*, a subsidiary of the consultant engineering company Schlaich, Bergermann & Partner (SBP), for the design of solar systems. The German company SBP with its technical staff of about 50 is well known for its lightweight construction of bridges, towers and buildings such as the Munich Olympic Stadium or the Ting Kau Bridge in Hong Kong. Besides this core business, the construction specialists with high-level expertise in structural steel design are also very active in solar systems engineering, such as the new parabolic trough collector structure EuroTrough, the development of solar dishes (e.g. EuroDish), or the design of the solar chimney in Australia.

The Flagsol GmbH is a common subsidiary of Solar Millennium (60%) and the Flabeg Group (40%). Flabeg is the leading provider of reflectors for trough technology and is further described in section 3.2.2.2. The subsidiary Flagsol concentrates the solar thermal project and technological experience gained by Flabeg over its 20 years in the CSP business. Flagsol provides services in the lay-out and engineering of parabolic trough solar fields for the Solar Millennium Group and Flabeg. The company is the successor of Flabeg Solar International GmbH, the former solar company of the Flabeg Group. Due to problems with its PV business, Flabeg Solar International went bankrupt in 2002, but the solar thermal know-how was transferred to Flagsol in June 2002. For plant projects Flagsol is a technology supplier (reflectors via Flabeg), provides the detailed design of the solar component as well as construction and commissioning coordination [64].

In addition, Solar Millennium founded the subsidiary Milenio Solar S.A. for the project developments in Spain. Another partner for the AndaSol projects is the Spanish company *Solúcar S.A.*, a solar company within the Abengoa Group. The company has vast experience in the production and assembly of solar field equipment at the demonstration-site Plataforma Solar in Spain [65, p.2].

In September 2003, Solar Millennium and the Spanish company *Cobra S.A.* agreed by contract that the major constructing company will play a crucial role in the construction process of the AndaSol plants and will most likely provide the turn-key guarantees. With 13.000 employees globally, Cobra is specialized in energy projects, telecommunications, railways and industrial systems and delivers engineering, installation and maintenance services. It belongs to the ACS Group which is the third largest construction company in Europe with 92.000 employees and a turnover of about 10,8 billion EUR. In addition, Cobra acquired the option to take an important part in the plant operation companies [63].

The Solar Millennium Group was also strongly promoting the development of the EuroTrough[19]. This new collector type, developed by a European multinational consortium and financially supported by the European Commission, based on the LS-3 collector technology of LUZ. Together with Schott Rohrglas GmbH, Kramer Junction Operating Company and the German Aerospace Center (DLR) Solar Millennium initiated the PARASOL-SKALET project to implement a 4,360 square meters EuroTrough demonstration loop in one of the SEGS at Kramer Junction. The project was co-funded and supported by the German Federal Government's Program for Future Investments (ZIP) provided by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). The loop was successfully integrated in April 2003, proving the reliability

[19] Further information can be obtained at `www.eurotrough.com`.

and competitiveness of this collector type. The next step is the implementation of a EuroTrough field in the AndaSol plant. It is not too far fetched to argue that the commitment of Solar Millennium contributed mainly to saved the parabolic trough technology during the last years from insignificance [65, p.2], [25], [72].

3.2.2.1.3 Solarmundo N.V. Despite some careful doubt, perhaps the fourth turn-key provider of a solar field could be the Belgian stock corporation *Solarmundo N.V.*. In June 12, 2001 the company unexpectedly presented to the public a finished plant concept. The spiritual father and co-founder of Solarmundo is Lieven Ven, formerly president of LUZ. This fact underlines again that LUZ is the origin of much brain power in the market. Over a number of years Solarmundo has developed a Fresnel collector based technology with a new type of trough design. The Frauenhofer Institute of Solar Energy Systems (Frauenhofer ISE) supported these efforts with scientific and technological know-how for the collector development. After a lot of design efforts the technology was tested at a demonstration facility in Liége using a prototype of a Fresnel collector with a width of 24m and a reflector area of 2,500 square meters. Due to its simpler structure, the new collector type should gain crucial cost reductions for the solar field, even if the efficiency is not as good as for parabolic trough collectors. Particularly the solar field accounts for the largest expenses of a CSP plant, more than 50% in the case of the Californian SEGS. Cost savings are possible because this technology is based on many flat mirrors instead of a few large parabolic mirrors. These mirrors can be provided by much lower costs than curved ones. In addition the Fresnel collector heats the water directly rather than via a HTF and a heat exchanger. The linear absorber is a non-vacuum tube, making this collector technology independent from the sophisticated and expensive absorber tubes provided by Solel, the only supplier to date. Besides, the construction as well as the materials are chosen for mass production, and the collector can be easy maintained and repaired. All these features lead to Solarmundo's optimistic estimation that future electricity generating costs of only 0,04 to 0,08 EUR per kWh in large scale power stations located in high radiation areas are reachable. Thus, Solarmundo announced their readiness to construct the first commercial scale plant. The company is now trying to establish alliances with large industrial groups and utilities in order to market the technology [67, pp.2], [5, pp.54].

However, many CSP experts are slightly in doubt whether this technology will be able to meet the expectations of technological performance. On the one hand the good start of this interesting technology is highlighted. But on the other hand there are some doubts concerning the use in practice, such as the suitability of the single driven mirrors, which adjust the radiation concentration on the absorber, under difficult desert conditions. Another critical point might be the non vacuum absorber tube. A constant heat process necessary to run the conventional power block efficiently could be difficult to reach due to cooling effects through wind or clouds for instance. In fact, the efficiency of a Fresnel collector is definitely lower than that of parabolic troughs, and no one knows if the cost of production and maintenance are actually low enough to counter this disadvantage. Basically, the technology is not really proven yet, and it is too early to give a more differentiated opinion. Like the other CSP technologies this one will have to prove itself and survive in the market as well. Still, the arising competition between both Fresnel and parabolic trough concept is interesting [8], [22], [25].

3.2.2.1.4 Others Another manufacturer and developer of parabolic trough technology is Industrial Solar Technology (IST). The company is located in Colorado, USA and was founded in 1983 by Ken May and Randy Gee, both of them engineers and formerly employed at the Solar Energy Research Institute, now called the National Renewable Energy Laboratory (NREL). With its six full time employees IST offers various applications using parabolic trough technology for small scale electric and thermal markets such as water heating, air-conditioning, or desalination. But there is no ability to provide large scale CSP plant equipment at present. However, the company has more than 20 years of experience in solar thermal technology and is involved in R&D efforts. In addition it has own production facilities for parabolic troughs. Hence, if an expanding market for CSP emerges, the likely corporate objective is also to play a significant role in future large scale parabolic trough plant projects [45].

In conclusion, there are currently not more than four companies in the market for parabolic trough systems (or a least trough related systems with regard to Solarmundo) with the credible capability to design and build a CSP plant, respectively the solar component of an ISCCS plant.

3.2.2.2 Suppliers of core components

The core components of parabolic trough collector, respectively a solar field are the absorber tube, the parabolic shaped mirrors, the collector structure and perhaps the pump system for the HTF.

As mentioned above, Solel is not only considered to be one of the turn-key developer, but with its production capability of the vacuum absorber tube, also one of the key technology supplier. For the production of the absorber, Sole purchases specific glass tubes at *Schott Rohrglas GmbH* in Germany, a company specialized in sophisticated glass products for various applications. Schott Rohrglas currently develops a new type of absorber tube on it's own initiative, i.e. to become a competitor for Solel in this field. It is planned to integrate the new Schott absorber into the EuroTrough collector. The supply of larger amounts of tubes is expected during the next year and would therefore enter into competition with Solel [8].

The German *Flabeg GmbH & Co. KG* (formerly part of the Pilkington Group), is one of the major companies providing special glassware for technical applications and has the best bending technology for mirrors. At present, the Flabeg Group is the only provider worldwide for the high precision solar reflectors necessary for parabolic trough collector systems. All commercial SEGS plants are equipped with Flabeg-mirrors as well as the newly developed collector EuroTrough. Thus, any trough collector, which will be constructed in the near future, relies on the reflectors provided by Flabeg.

