CHAPTER 1

Review of CSP Technologies

This chapter describes the technologies of concentrated solar thermal power (CSP) to provide the basis for the subsequent socio-economic analysis for the MENA-economies. Section 1.1 gives a general overview of CSP technologies. Section 1.2 presents the CSP market with its main commercial and industrial players along the value chain. In section 1.3, the main manufacturing processes are described. Lastly, section 1.4 analyzes the cost structure of a typical CSP plant.

Parabolic trough plants are the most commercial CSP technology, and amount at present to 94 percent of the CSP market and installations (CSP-Today, 2010). This is why the following sub-sections mainly focus on this technology. However, most findings apply directly or in analogy also for other CSP technologies because of technological similarity.

1.1 Overview of the CSP Technologies

In a nutshell, CSP power plants produce electricity by converting concentrated direct solar irradiation into energy. Unlike photovoltaic cells or flat plate solar thermal collectors, CSP power plants cannot use the diffuse part of solar irradiation which results from scattering of the direct sunlight by clouds, particles, or molecules in the air, because it cannot be concentrated..

The process of energy conversion consists of two parts:

- The concentration of solar energy and converting it into usable thermal energy
- The conversion of heat into electricity

The conversion of heat into electricity is generally realized by a conventional steam turbine (Rankine cycle). Concentrating solar collectors are usually subdivided into two types, with respect to the concentration principle:

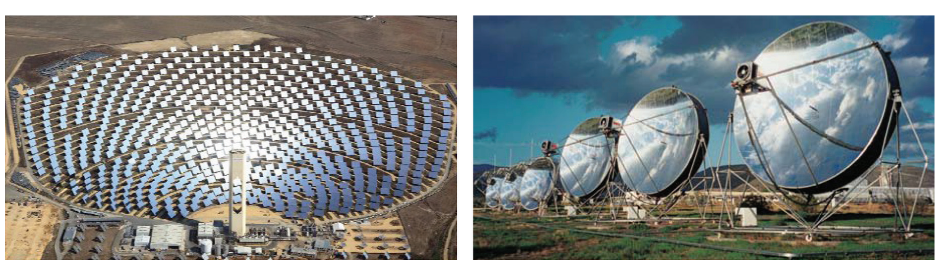
- Line-focusing systems, such as the parabolic trough collector (PTC) and linear Fresnel collector. These systems track the sun position in one dimension (one-axis-tracking), see Figure 1.2. Point-focusing systems, such as solar towers or solar dishes. These systems realize higher concentration ratios than line-focusing systems. Their mirrors track the sun position in two dimensions (two axis-tracking), see Sources: Abgengoa, 2010 and DLR, 2010.

Figures 1.1 and 1.2 show reference plants; the captions of the pictures include the approximate dimensions of the plants.

Figure 1.1 ■ Line-Focusing Systems: Left: Parabolic Trough Collector: 64 MW_{el} Power Plant *Nevada Solar One*; Dimensions: Collector Aperture Width 5 m (Morin, 2010). Right: Linear Fresnel Collector: 1.4 MW_{el} Plant *PE1* in Murcia, Spain; Dimensions: Receiver Height Above Mirror Field: 7 m (Novatec, 2010)

Sources: Morin, 2010 and Novatec, 2010.

Figure 1.2 ■ Point-Focusing Systems: Left: Solar Tower Plant PS10, 11 MW_{el} in Seville, Spain; 624 so-Called Heliostats, 120 m^2 Each, Focus the Sunlight Onto a Receiver on Top of a 100 m High Tower (Abgengoa, 2010). Right: Dish Stirling Prototype Plants of 10 KW_{el} Each in Almería, Spain; Diameter 8.5m (DLR, 2010)



Sources: Abgengoa, 2010 and DLR, 2010.

1.1.1 Parabolic Trough Collector Technology

Parabolic trough technology is commercially the most advanced of the various CSP technologies. Since the 1980s and early 1990s, nine parabolic trough plants—the Solar Electric Generating System (SEGS) plants, with a total capacity of 354 MWel—have been in operation in the Californian Mojave Desert in the United States. In the past five years, several trough plants have been built, such as a 64 MWel power plant near Boulder City, in the United States, and several 50 MWel power plants in Spain. The first commercial parabolic trough plant installed in Spain was the 50 MWel plant Andasol 1, which includes a thermal storage with a capacity of 7.5 hours of full load operation (Figure 1.3). An overview of the commercial power plants that are developed, built and operated globally is available at SolarPaces (2010).

The parabolic trough collector (PTC) consists of a receiver, mirrors, a metal support structure, pylons, and foundations. The parabolic-shaped and facetted mirrors concentrate the sunlight onto the receiver tube. The parabolic shape is usually implemented by four mirror facets, consisting of glass sheets (4 mm thick) which are thermally bent and coated with a reflective silver layer, with additional protective layers on the back side of the silver. The absorber inside the receiver is realized in the form of a coated steel tube. The coating is spectrally selective in the sense that

Figure 1.3 ■ Parabolic Trough Power Plants Andasol 1 (front) and Andasol 2 (rear) in Spain with a Capacity of 50 MW Each and a Storage Size of 7.5 Full-Load Hours. The Power Block and the Storage are in the Center of Each Solar Field

Sources: SMI, 2010.

it absorbs the solar (short wave) irradiation well and emits almost no infrared (long wave) radiation, which reduces heat loss (Hildebrandt, 2009). The absorber tube is surrounded by an evacuated glass tube which is highly transmissive for the sun light due to an anti-reflective coating. The absorber tube and the encasing glass tube together are called the receiver. In today's commercial trough systems the entire collector—including the receiver—is tracked according to the moving sun position.

There are several innovations in PTC technology under development or in prototype status. The current developments focus on cost reductions in the assembly and production process (e.g., automized production), lighter collector structures, new materials for collector structures (such as aluminum), and new heat-transfer fluids (e.g., molten salt and direct steam).

Examples of innovative products and companies include the HelioTrough, using a larger collector aperture and a slightly larger absorber tube with a diameter of 8.9 cm instead of 7.0 cm (Riffelmann, 2009); the Skytrough, using a high-reflectance polymer film instead of glass mirrors and an aluminum sub-structure instead of steel (Brost, 2009); and the new mirror technology Vegaflex of Xeliox and Almeco (Almeco, 2010), using a stiff aluminum sandwich sub-structure with a metallic reflector. Further details on technological improvements of parabolic trough technology can be found in ATKearney, 2010.

1.1.2 Parabolic Trough Power Plant System—Working Principle and the Option of Thermal Energy Storage

One main advantage of solar thermal power plants over other renewable power technologies, such as photovoltaic and wind energy converters, is the option of energy storage. Unlike the storage of electric energy, thermal energy storage is practically and economically feasible already today, even in large-scale applications. Solar thermal power plants can be equipped with thermal energy storage with a full-load storage capacity in the range of several hours. Usually, the storage is filled during the day, and emptied again after sunset, so that electricity is still produced even after sunset. This allows for plant operation in concordance with load requirements from the grid, because in many countries there is an electricity demand peak after sunset. During such demand peaks, electricity prices are usually far higher than base-load prices, creating a very important added value of CSP and storage.

Various thermal storage technologies are in principle feasible for solar thermal power plants, based on different physical mechanisms (such as sensible heat storage, latent heat storage, and chemical energy storage), and by applying different types of storage materials (such as molten salt, oil, sand, and concrete). The storage material needs to be cheap, because large quantities are required. A comprehensive overview of storage principles and technologies suitable for solar thermal power plants is given in Gil, 2010 and in Medrano, 2010. It should also be noted that different heat transfer fluids (HTFs) used in the solar field require and allow different storage options.

Thermal storage is in principle applicable not only to parabolic trough power plants, but also to the other CSP technologies. However, the only power plants that are in operation today using thermal storage are the Andasol power plants shown in Figure 1.4. The Andasol plants use a two-tank molten salt storage; see working principle in Figure 1.5. It stores heat by heating up a medium (sensible heat storage).

When loading the storage, the hot heat-transfer fluid, coming from the solar field, passes through a heat exchanger and heats up the molten salt. In turn, the storage is unloaded by transferring the heat from the salt back to the heat-transfer fluid. Many operation strategies are feasible for the operation of the plant and the storage. The most common one is to feed primarily the turbine directly with the heat from the solar field. Whenever excess solar heat is available, it is stored. Other options may also aim at storing the solar energy from the morning hours instead of directly converting it into electricity, and thereby using the storage for shifting rather than for maximizing the plant's operational hours.

1.1.3 Components of Parabolic Trough Power Plants

The main components of parabolic trough power plants are shown in Figure 1.5. A more detailed description of the single components can be found in Annex A to provide the basis for the subsequent analyses of the manufacturing processes, of the cost of components and processes, and of the potential to produce components in MENA countries.

The analysis of the components is based on state of the art technology, which consists of a parabolic trough using thermal oil as heat-transfer fluid and the power block. Optionally, a thermal energy storage can be used (see Figure 1.4).

Figure 1.4 ■ Sketch of a Two Tank Molten Salt Solar Thermal Energy Storage Embedded Into a CSP Power Plant

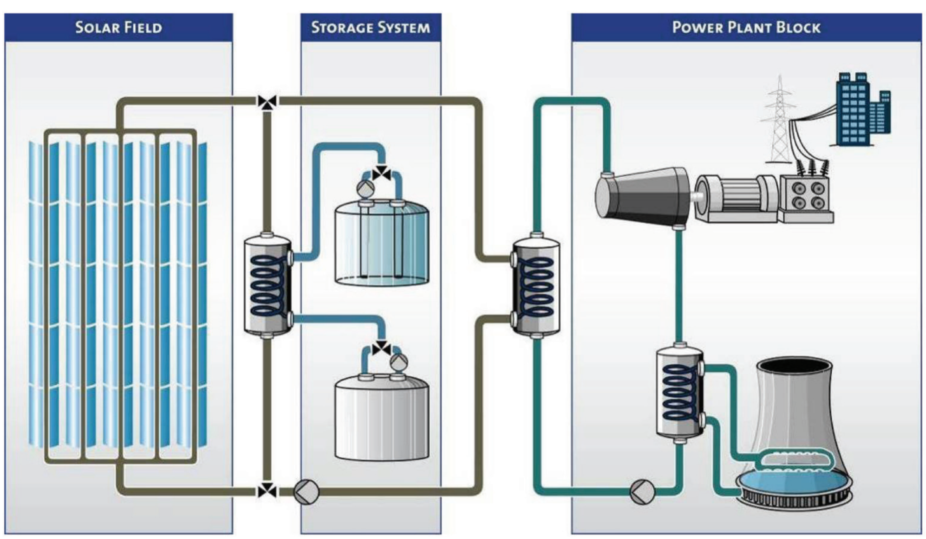
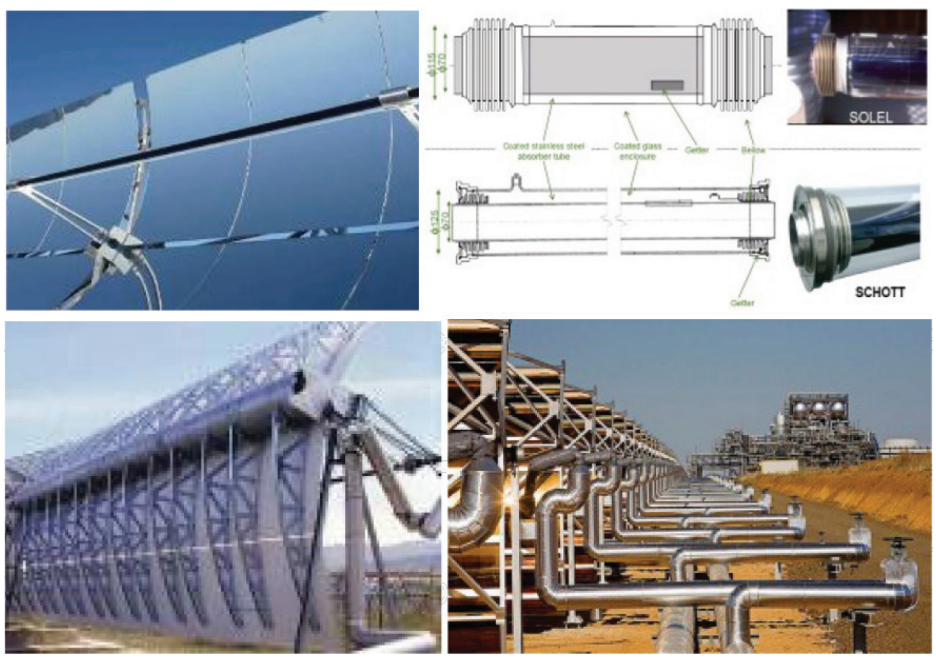