The supplier of the collector structure are more difficult to characterize in the case of the LUZ technology successors. For the construction of a new CSP plant (e.g. in India), Solel would probably fall back on the structure of the old and proven LS-2 or LS-3 collector developed by LUZ. But it is currently not exactly known which collector is planned to use by Solel for the Indian project. Things are similar in the case of Solargenix. The company might have developed an own collector structure, but records on this are not available. Thus, both companies have constructed neither the structure, nor a whole collector. The only collector with a new type of construction is the EuroTrough, which was designed and manufactured in many different European countries. The technical design of its structure, with a higher stiffness and lighter weight than the LS-3 structure and therefore cheaper to manufacture, was done by Schlaich, Bergermann & Partner. The actual manufacturing was carried out by a Turkish company. The EuroTrough could be licensed be anyone [8], [22].

Last but not least should Nagel Pumps be mentioned as an important technology supplier. The company provides pumps for special technical applications. These products are important for CSP, because it is a technological challenge to manufacture pumps that are able to pump hot fluids, such as the heat transfer medium, of about 500 degree Celsius. But there possibly are other manufacturers with similar capabilities, e.g. suppliers of nuclear power plant components.

3.2.2.3 Strategic engineering and consultant services

Most of the companies mentioned above are technology suppliers, or their main attribute is the capability of turn-key project development for parabolic trough plants. Supplier of strategic engineering and consultant services described in this section are those companies that are committed to additional services during or before the project development process. This includes technological design, the supply of feasibility studies, bid documents preparation, bid evaluation and construction supervision. On the other hand it includes overall strategic consulting for the CSP industry as well.

Fichtner Solar GmbH is a subsidiary of the Fichtner Group, a leading engineering company in Germany, known globally for its technological project engineering services. With about 1000 employees and a global network of associated companies and local partners the group provides technical services for all kind of projects, from small plants to projects in the range of a billion Euro. The corporate group's efforts in the field of renewable energies, especially solar energy are concentrated in the Fichtner Solar GmbH. This subsidiary basically consists of Georg Brakmann, one of the leading CSP consultants. Together with a changing number of associates he provides consulting engineering services for CSP projects. If any additional service which exceeds the capacity of Fichtner Solar is required, it is acquired by purchase at the parent company. As a result, Fichtner Solar on the one hand has the flexibility of a small company and on the other hand the resources of a large enterprise if required. Along with Lahmeyer International, Fichtner Solar is the leading company for feasibility studies, bid documents preparation, bid evaluation and construction supervision on parabolic trough plants. Except for the Mexican project Fichtner Solar is the main consultant for the other GEF projects in India, Egypt and Morocco.

Founded in 1966 and with offices in over 40 countries, the German company *Lahmeyer International* provides technical and economic planning and consulting services such as project planning and development, studies, tendering, detail planning, construction and commissioning supervision, etc. The fields of activities are energy, water, transportation infrastructure and environmental technology. With 650 employees in more than 10 associated companies worldwide the activities in CSP account just for a small share in the overall corporate projects [37]. Nevertheless, with its experience and expertise in renewable energies, Lahmeyer International is another leading company for consulting and engineering services such as feasibility studies or construction supervision regarding to parabolic trough plants (e.g. Egypt and Iran). Thus, the market for parabolic trough feasibility studies is dominated by Lahmeyer and Fichtner Solar.

Frederick H. *Morse* (Morse & Associates, Inc.) and David W. *Kearney* (Kearney & Associates) are perhaps the most important individuals for the CSP market. David Kearney is a leading consultant for CSP technology in the USA. Due to his former LUZ staff membership he has huge industrial and technological experiences and background in solar thermal technology. Fred Morse is considered as one of the leading consultants for CSP worldwide. He has more than 30 years of experience in solar thermal power technology amongst other things due to leading positions in the U.S. Department of Energy for many years. Mr. Morse, a Stanford Ph.D. in engineering, is very active to promote the progress of CSP technology globally and independent of individual industry influences.

The management consultancy *Sargent & Lundy* located in Chicago emerged in the market for CSP recently. As an independent strategic consultancy not involved in the CSP market, the company was engaged by the U.S. Department of Energy to perform an extensive study for cost reduction potentials of CSP technology.[20]

The consultant engineering company Schlaich, Bergermann and Partner (SBP), the engineering company Flagsol GmbH and the solar field equipment company Solúcar S.A. are also important to mentioned. Because of their relations to Solar Millennium, they have been discussed above in further detail.

3.2.3 Central receiver technology

The development and production of central receiver technology is concentrated in three countries worldwide: USA, Germany and Spain. The core components of a power tower are the central receiver unit and the reflectors, called heliostats.

The leading manufacturer and project developer for power tower technology is, undisputedly, *The Boeing Company*, USA. It seems that the major aircraft construction company tries to expand also in other types of activities. With the acquisition of *Rocketdyne* a few years ago Boeing purchased the know-how of one

[20] see Sargent & Lundy (2002)

of the core component - the molten-salt receiver.

Both Californian demonstration plants Solar One and Solar Two are based on the American technology of Boeing, respectively the Rocketdyne Division and constructed by the *Bechtel Group* (U.S.), which was the general contractor for the Solar Two. Bechtel is one of the world's premier service provider for developing, engineering, constructing and managing projects and facilities worldwide. The molten-salt receiver technology is close to being commercially ready and the experience gained from the design of Solar Two are used for achieving further cost reductions. At present Boeing has close business relations with *Nexant, Inc., A Bechtel Technology & Consulting Company* in planning power tower projects like the Solar Tres or the current project development in South Africa for instance. Founded in 2000, Nexant is a subsidiary of the Bechtel Group to focus and maintain the efforts of the latter in the field of CSP technology. Nexant provides various consulting services for the whole energy sector and different types of power-generating technologies. In addition the company supports the R & D of a molten-salt storage system. As in the case of Boeing, however, the commitment to central receiver technology is only a small part in the corporate activity to date [27]. With its 250 employees Nexant is a leading global expert for consulting and services for power tower technology and together with Boeing and Solargenix a key participant of the CSP industry in the USA.

The European concept of central receiver technology is based on the volumetric air receiver design. It was mainly developed by the German company Steinmüller, and successfully demonstrated in the 1990s in Spain. But Steinmüller went bankrupt recently. The *Kraftanlagen München GmbH (KAM)*, a German plant technology manufacturer with more than 1000 employees, bought the assets of Steinmüller and is going to continue the development together with G+H Isolite GmbH (Germany) and the scientific support of the German Aerospace Center (DLR). It was originally planned to install the receiver in the PS10 power tower project in Spain. Due to higher costs - not just for the receiver unit, but probably because of a miscalculation of the overall installation costs - this was refused not long ago. This lead to the situation that KAM basically offers EPC-contractor services for central receiver plants, but has no prospect for a project, because at present there is none. In the case of PS10 it is suggested to develop a new type of receiver based on molten-salt technology. The future costs of these efforts are totally uncertain [22], [72].

In contrast to Boeing and KAM, the Spanish *Abengoa Group* is not a supplier of central receiver technology but provides various other technology components and construction services. Abengoa is a major Spanish technology, plant engineering and construction company of more than 8000 employees and EBITAD[21] in 2002 of 174,7 million EUR. Almost all current project developments in Spain are promoted through its several subsidies, such as Inabensa, Sanlúcar Solar, Solúcar S.A. and Ghersa. Because of its size and solar thermal commitment, the corporate group is definitely one of the most important companies within the present CSP industry.

Heliostats, the second core component, provide the fuel for a central receiver plant. They currently represent approximately 40 - 50% of the costs of a power tower plant. It has to be emphasized that the currently manufactured and available heliostats are at various stages of development. They are usually well-tested prototypes, but have not been operated for long time periods [42, p.3].

The leading global supplier of heliostats is *Inabensa (Instalaciones Abengoa, S.A.)*, a subsidiary of Abengoa. At present, Inabensa offers different types of heliostat design and provides the heliostats for the PS10 project. *Ghersa*, another Abengoa subsidiary company is also involved in the development of heliostats and pursued mainly the Solar Tres project together with its American partners.