Figure 1.5 ■ Components of a Parabolic Trough Power Plant are the Solar Field and the Power Block. Optionally, Thermal Storage Can Be Integrated

Parabolic Trough Power Plant

Solar field	Thermal storage	Power block
• Receiver	• Molten salt	• Turbine
• Mirror	• Hot tank	• Generato
• Support structure	• Cold tank	• Condenser
• Tracking	• Heat exchangers	• Pumps
• Piping	• Pumps	• Heat exchangers
• HTF (oil)		• Fossil boiler (optional)
• HTF pumps		• Cold tank
• Heat exchanger		• Balance of plant

Figure 1.6 ■ Mirrors, Receivers, Support Structure, and Piping for CSP Plants



Sources: Morin, 2010; Castaneda, 2006; Estela Solar, 2010; NREL, 2008

CSP involves many components and much labor which can generate high local value in the MENA region. The largest share of both investment and operation and maintenance costs relates to the solar field (see section 1.4). The power block side uses mostly specialized equipment that does not differ from plant components that are used in conventional power stations. Apart from civil engineering and basic construction, works are performed by a few international players (see section 1.2). The thermal storage as an optional plant component has only a few commercial installations worldwide so far. The major cost in the storage is the salt itself (Herrmann, 2004), which can be delivered by a few companies with access to the raw materials, such as the Chilean company SQM (SQM, 2010).

As CSP power plants are designed to last for at least 20 years (feed-in-tariff contracts in Spain last 20 years), stability of each component is essential. The components have to resist the harsh desert climate without degradation.

1.1.4 Other CSP Concepts – Linear Fresnel, Solar Tower, and Solar Dish

Beyond the most commercial trough technology, which represents 94 percent of the installed CSP plant capacity today (CSP-Today, 2010), other technologies are becoming more commercial and will probably increase their market shares in the near future.

Linear Fresnel collector plants

Linear Fresnel collectors (LFCs) are a variation of parabolic trough collectors. Their main difference from parabolic trough collectors is that LFCs use several parallel flat mirrors instead of parabolic bent mirrors to concentrate the sunlight onto one receiver, which is located several meters above the primary mirror field. The horizontally aligned reflectors use flat glass mirrors that are slightly curved through elastic bending. Each mirror line is individually tracked according to the position of the sun.

The receiver also consists of a long, selectively coated absorber tube, without any need for the flexible hoses or rotating connectors required by a parabolic trough. Due to the optical principles of Fresnel collectors, the focal line is distorted by astigmatism (Mertins, 2009). This requires a secondary mirror above the tube to refocus the rays missing the tube in a secondary reflection onto the tube. Another concept is based on several parallel tubes forming a multi-tube receiver, thereby increasing the width instead of using a secondary reflector.

Compared to trough plants, commercial LFC technology is relatively novel. Several prototype collectors and prototype power plants have been installed in the past few years, but no fully commercial LFC power plants are yet in operation. Novatec, however, is currently building a commercial 30 MW_{el} power plant in Spain. Several concepts with different geometric and design characteristics have been developed by a number of companies, see Table 1.1.

The main differences between the Fresnel concept and the parabolic trough collector include:

- LFCs use cheap, flat mirrors (6–20 €/m^2) instead of expensive parabolic curved mirrors (25–30 €/m^2); furthermore, flat glass mirrors are a standardized mass product.
- LFCs require less heavy steel material, using a metal support structure with limited or no concrete (making for easier assembly).
- On-site installation of LFCs is predicted to be faster.

Table 1.1 ■ Different Concepts of Linear Fresnel Collectors

Name of Company	Aperture width	Photograph	Receiver	Location
Novatec BioSol (Morin 2010)	12 m (16 mirrors of 75 cm)		Single tube absorber with secondary concentrator	1.4 MW plant in operation in Calasparra, region Murcia, Spain
Fresdemo collector of SPG and MAN (Bernhard 2009)	15 m (25 mirrors of 60 cm)		Single tube absorber with secondary concentrator	Demonstration collector at Plataforma Solar de Almería, Andalucía, Spain
Areva Solar (Areva 2010)	approx. 20 m (10 mirrors of approx. 2 m)		Multi-tube receiver, no secondary concentrator	5 MW_{el} power plant at Kimberlina, California, USA
PSE/Mirroxx (process heat <200°C) (PSE 2010)	5.5 m (11 mirrors of 50 cm)		Single tube absorber with secondary concentrator	Collectors in Freiburg (Germany), Bergamo (Italy), Seville (Spain), Tunisia, Masdar (UAE)
CNIM	20 m (14 mirrors)		Single tube absorber with secondary concentrator Direct steam production	1 MW pilot plant in operation in La Seyne sur Mer, region of Toulon, France

Wind loads are smaller for LFCs, which leads to easier structural stability, reduced optical losses, and less mirror-glass breakage.

The receiver on LFCs is stationary, whereas the trough receiver moves with the entire trough system around the centre of mass. This necessitates flexible connections to the piping, which is technically challenging and maintenance intensive.

The receiver is the most expensive component in both parabolic trough collectors and in LFCs; however, the mirror surface per receiver is higher in LFCs than in PTCs.

The optical efficiency of LFC solar fields (referring to direct solar irradiation on cumulated mirror aperture) is lower than that of PTC solar fields due to geometric principles: In order to reach a certain solar concentration, the LFC mirrors are packed more densely than in PTC plants. The advantage of reduced mirror spacing is that it requires less land; the disadvantage is that mutual mirror shading and mirror blocking of the reflected sun-light occurs. Furthermore, the sun rays are not hitting the LFC mirror perpendicularly, which leads to cosine losses.

It is expected that the mentioned cost advantages will more than compensate for the efficiency drawbacks of LFC technology, but this will have to be proven in commercial plants. Linear Fresnel collectors seem to be more open for redesign and adaptation to local conditions. Local content is probably higher than for the parabolic trough due to the simpler components. All commercial Fresnel collectors use pressurized water/steam as an environmentally friendly heat-transfer fluid. A power plant with direct steam generation thus requires fewer heat exchangers than one using HTF thermal oil.

Solar Tower Plants

Solar Tower Plants, also called Power Towers (see Figure 1.7), concentrate the direct solar irradiation onto a tower-mounted receiver where the heat is captured, typically generating high temperatures. This heat drives a thermo-dynamic cycle, in most cases a water-steam cycle, to generate electric power. The collector system uses a huge number of sun-tracking mirrors, called heliostats, to reflect the incident sunlight onto the receiver where a fluid is heated up. Today's receiver types use water/steam, air, or molten salt to transport the heat. Depending on the receiver concept and the working fluid, the upper working temperatures range from 250°C to 1000°C.

The first commercial solar tower plant (see Figure 1.7) uses water as the heat-transfer fluid (HTF) and generates saturated steam to power its turbine. A promising pre-commercial concept that is currently under development uses compressed air as the heat transfer medium in combination with a gas turbine (Buck, 2008). In this case, the receiver replaces the combustion chamber of a conventional gas turbine. In the long run, high solar efficiencies in combination with a combined cycle—i.e., a combined gas and steam turbine cycle—are possible. The typical size of solar tower plants usually ranges from 10 MW_{el} to 100 MW_{el}. The larger the plants are, the greater is the absolute distance between the receiver and the outer mirrors of the solar field. This induces increasing optical losses due to atmospheric absorption as well as unavoidable angular mirror deviation due to production tolerances and mirror tracking. In addition to the Spanish

Figure 1.7 ■ 11 MW_{el} Power Tower by Abengoa, Hundreds of Heliostats Concentrate the Sun (up to 500 Times) Onto an Absorber on the Top of the Tower

Source: Abengoa, 2010.

company Abengoa Solar, which developed, installed, and operates the solar tower technology shown in Figure 1.7, several new solar tower technologies have been developed in the last few years and are currently being proven in prototype power plants by the companies BrightSourceEnergy, Sener, eSolar, and Aora.

Dish Stirling plants

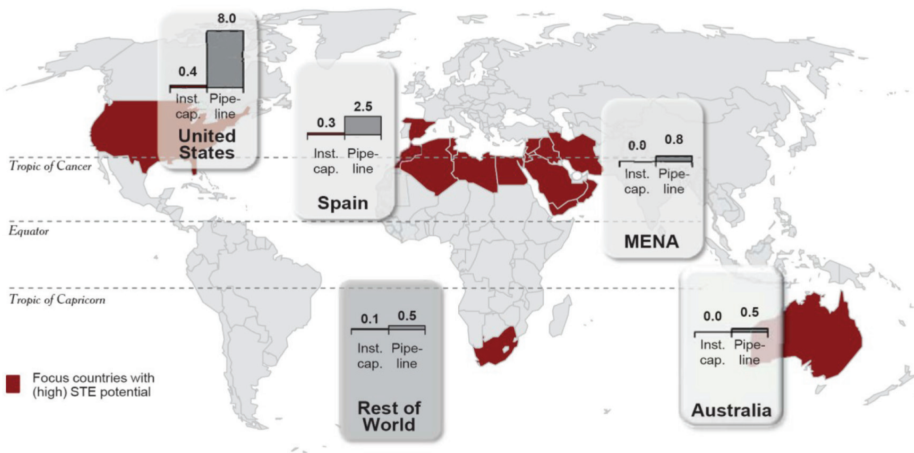
Dish Stirling plants use a parabolic dish concentrator made of reflector facets to concentrate direct solar irradiation onto a quasi-punctual thermal receiver. Usually, a Stirling engine in combination with a generator unit, located at the focus of the dish, transforms the thermal power to electricity (see Figure 1.8).

There are currently two types of Stirling engines: kinematic and free piston. Kinematic engines work with hydrogen as a working fluid and have higher efficiencies than free piston engines. Free piston engines work with helium and do not produce friction during operation, which enables a reduction in required maintenance. Multi-cylinder free piston developments promise cost reduction and overall concept simplification. The size of a single Dish engine typically ranges from 5 to 50 kW_{el} (Laing, 2002).

Figure 1.8 ■ Maricopa Dish Stirling Farm in Arizona, the Park has a Rated Power of 1.5 MW_{el} Consisting of 60 Dish-Stirling Units

Source: Stirling Energy Systems, 2010, srpnet.com, 2010.

Figure 1.9 ■ Global CSP Capacity – Existing and through 2015



Source: Estela, 2010*.
* The CSP operational power tends to change quite rapidly, especially in Spain and the US: Protermosolar provided in December 2010 the following figures: Spain Total operational 674 MW (Tower: 21 MW, Parabolic Trough 13x50 MW=650 MW, Fresnel+Stirling 3 MW), USA 505 MW(Parabolic Trough 354 + 64 + 75 MW = 493 MW, Fresnel + Stirling 7 MW, Tower 5 MW).

Dish Stirling technology presents the highest efficiency (Direct Normal Irradiance [DNI] on reflector area to power generation) among CSP systems. Stirling Energy Systems, together with Sandia National Laboratories, achieved a new world record of solar-to-grid system conversion of 31.25 percent (Taggart, 2008).

A benefit of Dish Stirling technology over other CSP models is the dry cooling[1] that is used in most constructions, enabling electrical supply in arid regions. Another clear advantage over parabolic trough and linear Fresnel technologies is adaptability to slopes. A CSP power plant of MW scale can easily be installed in a mountainous region like the Greek islands. These two points—dry cooling and adaptability to mountainous regions—are the major advantages of Dish Stirling, opening an economically valuable niche to this modular scalable technology, even though the levelized cost of electricity is still higher. Another really interesting area of application is the replacement of diesel engines supporting mini grids. Since the dish Stirling concept is based on a modular scalable energy output, it presents an ideal renewable alternative to relatively expensive and oil-demanding diesel energy supply.

In the United States, large scale centralized power plants in the power range of several hundred Megawatts, consisting of thousands of Dish-Stirling units, were announced many years ago, but have not yet been produced.

[1] Dry cooling concepts also exist with other CSP technologies, but the standard technology is based on wet cooling systems.

1.1.5 Status of CSP Project Development

After twenty years of operation in the Solar Electric Generating System (SEGS) plants in California, the world-wide market growth of renewable energies has given CSP technology a new prospective in countries with high direct radiation. Starting in the Spanish and U.S. electricity markets, many projects are now under development and under construction. As parabolic trough plants gain status as a commercially bankable technology, this technology has announced the highest share of new projects world-wide (up to 9000 MW). However, some new projects have also been announced using Central Receivers with high solar towers, mainly in the United States. Dish Engines still show some cost disadvantages, but U.S. developers hope to overcome these cost aspects through mass production and thousands of single installations in a large area (total capacity 800–1000 MW).

Although Fresnel technology has a similar solar field design and mirrors with lower production costs, due to a late development of direct steam generation (DSG) about 10 years ago, it is behind in volume of announced projects (the first 30 MW plant in the South of Spain will create commercial experience). However, compared to that, no single DSG project with parabolic trough has been announced. Table 1.2 shows the size of the CSP market according to the project status and lists the current CSP projects in the world market by applied technologies.