Advanced Thermal Systems, Inc. and the *Science Applications International Corporation (SAIC)* Energy Products Division are developing and manufacturing heliostats in the USA. In both cases, the heliostat design and performance has been tested at the domestic test-sites, such as those of NREL and Sandia National Lab [42, p.6]. But also Solar Kinetics, Inc. in Dallas, Texas seems to be involved by redesigning heliostats in order to improve their manufacturability [69, p.2].

The German company Babcock Borsig Power Equipment has been developed and manufactured a heliostat type as well, but after the recent demise of the parent company Babcock Borsig, the efforts relating to this are unclear. Some assets seem to be overtaken by Shell.

3.2.4 Plant operators

Professional plant operation and management is very rare, because it could only be developed at the nine commercial SEGS sites in the Californian Mojave Desert. The plants are clustered there in three facilities at Kramer Junction, Daggett and

[21] Earnings before interest, taxes, depreciation and amortization

Harper Dry Lake. After the demise of LUZ the different ownership of the sites lead to varying ways of managing the businesses and operating these plants. The investors of the biggest facility with five SEGS (SEGS III - VII) at Kramer Junction founded the Kramer Junction Company (KJC) to manage the site. For the operation and maintenance of the plants the *KJC Operating Company (KJC OC)* was created, which is a wholly owned subsidiary of KJC [19]. By following the opinion of the CSP experts KJC OC can be considered as the world leader in commercial O&M of a solar thermal power plant. Thus, the company is another key player of the CSP industry.

The SEGS I and II, located near Daggett and owned by the investors group *Sunray Energy* (formerly Daggett Leasing Corporation DLC), which also operates the facility. The remaining SEGS VIII and IX plants, located near Harper Dry Lake, are owned by the FPL Group, a large utility from Florida together with a partner called Caithness Energy. The plants are being operated by *FLP Operating Services* [19].

But what, then, distinguishes KJC OC from the other operators and justifies its unique position? First of all, after the bankruptcy of LUZ, the Kramer power park ended up with a large share of the accumulated solar knowledge, which included key personnel from LUZ. This core group took to operating and maintaining the plants with great care and interest. KJC OC participates in several research and development projects with domestic and foreign laboratories and private stakeholders (e.g. the PARASOL-SKALET project for the EuroTrough). This allowed to collect most data for calculating further cost reduction potentials for the parabolic trough technology. The objective is always to increase the overall output of the plants by improving the solar performance, as well as the steady reduction of the O&M costs. In contrast, the other facility operators are running their sites just as power plants without any further effort and enthusiasm. That is why they remain relatively unknown in the market. In addition KJC OC is very accessible regarding their facility, giving plant visiting tours for all kinds of interested parties.

With its 120 emloyees, KJC OC's fields of activities are in detail: (1) Management & Operations which includes management, administration and staffing for corporate activities, as well as operations and optimizing the collection of available solar radiation; (2) Engineering, monitoring and analysis of collector field and power plant component performance in a large scale solar thermal electric environment; (3) Development of design enhancements; (4) Spare parts specification and (5)

Information services to provide computer control systems and plant information retrieval systems. In addition KJC OC incorporates new techniques, pushes the installation and/or modification of process equipment and provides specialized training for cycle plant and collector field operation, monitoring and repair [34].

A professional company with experience in the O&M of a central receiver plant is not existing yet, because all presently erected plants are non-commercial and located merely at demonstration sites.

4 CSP Industry and Market Analysis

4.1 Starting point

Having sketched out the demand-side and the industry for CSP technology this chapter deals with the characterization and analysis of the CSP industry and its environment. The aim is to develop probing, insightful answers to the following questions:

- How could the current stage of market and industry development being characterized?
- What are the specific structural factors and boundaries of the CSP industry?
- What are the industry's dominant economic characteristics?
- What are the key success factors and driving forces?
- What competitive forces are at work in the industry and how strong are they?

The starting point for an analysis of the industry and market development is usually to employ the *Five-Forces-Model* of Porter (1980).[22] This standard industry analysis framework of the strategic management approach provides a structure for the systematic diagnose of the wide ranging and complex economic issue of an industry and its environment. It can be very useful to describe the single forces that affect the competitive process and the profits of an industry. The five major forces that determine the strategic competitive environment of an industry are: internal rivalry among competing sellers, supplier power, buyer power, potential new entrants and the threat of substitutes. The understanding of the industry's competitive character enables companies within the industry to devise a successful competitive strategy [70, p.73].

[22] see Figure A.4 in the appendix

However, in the case of the CSP industry it is doubtful if performing a five forces analysis would lead to sufficient results. To date, the CSP market is in a very early phase of development. The industry is very new and a market for solar thermal technology is hardly existing at present. It remains to be shown, that no real competition among the industry participants have evolved in the CSP market yet. This makes it very difficult to employ the Five-Forces-Model, because of its strong focus on the competitive process. Moreover, no serious internal rivalry or bargaining power of suppliers of inputs can be observed, for instance and there is no threat that the entry of new companies may erode the profits of the established companies at the presents state. The incentives are still missing, because there is no market and no money to earn.

In addition, the point of view of the Five-Forces framework is mainly that of a single firm within the industry to provide assistance in reaching strategic decisions. But the aim of this study is not to provide strategic advise for CSP market players, but to give a situation assessment for the entire CSP industry. The following discussion will do without a detailed Five-Forces-Model analysis.

The first step of the CSP analysis is to identify and classify the current phase of the industry and market development. For this purpose, an industry life cycle theory is introduced in the following section. This framework should provide some general insight into the current market development for CSP technology and its industry.

4.2 Characteristics of the CSP industry

4.2.1 Theory of the Industry Life Cycle

Several approaches have been developed to explain the dynamic and evolution of an industry and the market for its new product.[23] Heuß (1965) has described a general development process for new industries which can be observed in many industries and their relating markets. Accordingly, industries tend to follow a prototypical pattern of five different stages in their evolution by the diffusion of a new product: the stage of development and introduction, the stage of expansion, the stage of maturity, the stage of stagnation and the stage of shrinking. The

[23]The terms *industry* and *market* are close related in this context and could be used simultaneously to a large extent. This is due to the fact that a well-developed market induces a well-developed industry and vice versa.

distinction among these different phases of development can be shown graphically with respect to the units of output. Figure 4.1 shows the typical connection between the market stages and the units of output [15, p.19], [29, pp.15].

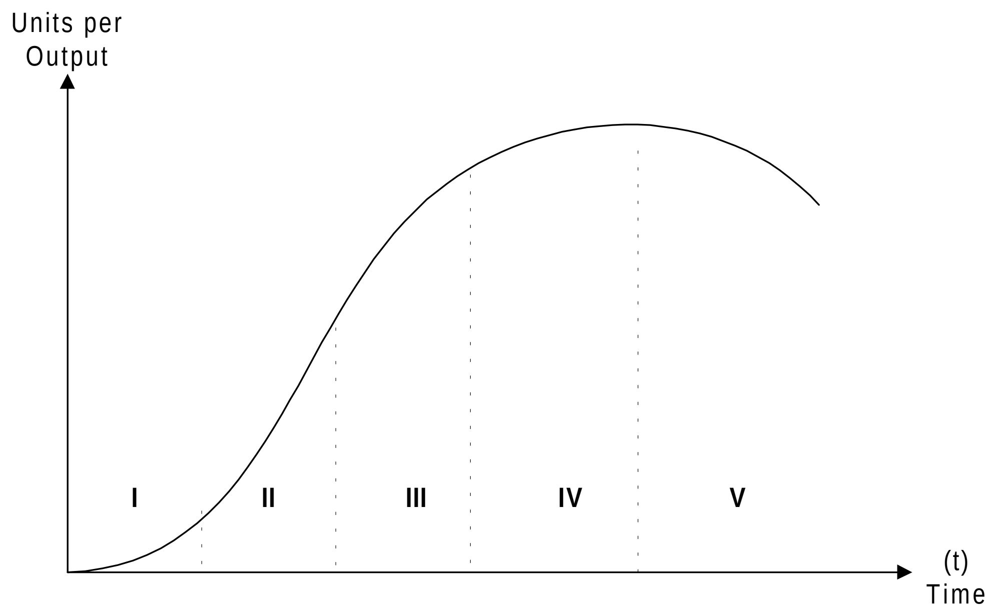

Figure 4.1: The five stages of the Industry Life Cycle

These five stages represent a prototype of the life cycle of new markets or a new industry, respectively. A similar approach was presented by Gort and Klepper (1982) who attempted to measure and study the diffusion of product innovations. In this context, they defined the term *diffusion* as the spread in the number of firms engaged in manufacturing the new product. For this purpose, they also constructed an evolutionary theory of the development of industries for new products and focused in their analysis on the net entry rates of producers in the market instead of units of output. Product innovations are composed of the technological development of a new product and its introduction in the market. The time period between those two steps varies substantially among new products, ranging from month to decades [26, p.630]. However, both life cycle concepts are equal to a large extent in their basic approach.

The concept of the industry life cycle is comparable, but not equal to the product life cycle theory. Several single product life cycles are experienced within an industry life cycle and there might be a variety of product differentiation available among the industry participants. Thus, the industry life cycle concept is founded on a broader basis. [15, pp.20]. In the end, however, also the industry life cycle concept is based on the assumption that an entire market, like a single product, is established by an innovation and follows the same specific stages and the typical S-shaped curve of the product diffusion [46, p.46].

In the first stage, the *stage of development and introduction* there is no market existing in the literal sense. The product is developed and brought to a state of market suitability. Little is known about the features of the product until then. At the same time it has to be found out if there is a sufficient potential demand for the product idea and which product attributes are of priority requirement by potential customers. The early entrants into the industry are typically small firms with experience in related technologies. At the end of this stage the commercial introduction of the new product can be started. During the second *stage of expansion* the penetration of the market takes place. A successful product will now lead to a high degree of demand and explosive growth rates. Another hallmark is the sharp increase in the number of firms due to the entry of many imitators in the market during the early stage of expansion. The market shares often change rapidly as successful innovators displace less efficient competitors. Gradually, a *dominant design* emerges for the product and companies which are able to produce these design grow, while others, being unable to adapt exit the industry. As a consequence, an increasing selection process will appear in the ensuing time which reduces the number of manufacturers significantly in the end. In the following *stage of maturity* the market growth is declining. A lot of firms merge or exit from the market because they are not able to survive anymore. The *stage of stagnation* is characterized by a very low market growth around zero and that of the economy as a whole, whereas in the last *stage of shrinking* the growth rate goes down below zero. However, these five stages represent a general pattern and are not necessarily present for all new products [15, p.19], [35, p.35].

The more aggregated level of the industry life cycle can be useful for the characterization of typical market and competition conditions. It may also be suitable for the foundation of fundamental strategic decisions of the single market player. But it should be kept in mind, that the meaningfulness of this concept is limited. For example, it is undisputed that markets experience a life cycle, while there is no criterion to separate the stages from each other so that the concrete identification of a stage is mostly just possible ex post. Furthermore, there is neither universal validity nor the conformity to a theoretical law. The stages are determined by a variety of hidden environmental influences and corporate activities which make precise predictions about the market development virtually impossible [46, p.343]. Therefore, further theoretical research and empirical data will be needed to determine the different forces being at work in the development of new industries [26, pp.651].

4.2.2 The stage of the CSP industry within the life cycle

Despite the legitimate objections to the life cycle concept, it as an independent tool of strategic planning and could serve as foundation and yardstick in any case [46, p.256]. It is obvious that the CSP market is just in the beginning of its life cycle. To be exact, the market could be said to be at the end of the first stage of development and introduction, right before entering the second stage of expansion with the commercial introduction of the technology. One might argue, that the commercial introduction has been carried out with the SEGS in California. This is certainly true, but this introduction achieved no further sustainable effect which justifies the classification between both stages.

The first phase of market development goes on since about two decades. This is quite unusual but can be explained by the fact, that the capital investment volumes necessary to build a CSP plant are extremely high. Therefore, the market diffusion process is more restricted and runs slower than for other innovations as a result. According to the specific conditions and requirements in the CSP market, the World Bank study (1999) suggested an individual pattern of market diffusion steps for CSP technologies [79, p.61].

- Step 1: Research and Development
- Step 2: Pilot-Scale operations
- Step 3: Commercial Validation Plants
- Step 4: Commercial Niche Plants
- Step 5: Market Expansion
- Step 6: Market Acceptance

These six steps to some degree represent the critical first two phases of the above mentioned general life cycle. Within the World Bank pattern, solar thermal technology could be understood to be beyond the first three steps, with the exceptions of central receivers and thermal storage systems. The objective of all past and future efforts is to move CSP through Steps 4 - 6 on the path towards commercialization, respectively in the stage of expansion.

4.2.3 The structure of new industries

4.2.3.1 Common structural features of new industries

As shown in the previous section, the CSP industry is one in the early, formative stage and therefore a new, or emerging one. The market for CSP is new and unproven and there are many uncertainties about its function, its potential and future growth rates.

Most companies as part of an emerging industries are usually in a start-up mode, constructing facilities, adding personnel, trying to gain buyer acceptance, etc. [70, p.176]. No rules of the game are established in new industries. According to Porter the key aspects and structural features of new industries are as follows [56, pp.281]:

- Technological uncertainties. Technologies in emerging industries tends to be developed in-house by pioneering firms. Some companies may file patents to secure a competitive advantage. However, these technologies are almost always characterized by considerable uncertainties. It is open which product design will be successful in the market, or which production technology will turn out to be the most efficient [70, p.175].

- Strategic uncertainties. Because the market is new and unproven, the industry participants use widely varying strategic approaches. But any of these strategies turned out to be superior yet. The companies make tentative attempts concerning product/market placement, marketing, service, but also different product designs and production technologies. Furthermore, the industry participants usually have only scanty information about their competitors, the buyers and the industry conditions in general. Reliable data of industry turnovers and market shares are often simply not available.

- High costs in the beginning with sharp cost decreasing. Small production output together with the novelty of the industry lead to high costs in the early stage of the life cycle. As a result of strong experience curve effects, the initial high cost decrease with a high rate as production volume increases.

- Founding of new companies. There is no phase in the industry development where more companies are founded as during the early stages in the development. Entry barriers tend to be very low at that time and make it easy for new companies to enter the industry. If the industry promises explosive growth, financially strong outsiders who are looking to invest in a growth market are likely to enter as well. The emerging PV industry in the 1990s is a good example in this context. Also the foundation of many *Spin-off* companies is closely related to this phenomenon. They are founded by key personnel of established companies who are leaving to start their own business.

- Subsidies. Early suppliers are subsidized in many new industries. Particularly, if it is a matter of a completely new technology, or it may affect public interests. Possible forms of subsidies for renewable energies are mentioned in paragraph 3.1.5.1 and are usually unavoidable for a successful market development. But subsidies also contribute considerably to the instability of an emerging industry, because it becomes dependent on political influences and decisions. Those decisions could be cancelled or changed within a short time with far-reaching consequences for the industry. The LUZ experience is the best example for this threat again. Thus, subsidies are a sword cutting both ways.

- First-time customer. Buyer of the products or services of the emerging industry are naturally first-time users. The marketing task is to induce initial purchase and convince the buyer of purchasing the new product instead of an older one. The buyer has to be informed about the advantages and function of the new product to overcome the concerns about product features and performance reliability. This tends to be quite difficult, because potential customers often have to deal with conflicting judgements about which of the competing technologies will succeed or which product features will gain the buyers' highest acclaim.

4.2.3.2 Boundaries for the industry development

In general, emerging industries are facing a lot of barriers and obstacles in their efforts to become established. Many of the following boundaries are the direct cause of the specific barriers mentioned in section 3.1.2 that prevent the market penetration of CPS to date [56, pp.286]:

- Inability to get sufficient access to raw materials and complementary components. During the development of the emerging industry new suppliers for complementary components have to be found, or existing ones have to change their output to meet the industry requirements. Serious bottlenecks for raw materials or certain components are very frequent in emerging industries. As a result, prices of raw materials and components could increase considerably in the early stages of development.

- Missing industrial infrastructure. New industries are often facing problems due to a immature industrial infrastructure, such as trained personnel, distribution channels, complementary products, etc.