By the middle of 2010 over 800 MW of CSP plants were in operation (see Figure1.9); the electricity producing plants have consequently doubled their capacity with the new installation since 2007, after the installation of the SEGS plants in California. In all categories, (operational, construction, and planning phase), parabolic trough technology is leading the world market, but the alternatives—Fresnel, solar tower, and Dish-Stirling—might enter the market quickly after further technology breakthroughs and achieved cost reductions.

The two markets in the USA and Spain are strongly dominating the CSP market (see Figure 1.9). Based on national support incentives for CSP, the market has shown a boom in recent years. Other countries in MENA (see Figure 1.10), Australia, and Asia are developing their first projects; if implementation is successful, further projects are expected in all of these countries.

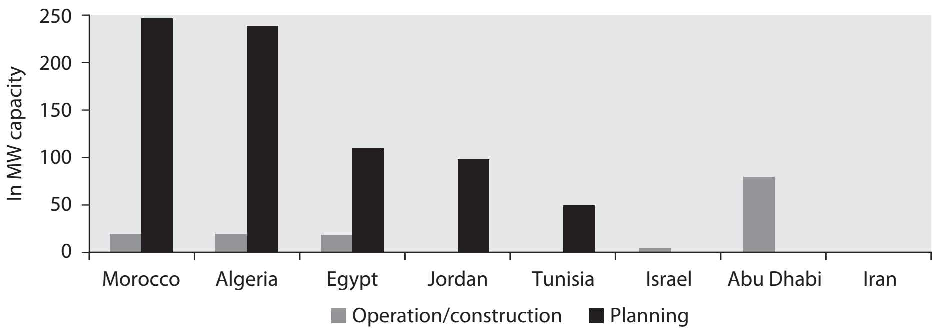
There are, however, some threats to these developments, especially on two fronts:

Table 1.2 ■ Current CSP Projects in the World Mark

	Operational [MW]	Under construction [MW]	Planning phase* [MW]	Total [MW]
Tower	44	17	1,603	1,664
Parabolic	778	1,400	8,144	10,322
Fresnel	9	30	134	173
Dish & Stirling	2	1	2,247	2,250
Total	833	1,448	12,128	14,409

Source: Sun & Wind Energy 2010.
* Planning phase: Projects are announced by project developers or owners. Pre-engineering is taking place, but real construction and all administrational authorizations have not been finished yet.

Figure 1.10 ■ MENA CSP Capacity: Projects under Operation/construction and in Planning Phase*



* Higher figures have been forwarded in some countries, e.g., 2000 MW in Morocco. This figure only includes planned plants that are sufficiently well documented, e.g., through calls for tender. It is not always clear how large the CSP share in those plans could be.

- Due to the long-term impacts of the financial and economic crisis, a larger number of planned installations are not being realized. This could hamper the cost degression of the technology and its penetration in the MENA region.
- Other renewable energy sources show far greater dynamics: by the end of 2010, wind energy may have passed the 200 GW level of installed capacity, photovoltaic (PV) will reach 32 GW. Although CSP is seen as a complementary renewable option to wind and PV, there is also an increasing element of competition, especially with PV.

Installed capacity (GW)	End 2009	Mid 2010	End 2010
Wind energy	159,2	175,0	200,0
Photovoltaic (PV)	22,9		32,0
CSP		0,8	

Sources: World Wind Association 2010 (http://www.wwindea.org/home/index.php); Solarbuzz 2010 (http://www.solarbuzz.com/)

1.2 Structure and Characteristics of International Players in the CSP Value Chain

1.2.1 The CSP core Value Chain

This section provides an overview of the existing CSP value chain. It will describe the international CSP market, the key players in completed and ongoing CSP projects, and the CSP component manufacturing industries in the main markets (Europe and the United States).

The CSP core value chain consists of six main phases:

- Project Development
- Materials
- Components

- Plant Engineering & Construction
- Operation
- Distribution

There are also three cross-cutting activities, which are not directly part of the value chain, but rather serve a super ordinate function. They support the project from the beginning to the end or accompany the technology development and specifications over many years:

- Finance & Ownership
- Research & Development
- Political Institutions

In addition, these cross-cutting activities also offer prospects for local employment.

Project development

The first phase of a CSP project is the ***project development***. The decision-making process begins with technical and economic feasibility studies, the site selection, and financing opportunities, which provide the basic scope of the project. After drawing up a first draft incorporating these basic decisions, the conceptual engineering of the project starts with a proposal for the technical specifications. Once the conceptual design is established, the permission process and contract negotiations can begin. These phases are closely interlinked with the financing of the whole project. In current projects, engineering experts specializing in power plant projects offer all the services needed for the project development. Often the project development phase tends to be the longest, due to the fact that feasibility studies, the permission process, and public decision-making processes take a lot of time. Typically, between one and three years pass between the first tender and the final project start (FichtnerSolar AG 2010 and Solar Millennium AG 2010).

Materials

The second phase of the CSP core value chain involves the selection and gathering of the ***raw materials and further transformed materials.*** While some materials are provided by the world market, others are supplied locally, depending on costs and logistical aspects. Quantitatively, concrete, steel, and glass are the materials most needed for a CSP plant. For a 50 MW reference plant, for example, about 10,000 tons of concrete, 10,000–15,000 tons of steel, and 6,000 tons of glass are required. For the Kuraymat plant in Egypt as well as for plants in Spain, concrete and steel have been provided by local suppliers. These are the materials principally required for a CSP plant: glass for the mirrors, steel for the mounting structure, chemicals for the heat-transfer fluid (HTF), and insulating materials together with different metals for the piping.