- Missing standards. Another important factor is the inability to agree on product and technology standards, which can intensify the problems with the supply of complementary components and raw materials and could additionally hinder cost decreasing.

- Customer expectations. On the other hand, missing product standards could prevent a quick market penetration of the new products. New industries typical have to struggle with serious customer confusion, resulting from the variety of product designs, technology performances, as well as conflicting claims of competitors. This raises customer expectations about the risks until market forces sort these things out.

  In addition, many potential customers expect first-generation products to be rapidly improved. As a consequence, they delay purchase until the technology and product design is more mature [70, p.175].

- Image, credibility and high costs. Due to missing standards and technological uncertainties, the product quality is varying in emerging industries. This could damage the reputation of the industry as a whole despite the fact that perhaps only a few companies could be held responsible for the variation.

  Moreover, the image and credibility of the industry in the finance sector could possibly be bad because of its novelty, varying product quality, uncertainties, or confused costumers. This impedes new companies to get access to financial resources. Because of all these structural conditions, emerging industries have to deal with high initial costs per unit which are much above the future level.

- Reactions of threatening economic participants. There are always other economic participants who are feeling threatened by the emerging industry and fight against it by means of policy and regulations. In addition they often have the possibility to decrease the profits, increase the marketing expenses or invest into R&D to make the threatened product more competitive.

It is apparent from this that besides all existing demand-side obstacles, those structural features and boundaries also contribute to a greater or lesser extent to the market penetration problems of new industries. The CSP industry makes no exception. Almost all of the mentioned boundaries are fulfilled by considering the CSP industry conditions as well. To gain a more detailed insight, the specific conditions that shape the CSP industry are discussed in the following sections.

4.3 Specific CSP industry features

4.3.1 Economic features and corporate structures

Essentially, most companies are small and usually do not rely completely on the market for CSP at present. Because there have been no projects during the last years, the industry is dormant and the growth rate for the market is close to zero. The industry participants, if they are strongly committed to CSP and not a subdivision of a large scale enterprise, earn their money in related fields of the business, such as solar thermal technology for water heating, desalination, etc. This is shown also by the proportion of the staff the companies employ. None of the turn-key project developers for the most mature parabolic trough technology, Solel, Solargenix, Solar Millennium and Solarmundo employs more than about 25 full time employees. Moreover, financial data are hardly available.

It is certainly not abnormal for an emerging industry that the companies are of a small size and financially weak. But it becomes a serious obstacle if one takes a look at their very own business. Those companies have to deal with plant projects in a range of some 100 million USD, burdened with economical and technological uncertainties. Therefore, the access to sufficient financial resources may be restricted, or is at least uncertain for many CSP industry participants. As a result, it could be difficult to attract sufficient capital for the project development, the construction of a plant, or to acquire necessary additional production facilities. Furthermore, potential customers may expect these problems and might be afraid of the financial risks during the construction process, because of possible huge advance payments for materials and components [30]. Companies which could take the turn-key responsibility for the implementation of a plant project are still missing in the industry. As a consequence, a powerful EPC-contractor who guarantees the completion of the plant project as a whole, also under the circumstances of financial breakdown of a CSP company during the solar field construction process, has to be found. However, potential EPC-contractors are often not willing to give such guarantees for the small CSP project developer. On the other hand, large scale enterprises from related energy technology industries with sufficient financial power are very reserved and risk-averse concerning the investment and further promoting of solar thermal power technologies [72]. The activities of the Boeing Company and Abengoa as well as Bechtel with the construction of Solar Two in the 1990s, constitute an exception for power tower technology. But Bechtel seems to withdraw the CSP construction activities and focuses with its subsidiary Nexant more on consulting and engineering services. Also in the case of Boeing a fierce determination can not be realized.

Concerning the commitment to CSP technology, things are slightly different if just the supplier of some core components for for solar thermal facilities are examined. In contrast to parabolic trough turn-key development, those components (e.g. the curved reflectors of Flabeg) are often developed and manufactured by subdivisions of larger companies and contribute only little to the overall performance. The same is true for many main suppliers of engineering and consulting services, like Lahmeyer International, Fichtner, or Nexant/Bechtel.

Basically, things are different for these suppliers of CSP consulting services. There is a demand for feasibility studies or the preparation of bidding documents for example. As a result and other than the technology manufacturers, the consultants can earn money with their services at present.

Anyway, it would be necessary for the CSP industry that a few credible and experienced companies with a track record emerge, which could take reliable turn-key responsibility for a CSP plant.

4.3.2 Industry capacity

A reliable statement or measurement of the industry capacity is almost impossible today, because there is no steady production and therefore no data are available. But the threat, or at least the possibility of restrictions in CSP industry is always present as a typical problem of new and small industries. If one makes the assumption, that several of the announced parabolic trough projects are doing further progress within the next 2 years, a huge amount of components would be required at the same time. But it would take time to scale up the production facilities. Bottlenecks are perhaps the supply of absorber tubes and the curved reflectors, but could be also other complementary components [7].

The threat of capacity restrictions for power tower technology might not be as big as for parabolic trough components. The technology is not at the same stage of maturity yet. As a result, there are only a few projects announced worldwide to date, which could be easily handled by the industry.

But there is a further crucial capacity restriction, as well as a lack of industrial infrastructure concerning the commercial plant operation: Who would run the solar field and the ISCCS process for further plant projects, especially those located in developing countries? It is obvious that in developing countries, where most GEF projects are located for instance, the O&M of a CSP plant is another critical point. These countries do neither have the know-how and experience nor the personnel to operate and maintain a CSP plant. To close this gap, technology transfer is expected by those countries and is necessary to achieve the missing technical skills to run a solar field with local personnel. Therefore, most new developments envision the creation of local O&M companies. This would provide additional socioeconomic benefits to the hosting countries, such as the creation of many skilled jobs. To achieve these aims KJC OC has been solicited by most developers to provide training and other services to support this efforts. However, it might take years until a reliable domestic O&M provider can overtake the operation of a new plant [19], [7].

4.3.3 Business relations and alliances

Most industry participants have been in the business for a long time already. In addition, many of the present industry key individuals have been former LUZ staffers. As a result and because of the generally small size, everybody knows everybody within the global industry.

Still there are also formal forms of business relation. Two groups of companies in the industry that formed a kind of *strategic alliance* can be observed. These are Boeing and Nexant in the field of central receiver technology and Solar Millennium, Flagsol, and Schlaich Bergermann & Partner GmbH for parabolic trough systems. In a strategic alliance, two or more companies agree to cooperate on certain projects to share information or productive resources. The majority of the strategic alliances are found in the high-tech industries [17, p.516]. Some of the benefits of pursuing an alliance are risk and cost sharing for any single participant for investment or R&D projects. In addition, collaboration may substitute for company size, which could lead to economies of scale or market concentration. On the organizational level, a successful strategic alliance will blend the core competences of the firms in such a way that the created value exceeds the sum of its parts [6, pp.185].

The strategic alliances of the Solar Millennium Group may raise the credibility of turn-key project development offers. The success of this strategy could be also seen in the EuroTrough development, for instance. Also the cooperation of Boeing (technology) and Nexant (consulting and engineering services) for power tower projects may raise the chances of a successful project implementation as well. Therefore, a stronger cooperation among the industry participants, at least for the next initial projects, could be favorable for the reliability of CSP.

4.3.4 Patents

Patents may impede a fast market development, because if an important technology solution or production process is patented by a single company, it may hinder the market diffusion of the new product. Additionally, patents could sometimes be seen by the incumbents as legally erected entry barriers. But patent laws vary from country to country and are not always effective entry barriers, because for the government patent offices it is often hard to distinguish between new products and imitations. Some innovations, like personal computers or Rollerblades seem to have had no patent protection as a result [6, pp.331], [71, pp.894].

There are no important CSP components that are protected by valid patents and prevent further use or development by other industry participants. Thus, there are no important companies which owe certain patents on core components and technologies that may in turn prevent other industry participants from exploiting business opportunities. Anyway, there is a lot of knowledge contained in the technologies but not much to file a patent on [72]. A good example are the products of Solel and Flabeg, both are presently monopolists for core components of a parabolic trough plant. No one knows exactly about Solel's selective coating process and how they connect the glass and steel tubes and create a vacuum inside to get their unique absorber tube. Other experienced glassware supplier might also be able to manufacture curved mirrors, but probably have to invest in new production facilities. Therefore, new manufacturer of reflectors are most likely to enter the market once production volume builds up.

Although there are hardly utilizable patents for either components, however, there is a lot of necessary knowledge in the market. Also the new EuroThrough collector, which is a development of a European consortium and financially supported by the EU, can be manufactured under license by any company [8]. As a conclusion, it can be emphasized that important patents are no obstacle for the successful implementation of CSP technologies.

4.3.5 Image and marketing aspects

As a consequence of the great deal of technological or product related uncertainties in emerging markets, an offensive marketing is essential. Marketing efforts are important for all new products, because potential customers have to be educated to see its benefits. In the context of CSP little have been done yet. There is a lack of information about potential uses and specific advantages of CSP technology. As a possible result, a general lack of awareness and confidence among the general public and political decision makers can be observed. The general public interest has much more focused on other renewable energies such as PV and wind energy in recent years, whereas CSP with its mirrors spread over an area of a few football fields is often considered as a kind of *odd* technology. From the beginning, PV was much more successful for instance even in the days when this technology was much less developed than to date. For most people PV is more or less equated as solar technology in general [30]. On the other hand, it was easier for PV in particular to win the hearts and minds of the people, because they could also purchase and use those technologies in their houses. The problem is that the target group for CSP applications differs from that of PV. The customer for CSP are utilities, IPPs or other stakeholders, such as big companies, or federal state regulators [62]. Thus, it is more difficult to employ effective marketing. Nevertheless, to achieve more public attention it would not be a bad idea to spend some money on a marketing campaign to show the potential benefits to a bigger audience. In turn this may influence the decisions of the potential customers.

4.3.6 Key success factors

The CSP industry has not yet reached the dynamic of other emerging industries. It is still very dormant and serious costumer and political decision makers confusion through newly announced technology improvements and its expected performances can be observed. This delays the commercialization and market development as well [8].

The following key success factors to achieve sufficient market development and profitability refer to the industry as a whole and not necessarily to its single participants. The first and foremost success factor for the CSP development is to overcome the insufficient supply of qualified organizations. This means that the industry needs a few credible and reliable turn-key developers with the ability to design, build and operate the plant in one hand. In addition, those companies require the capability to finance a plant and additionally guarantee its completion. The industry must move toward turn-key guaranteed plants [10].

Still, considering the small size of most current CSP companies this objective might be hard to reach. For the central receiver technology, Boeing and Nexant/Bechtel are in a position for this kind of turn-key offers, because of their vast potential economic resources. Another company with the potential of future turn-key guaranteed facilities could be the Spanish Abengoa Group. On the one hand, Abengoa is already a supplier of CSP technology (e.g. heliostats from Inabensa, or solar field equipment from Solúcar, S.A.). In addition to its technological commitment, the company is the EPC-contractor for most projects in Spain.

For parabolic trough technology, perhaps the Solar Millennium group is in a starting position, due to its various strategic alliances. But also Solel and Solargenix are in a good position because of their huge experience in this field of business.

Another important factor is the reliability of the technology itself. First of all, a few project opportunities have to be realized in the near future. It does not matter which company actually implements the next CSP plant project, but a technology failure or the breakdown of the implementing company during the next commercial projects would be the worst case scenario for the market penetration of CSP. A bad reputation for the technology and the whole industry would be the consequence. A small industry has to be aware of this situation. Therefore, more international cooperation might be desirable in the beginning in order to prevent such failures.

4.4 Competition Analysis

4.4.1 Market definition

This section aims at providing an overview about the global competitive environment of the CSP industry participants, as well as of the CSP technology with regard to other electricity generating sources. Competition assumes a functioning market, but as shown with the model of the industry life cycle, the market for CSP is just in the very early stage of its development.

Adam Smith described the function of a market with the picture of an *invisible hand*. This was to emphasize that ideal markets idealized are coordinated by individual decisions and actions without external control. Markets can be entirely seen as a more extended version of traditional weekly farmers' markets where producer and consumer meet to buy and sell goods. In the modern sense, a market refers to all kinds of exchange relations arising form the meeting of supply and demand. The more similar the traded goods, the more homogeneous or perfect this market appears to be considered. Markets are inseparably linked the to concept of competition with regard to the usage of scarce goods. Unlimited needs are confronted with scarce resources. Therefore, the actors are in conflict with each other by realizing their own aims and competing for the same goods. The dynamic character of markets is important, because of the competition process for scarce goods which give incentives for constant performance improvements. This dynamic competition defines the exchange ratio of the goods - in other words: the prices. The price of a specific good is an indicator of its scarcity measured by its available amounts and the quantity demanded by all market actors [20, pp.6]. According to the neoclassical theory the prices summarize all relevant information for this market. Therefore, market theory is often also called price theory. From this point of view, market analysis is based on the assumption of perfect information. In addition all necessary information for the decision are available free of charge [52, pp.25].

In the real world the common interpretation of market transactions as being the exchange of goods or services is not precise enough. Very often a physical exchange does not occur like in currency markets. Hence, the value of a good is not only determined by its physical properties. Basically, it can be assumed that property-rights are transferred on markets. Four types of property-rights define the rights on a certain good:

- the right to use a good
- the right to change the good with regard to form and substance
- the right to gain profits by using the good and the duty to cover losses respectively
- the right to sell or transfer the good

These types or their combinations are the fundamental object of market transactions which means that a single transaction is defined as a transfer of property-rights. A necessary condition for the exchange of property-rights is their definition as well as the possibility of enforcement. Their dimension and enforcement are restricted through the legal system. Without a precise definition the object of a transaction would be unclear and without the possibility to enforce the rights, no one would be willing to offer a service in return. No considerable market transactions would be carried out under such conditions [20, p.8]. Finally, the last point to be emphasized are the costs of using a market. These costs are directly linked to a particular market transaction and include the efforts of contracting and controlling, for instance. These transaction-costs may also play a role as market barriers in the context of CSP.

Like all emerging markets, the CSP market is highly imperfect as well. According to the above mentioned market characteristics, it is doubtful whether a real market already exists. CSP technology is not a homogeneous good and there are no exchange relations, because there have not been any commercial project implementations for the last decade. However, the definition is a perfect type of a market and hardly a single existing market would fulfill the theoretical requirements. Even if it is very small and immature to date, there is already an industry for CSP technology in existence, waiting for the breakthrough of its technology in the power markets.

4.4.2 Theory of market structure

This section provides an outline of possible market structures of industries in a competitive environment in which firms interact. The term *market structure* refers to all characteristics that may affect the behavior and performance of the firms in the market, such as the number or the sizes of firms in the market. It often permits an accurate assessment of the likely nature of competition in the market. Markets are often described as being concentrated, having just a few suppliers, or unconcentrated. A commonly used measure of market structure, respectively the market concentration is the Herfindahl-Hirschmann index, which is the sum of the squared market shares of all firms in the market [6, p.235]. But also this measure is not employable for CSP industry conditions, since the market shares of such an inhomogeneous and small industry are not ascertainable.

To break down the market structure analysis to a manageable extent, the focus is usually on four theoretical market structures that generally cover more or less most cases: Perfect competition, monopoly, oligopoly and monopolistic competition [39, p.211]. Within the framework of this study it is definitely not possible to give a detailed analysis of virtually all theoretical aspects of these models.[24]

- ➢ PERFECT COMPETITION. The standard neoclassical approach to market analysis is the model of perfectly competitive market structure, usually simply called *perfect competition*. It has to be indicated that the term *perfect* does not refer to a connotation of desirability. In this context perfect means the highest degree of competition conceivable. A market is said to be perfectly competitive if all firms are price-takers [40, p.180]. This expresses the idea that a competitive firm in that market is one that takes the market price as being given and outside of its control. More generally speaking, the market price is determined by the interactions of all participants, but is beyond control of any of them. Therefore, the price is independent of the firms' individual actions, although the actions of all firms taken together determine the market price. However, the firm is free to set whatever price it wants and to produce as much output as possible. But no one would purchase its products if the price were just one cent above the prevailing market price. The demand curve confronting the firm in this case is perfectly elastic. If a competitive firm wants to sell any products at all, it has to accept the given price which is driven to the level of marginal costs of production. As a result, the economic profits in the long run equal zero [76, pp.215]. The model of perfect competition is built on a set of key assumptions which are important to recognize:

  - → A LARGE NUMBER OF SMALL FIRMS. The number of firms in the industry must be large enough so that no single seller can influence the market price. Both seller and buyer are price takers.