Figure 1.11 ■ Basic Structure of the CSP Value Chain Including Cross-Cutting Activities

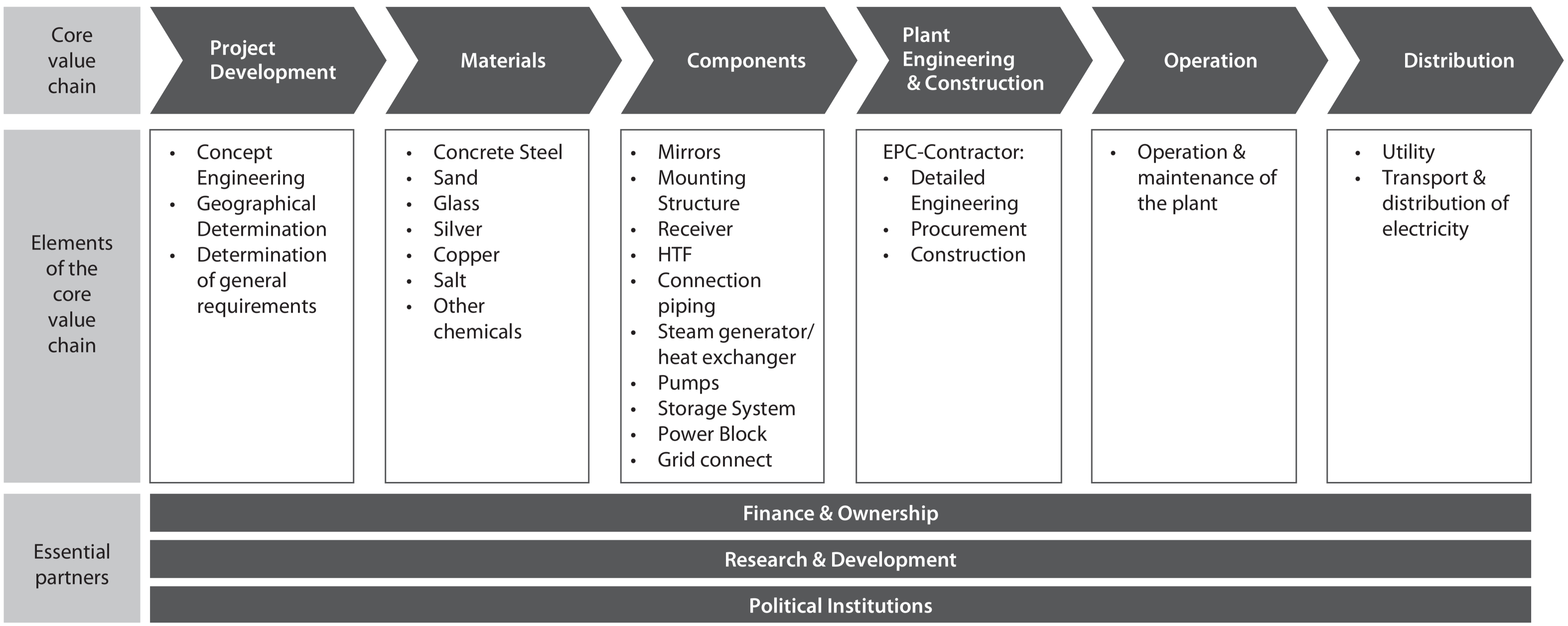
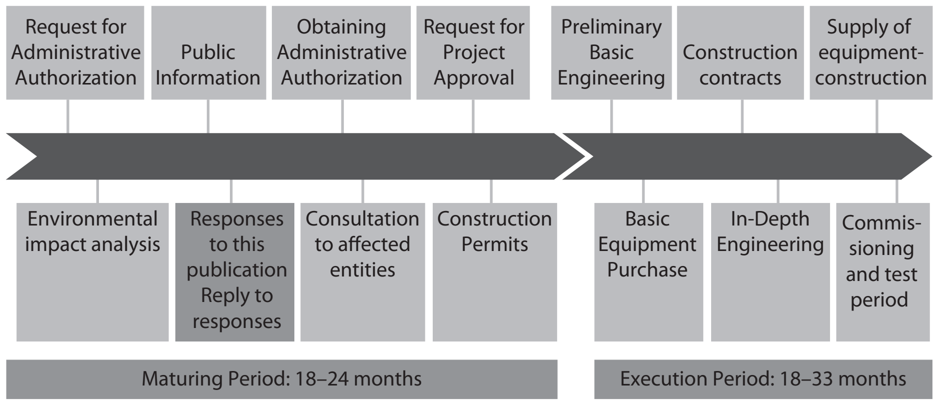


Figure 1.12 ■ Project Development of a CSP Plant

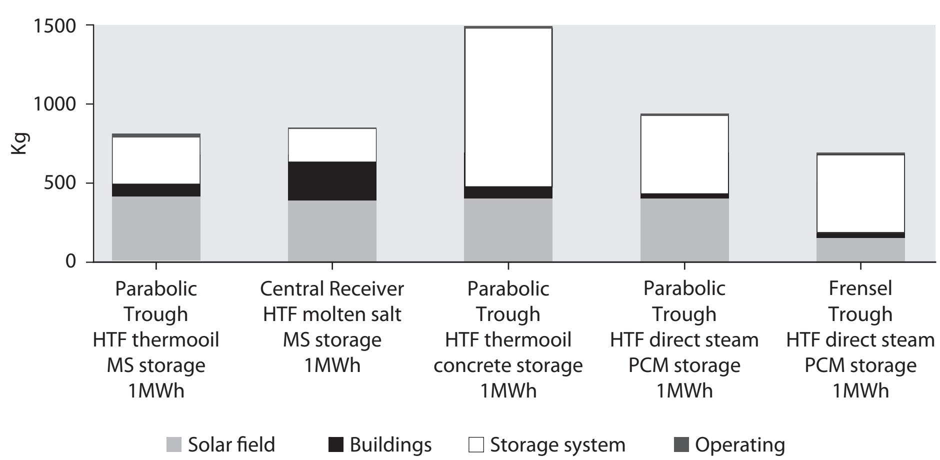


Source: Fraunhofer ISE.

The German Aerospace Center (DLR) compared the materials required for different CSP technologies (Viehbahn, 2008). The material needs were normalized to 1 MW_{el} in plant size and 1 hour of thermal storage capacity in order to balance technology specifics (such as differences in efficiency), see Figure 1.13.

Like Table 1.3, Figure 1.13 shows that the storage system accounts for a large portion of the used material. This is true for all shown technologies, despite the relatively small assumed storage size of one hour. The solar tower plant uses a

Figure 1.13 ■ Comparison of Components of the Basic Solar Thermal Power Plants, Scaled to 1 MW_{el} and One Hour of Storage Capacity



Note: The combinations of collector and storage technologies shown in Figure 1.13 is exemplary. The molten salt storage (MS) is the only commercial storage technology shown. The storage systems based on concrete and phase change material (PCM) is at prototype status, today.