[24] For an advanced economic analysis of competitive market structures see Varian (1992) or Tirole (1999).

- → HOMOGENEOUS PRODUCT. All firms in the industry sell identical products which are in no way differentiated among the producers. If a producer could differentiate its product from that of others, it may gain a partial control over the price
- → PERFECT INFORMATION. All market participants have perfect information on (present and future) prices, costs and the qualities of commodities offered for sale. As a result, for example, no customer would pay more than the present market price. In addition, all of these information are available from the market actors for free.
- → FREEDOM OF ENTRY AND EXIT. The first three assumptions refer to the individual actors. This assumption relates to the industry in general. All factors of production are completely mobil. Moreover, there are no barriers, neither legal nor other restrictions either to enter or exit from an industry [17, p.102].

It is hard to find any particular perfectly competitive market which satisfies the all the literal conditions of the model. However, some markets approximate perfect competition, such as those for many basic raw materials and agricultural commodities.

➢ MONOPOLY. A monopoly is the complete opposite to the perfectly competitive firm. It is a market structure featuring a single firm serving the entire market and facing no or only little competition. A monopolist acts as a price-setter, and there must be sufficient barriers to enter the industry. Examples of pure monopoly are rare but much more common for regional areas. Electric power supplier utilities are often monopoly firms in their region, as are firms that provide local telephone services [39, p.232]. Monopolies are considered to be inefficient in most cases. A monopoly industry supplies a smaller output and sells at higher prices than a similar competitive industry; and it reaches non-optimal levels of R&D in addition [11, pp.170].

➢ IMPERFECT COMPETITION. The previous two sections described briefly the two polar cases of markets structures. In the real-world the competition in most industries is far less than *perfect*, but with barriers. The two other *imperfect* types of market structures are to be found half-way between both polar cases.

- → MONOPOLISTIC COMPETITION. The market structure termed *monopolistic competition* contains fewer companies than in the perfect competitive market, but more than the single or few firms in the monopoly or oligopoly. This structure is considered to be the most realistic and suitable model regarding to real-world market conditions.

Firms in many industries especially those involved in producing, distributing and selling of consumer goods and services operate in imperfect markets. The same is true for most firms in the capital goods industry. They are neither price-takers nor alone in the industry. Hence, they do not operate under perfect competition, nor as a monopoly but somewhere between these extremes [40, p.196].

→ OLIGOPOLY. An oligopoly refers to market conditions in which there is competition among a few firms dominating the industry. The basic difference that distinguishes the oligopoly from perfect and monopolistic competition is that the number of firms is so small that each individual firm is directly affected by the actions of its competitors. The firms are aware of the fact that their actions are interdependent and each decision will provoke a reaction of the rivals. This behavior distinguishes the oligopoly from the monopoly, where barriers of entry protect the single firm from potential rivals [40, p.200]. But barriers to enter could be present in an oligopoly as well and the product of the industry can be homogenous or differentiated.

Game theory is often used to analyze strategic interactions among oligopolists, whereas cartels are founded to limit the scope of competition among the industry participants [11, pp.210].

As shown above, the CSP market is imperfect. However, a *perfect market* for CSP in this early stage of development is not desirable either, because of the impossibility to gain long run profits by definition. There would not be any incentive to enter the market for new companies as a consequence.

4.4.3 The present CSP market structure and competitive environment

There can be observed a kind of oligopoly for the key developer of parabolic trough plants, consisting of Solar Millennium, Solel, Solargenix and Solarmundo. But this has little impact on the industry or the company's strategy. However, a strategic decision might be the focus of the project developer on their *domestic* markets. Solar Millennium concentrates on the projects in Spain and Solargenix on the projects in Nevada and Arizona. Both companies did not make any offers for the most advanced GEF project in India, where Solel is very active.[25] On the one hand this behavior could be interpreted as a geographical differentiation of the markets, at least in this early stage. On the other hand it could indicate a weakness of the industry.

Flabeg has a monopoly position for curved mirrors and Solel is still a monopoly for absorber tubes. Both monopolies would need barriers to entry to persist, but these are actually low. Thus, both are weak monopolies. For the next year Schott Rohrglas announced to provide a new type of absorber tube which is planned to be installed in the EuroTrough collector. This is supposed to have a positive influence on the price of absorber tubes, because of the arising competition. The production process of Flabeg and the quality features of the parabolic reflectors are so unique that it might be very expensive for other manufacturer to build up the know-how and the production facilities in the same manner. But it is certainly not impossible. If money can be earned, other large companies with huge financial resources are most likely to enter the market [72]. In addition, perhaps Solarmundo could also be seen as a potential threat for the Flabeg monopoly in the future, because the used Fresnel technology does not afford sophisticated curved mirrors [16].

Boeing has a monopoly position as a power tower technology supplier, because in contrast to the German volumetric air receiver, the molten-salt receiver is available and could be implemented immediately.

Also the supplier of consulting services could be considered to be in a quasi-monopolistic position. Especially technical consulting services for parabolic trough projects are shared among Fichtner Solar and Lahmeyer International. This can be also a limitation because customers might be interested in getting different independent opinions to increase the confidence in the technology and the feasibility of specific investments.

As a conclusion, there is presently no real competition among the industry participants existing. The statements of most interviewees agree with this. The existing monopolies are weak and basically not a real problem for the development of further plant projects. The same principles are true for the oligopoly of the trough developers. However, it could be expected that CSP would benefit from increasing competition. Potential CSP customers may prefer competition to build up more

[25] Solarmundo did not apply for any of these projects which may denote that the technology is presently not yet completely at a marketable state.

confidence in the offers of the companies, because the competitive pressure would lead to improving product concepts. In addition, and most importantly, a rising competition would have the positive effect to lower the component prices to an acceptable level.

However, with the successful implementation of a few projects this position may change quickly. It could be assumed, that large scale enterprises will enter the CSP market if money can be earned. At the point of accelerated installed capacity and increasing equipment production, a functioning market will emerge with a competitive environment for the incumbents and newly entering industry participants. At this time it is crucial for the established and specialized CSP companies how they are positioned and how they could use their strategic advantages.

All important CSP companies are located in the three centers which promote CSP the most: Europe (Germany + Spain), USA and Israel. Also between these centers there is no real competition or any kind of distrust ascertainable at present. For example, the good and successful cooperation of the Solar Millennium group, together with its partners, and the American KJC Operating Company to include a loop of the EuroTrough in one of the SEGS at the Kramer Junction site underlines this fact. However, there can be observed a minor competition between the different technology representatives representing themselves as having the better technological solutions.

At this point of analysis it has to be emphasized that the global competitive environment of solar thermal power is characterized by other types of energy sources. It is obvious that conventional fossil-fuel power plants are basically the biggest competitors, and that it will probably take many years until CSP will be able to compete on the same level in terms of cost. In the short term, and this is more serious for the market development, CSP has to compete with other forms of renewable energies. Form the point of view of Porter's Five-Forces-Model, technologies exploiting other renewable sources could be interpreted as substitutes and are therefore a remarkable competition for CSP. Many competitive renewable energies have a large scale power generation nature as well. At the present state of development, CSP is more expensive than wind or geothermal for example, but much cheaper as PV.[26] Nevertheless, it also has to be kept in mind that under the assumption of a successful market introduction, CSP is expected to have the highest potential of becoming competitive with fossil fuels in the future.

[26]Figure A.1 in the appendix compares renewable energies in terms of capacity and cost.

4.5 Comparison with the photovoltaic and wind energy market

The emerging PV market is characterized by ever-expanding economic niche-markets in a diverse range of applications and a well-developed industry with ascertainable annual growth rates. Referring to the life cycle concept, it is in the stage of expansion. The average annual growth rate of the PV market has been approximately 21% in the last 15 years and the total production capacity grows rapidly. In 2001, the Japanese PV cell and module production increased 31%, in the USA 34%, in Europe 42% and in the rest of the world the production increased 39% [44]. The speed of market growth is expected to increase further on, because if the cost decreases in the industry, larger markets will also become viable for PV. Due to low entry barriers of new industries many companies entered the PV market in the early stages of its development. The companies currently involved in this market range from glass manufacturers to oil companies, with the domination of the industry by larger firms, such as Sharp, BP, Sanyo, Siemens, etc. In general, a dominance of the Electronics and Petrol/Chemicals industries over independent companies specializing in PV can be observed and let assume a strong competitive environment. Also the concentration in the market is high. The top ten producers of PV cells and modules produced 336,24 MWe, reflecting 86% of the world production in 2001. The commitment of those large scale enterprises might be explainable by the wide range of potential applications of PV that caused large companies to enter the market at an early stage [50, pp.372], [44]. This bears the additional advantage that those big companies are more likely to overcome a crisis than do small and specialized companies. Furthermore, they can protect the market development and influence political decisions.

During the last two decades, the wind turbine industry has developed into a professional high-tech industry as well. The installed wind energy capacity has been increasing at an average annual growth rate of about 25% between 1992 to 1997 and over 30% between 1998 and 2000. The revenues for equipment sales and installation exceeded 5,2 billion USD in 2001. This makes wind energy the fastest growing energy sector and a good example for a successful and dynamic emerging industry. Although the market concentration is high too, the industry structure differs a little bit from that of PV. The majority of industry participants are specialized wind energy technology supplier. For instance, the first three of the largest manufacturers Vestas (Denmark), Enercon (Germany) and NEG

Micon (Denmark) which together account for approximately 50% of the world's turbine production are joint-stock companies, or in the case of Enercon, privately owned and not subsidies of corporate groups. All are exclusively committed to wind energy [59, pp.215], [24]. This emphasizes that under certain conditions a successful industry development could be also possible without the engagement of large corporate groups from related industries. However, since CSP project developments require a vast amount of capital the commitment of large companies would be favorable.

In contrast to PV and wind, the lack of an existing commercial market is obvious for CSP. As a result, a reliable and credible industry and a mature technology with a lot of reference facilities is still missing. In comparison with the above mentioned renewable technology industries, again it is obvious that CSP is still in the very beginning of the development.

A new study of Navigant Consulting [49] on the present state of renewable energy technologies in the United States and Canada analyzes the varying market conditions for the different technologies. According to this study, wind energy is expected to be the leading technology in terms of new installed capacity over the next 10 years. For PV a robust growth is expected in the USA. But it is also being emphasized that the prices are still very high compared to grid power and the absolute necessity of continued government support for grid-connected applications is underlined. Those drivers of growth are crucial for wind as well. For CSP in contrast, the study expects only minimal development due to continued high capital costs and a lack of intermediate markets, unlike PV, which has cost-effective off-grid applications. Nevertheless, a potential advantage is seen in the ability to incorporate storage systems.[27]

In this context it is also interesting to notice, that CSP was hardly mentioned at the 2nd Annual Conference of the American Council for Renewable Energy (ACRE) on July 8-9, 2003 in Washington, D.C., which discussed the state-of-things of the development of renewable energies with a focus on North America. The discussion was mainly on the mature renewable energy technologies PV and wind and their further perspectives.

[27] The US government cut down the annual financial support for the R&D of CSP technology to a large extent. That will amount to just enough for the industry to survive. However, this could be a chance for the European industry to gain market share, if CSP emerges within the next few years.

5 Conclusions

As a new industry in the first stages of its life cycle, the CSP industry faces problems typical for its state of development. Besides all existing demand-side obstacles, structural features and boundaries of an emerging industry contribute to a greater or lesser extent to the commercialization problems of solar thermal power as well. Consequently, the responsibility for the market introduction problems of solar thermal power is not just a demand-side issue. It can be underlined that also the supply-side adds to the insufficient market introduction.

The potential turn-key developers for the most mature parabolic trough technology are small and correspondingly financially weak, and their products contain a lot of risks and uncertainties. Things are similar with central receiver technology. Despite the fact that the Boeing company or the Abengoa Group are huge corporations, the CSP industry is basically dominated by small and specialized companies or subdivisions of large corporate groups. The final realization of a plant project, however, depends significantly on a company large enough to provide guarantees for the entire facility. Similar to the PV industry, where the PV cell production process is very capital intensive, the high financial volume of a solar thermal plant project may also require the commitment of large scale enterprises form related industries which could be very favorable and beneficial for the CSP industry as a consequence.

To drive CSP into competitive markets, a few credible and experienced companies with a track record have to emerge. Those companies have to be strong and reliable enough to take the turn-key responsibility for the implementation of a plant project. The Solar Millennium Group with its strategic partners is probably on the best way to reach this objective, provided that the Spanish projects can be realized successful. The CSP companies are facing a pressure to succeed regarding the technology performance during the next initial projects. A technology failure would be the worst of what could happen to the industries' reputation.

In addition, CSP facilities did not manage to get market acceptance. As a result, a real commercial market with a competitive environment is not existing and the industry is not able to get sufficient orders for its development. The lack of competition within the industry might also impede to build up more customer confidence in the technology and the reduction of prices. This may prevent the market penetration as well.

Another important topic are possible restrictions in the industry capacity. Those boundaries may become crucial if a few announced projects are implemented simultaneously and may be most prominent for certain core components, such as receiver tubes or reflectors.

Despite all current problems in the market, it can be emphasized that most interviewed experts are very confident about the future perspectives of CSP, provided that sufficient power purchase agreements can be negotiated. However, some project implementations have to happen in the near future. Otherwise the industry, after so many years of inactivity, will probably come to an end.

A Appendix

A.1 Interviewees

Aßmann, Dirk *Personal Conversation*, Energy Specialist, Wuppertal Institut for Climate, Environment, Energy GmbH, Wuppertal, Germany

Bjerde, Anja *Personal Conversation*, August 16, 2003, Senior Infrastructure Specialist, World Bank, Washington, D.C., USA

Brakmann, Georg *Personal Conversation*, August 11, 2003, Consultant, Fichtner Solar GmbH, Stuttgart, Germany

Frier, Scott D. *Email Communication*, August 14, 2003, Vice President & COO, KJC Operating Company, California, USA

Cohen, Gilbert E. *Personal Conversation*, July 10, 2003, Vice President of Engineering, Solargenix Energy, Raleigh, USA

Fischedick, Manfred *Personal Conversation*, April 16, 2003, Energy Specialist, Wuppertal Institut for Climate, Environment, Energy GmbH, Wuppertal, Germany

Geyer, Michael *Personal Conversation*, August 04, 2003, Executive Secretary, IEA/SolarPACES, Aguadulce, Spain

Gladen, Henner *Personal Conversation*, August 04, 2003, Chief Executive Officer, Solar Millennium AG, Erlangen, Germany

Gould, Bill *Personal Conversation*, July 10, 2003, Program Manager, Nexant, San Francisco, USA

Hilliges, Peter *Personal Conversation*, Program Manager Climate Change, GEF, Washington, D.C., USA

May, Kenneth *Email Communication*, July 17, 2003, President, Industrial Solar Technology, Golden, USA

Sklar, Scott *Personal Conversation*, July 07, 2003, Consultant, The Stella Group, Washington, D.C., USA

Trieb, Franz *Personal Conversation*, September 05, 2003, German Aerospace Center (DLR), Stuttgart, Germany

Wilkins, Frank *Personal Conversation*, July 17, 2003, Program Manager, U.S. Department of Energy, Washington, D.C., USA

Morse, Fred *Personal Conversation*, July 18, 2003, Consultant, Morse & Associates, Washington, D.C., USA

Woerlen, Christine *Personal Conversation*, July 18, 2003, Program Manager Climate Change, GEF, Washington, D.C., USA

Wyder, Joe *Email Communication*, July 28, 2003, Program Manager, Australian Greenhouse Office, Canberra, Australia

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Hamburg, den 09.10.2003

Hajo Wenzlawski