Table 1.3 ■ Material and Land Requirements for CSP Reference Plant

	Parabolic Trough Plant 50 MW with 7 hours storage
Steel	10,000–15,000 tons
Glass	6,000 tons
Storage Medium (Salt)	25,000–30,000 tons
Concrete	10,000 tons
Insulation Material	1000 tons
Copper*	300 tons
Land	2 km^2

Source: Author.
* Personal communication from Protermosolar. Although this figure is lower than for other materials, copper has a much higher value than other materials; for example, it has
10 times the value of steel at present.

higher fraction of buildings (due to the tower itself). The linear Fresnel technology uses strikingly little material. This is because of a very light collector design, but also because of the absence of the heavy concrete foundations used for all other technologies shown.

Components

This section describes the ***components***, the third phase in the value chain. Conceptually, a CSP plant can be divided into two parts: the solar field and the traditional power block. The key components of the solar field are the metal support structure for the mounting, the mirrors, and the receivers. Since the CSP market worldwide is still at a very young stage, only a few companies exist which can supply these components.

Solar Field of CSP Plant

- The metal support structure is made of steel or aluminum and is provided by traditional steel and aluminum companies. The structure has to meet certain requirements for the structural stability against wind loads in order to ensure the precise alignment of the mirrors over the entire length of the collector row, which can reach up to 150 meters.
- Mirrors for the CSP industry can be either flat (towers, linear Fresnel) or bent (parabolic trough, dish). Bending and mirror coating are standard processes of the glass industry, and can essentially be performed on standard equipment. Mirrors have to be highly precise. Even marginal reflection losses of direct radiation lead to a lower degree of electrical efficiency and therefore jeopardize the economic efficiency of the whole project. Commercially viable CSP mirror plants must have a minimum capacity (more than 200–400 MW_{el} equivalents per year). Typical glass and mirror companies have a wide range of customers in many industries, e.g., automotive

glass, technical glass, solar mirrors, and different kinds of special-purpose glass. According to Guardian, the level of complexity for solar products is comparable to automotive requirements (shapes are more complex in the automotive segment, but geometric specifications are stricter for solar mirrors). Although raw flat glass and mirrors are traded globally, the cost of transporting heavy items in a competitive industry is a barrier; locating mirror production near consumption centers is therefore likely to happen once markets reached sufficient size.

- Receivers are the most complex part of the solar field. They have to absorb as much light as possible while reflecting as little thermal energy as possible. The transition from glass to metal has to have the same coefficient of thermal expansion. Very few companies worldwide produce this specific component. The steel in receivers has to be specifically selected for good durability and compliance with coating requirements. This steel would impose strong requirements on local production.

Mirrors, receivers, and the mounting support structure represent the main elements of the solar field. In addition, an important role is played by the heat-transfer-fluid system, which includes the heat-transfer fluid (HTF), the piping, insulation materials, and pumps.

In most of the current CSP plants, thermal oil is applied as the HTF. It is produced by large chemical companies. Approximately 13 tons per MWe installed power are needed. Insulation material (about 20 tons per MWe) is widely used and consequently a large number of producers can be identified. The quality of the insulation is highly important as it directly influences the thermal efficiency, and consequently the plant output. Some CSP projects are trying to use molten salt, which entails some technical advantages (large storage capacity) but a couple of disadvantages as well (e.g., freezing of salt).

In a CSP plant, the hydraulic pumps that circulate the oil or molten salt in the 20 km to 200 km long piping system, and the heat exchangers that transfer the thermal energy into steam, are rather complex and expensive components. International companies with a large degree of know-how in this sector provide these components. Some publications include the HTF systems as part of the solar field; others display it separately, as will be done in this study.

Electrical components, electronic cables, and hydraulic adjustment units (for mirrors) used in the solar field and the power block for all adjustment and control processes have to be precise and of good quality to assure a plant lifetime of at least 25 years.

Power block of CSP plant

The key component of the power block is the steam turbine. Technically, turbines could be considered the most complex and difficult part of a CSP plant. Normally turbines are manufactured by big industrial companies with long-term experience in the field. Due to the extremely specialized requirements of turbines, shipping costs are irrelevant and suppliers can be found all over the world. The power block used for CSP is very similar to that used for combined cycle power plants.

The grid connection is organized and fulfilled by the EPC contractor or other subcontractors that build the access to the local and regional power grid. By means of standardized substations and transformers, the system is connected to the medium voltage or high voltage grid for larger transmission to the final end consumer.

Engineering and construction

The fourth phase of the value chain involves the ***plant engineering & construction.*** This is performed by the engineering, procurement, and construction (EPC) contractor. The EPC contractor is responsible for the whole plant construction. As project manager, he selects all the suppliers and awards most of the jobs to subcontractors. Sometimes, even before the contracting entity chooses the final EPC, candidates have already chosen certain component suppliers due to logistical, time-sharing, or political motivations. Normally all component suppliers as well as the subcontractors who carry out the detailed engineering and the civil works are chosen by the EPC contractor. The main task of the project manager is to coordinate all partners. EPC contractors are usually subsidiary companies of industrial groups and can resort to building companies and engineering consultants in their own company group. The civil works for the total plant are also often closely connected to the EPC contractor, as many companies have their own subsidiaries or joint ventures to undertake these tasks. Large infrastructure companies for buildings, power plants, and other infrastructure projects provide the basic services for civil works, such as preparing the ground, building the supporting infrastructure (streets, houses), and creating the foundation of the power plant. For these civil works, and for the assembly and installation of the collectors, a large number of low skilled workers is required on the construction site. For example, at a Spanish power plant, 500 workers were needed for these works. In North Africa, due to lower productivity, the number of employees can increase to up to 1000–1200. EPC contractors have often been general contractors, building different kinds of plants and industry projects, for many years; they therefore have a wide range of experience to draw upon. In current projects the EPC contractor even serves, in part, as financer and owner, and for the first years is also responsible for the operation and maintenance (O&M), which binds him to the plant.

Operation

The fifth phase, ***Operation,*** includes the operation and maintenance (O&M) of the plant for up to 25–30 years. This is often performed by local sub-contractors and, as mentioned before, sometimes coordinated by the EPC contractors in the first years. Currently, about 30 people are necessary for the operation and 10 people for the maintenance of a 50 MW CSP plant (see Table 1.10). The tasks for operation and maintenance can be split into four different groups: Plant administration (6 workers needed), operation and control (13), technical inspection of the power block (7), and the solar field operation and maintenance (14). For bigger plants, the O&M cost per installed MW decreases (IEA 2010 Roadmap).

Distribution

The sixth and final phase, the ***Distribution***, involves delivering the electricity from the plant to the consumers. Large utility companies take the responsibility for the distribution. In the United States, these large utilities are obliged to buy or produce a certain amount of solar electricity by the Renewable Standard Portfolios of each U.S. state.

Finance & ownership and political institutions

Two of the cross-cutting activities are absolutely crucial for the realization of a CSP project: ***Finance & Ownership*** and ***Political Institutions***.

Since CSP projects are still not profitable without financial support, the project financing is often the most difficult part of the project development. In Spain for example, feed-in tariffs ensure the payment. Based on the feed-in tariff levels and specifications, private investors, together with the project developers (which can be within the same company), calculate the profitability of a proposed plant. This support mechanism improves the process of making the project bankable because of the long-term guarantees and continuous revenue flows to the owners and consequently to the creditors.

However, if the tariffs are statically set too generously over a longer period of time, the country cannot control the number of plants constructed, as it happened in Spain in the PV market. In North Africa so called PPA (power purchase agreements) are often used to assure financing. In a PPA, the state controls the number of plants, and every plant is tendered separately. This leads to individual conditions for every plant constructed, but does not easily promote a dynamic market evolution. In practice, different kinds of ownership structures can be found. There are three common operator models in the context of power plants: Build-Own-Operate (BOO), Build-Own-Transfer (BOT) and Build-Own-Operate-Transfer (BOOT) (Daniel Beckmann 2003).

- In a BOO, the private sector finances, builds, owns, and operates a facility or service permanently. In the original agreement, requirements of the public sector are stated and the regulatory authority takes control.
- The BOOT contract encloses a final transfer of the plant ownership to the government or to another entity at a previously agreed-upon price or the market price.
- Compared to the BOOT contract, a BOT agreement starts the transfer to the government at an earlier point of time (5 years instead of longer periods of 20 to 30 years for BOOT contracts).

Existing financing and ownership structures demonstrate the high level of importance held by political institutions in building CSP plants. Currently, CSP technologies can only be developed with political support. With time, more countries are recognizing this and joining in providing financial support to CSP. For example, Spain has had a feed-in tariff since 2003; some states within the United States support CSP with renewable portfolio standards; Morocco has announced a national solar plan; and India has introduced a feed-in tariff for solar energy.

Research & development

Research & development (R&D) is a cross-cutting issue and a very important aspect for technological progress and fast market entry. To bring the technology forward, project partners must work closely with research institutions. R&D plants play a large role here. Existing R&D plants include the solar tower in Jülich (Germany) and the Plataforma Solar de Almería (PSA) in Spain, where different CSP technologies are tested. In order to reduce the final acceptance period at the end of the construction and commissioning phase of a commercial plant, new methodologies for testing are required. A standardized testing and monitoring procedure for installed solar fields will be an important task for all future projects.

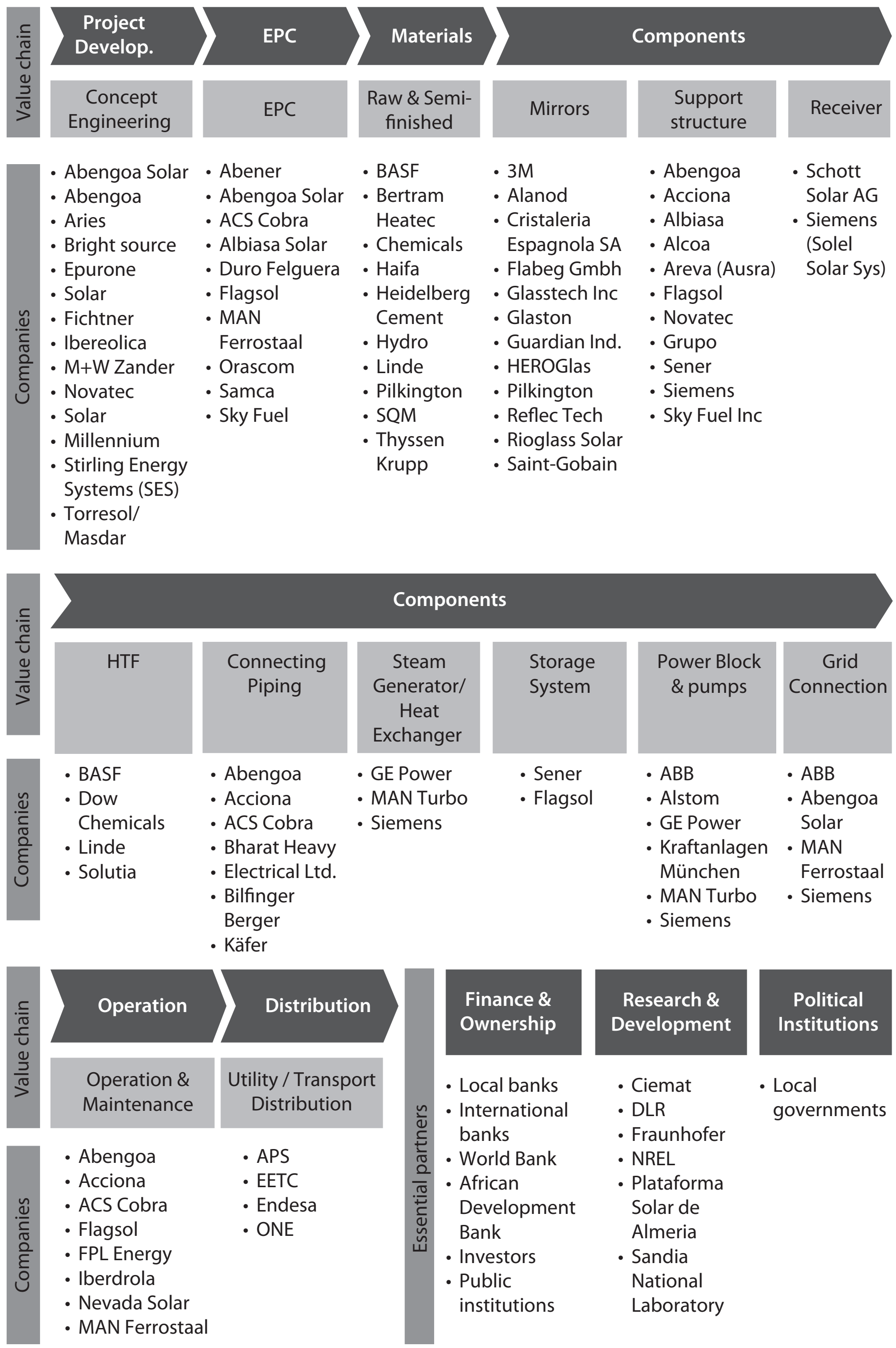
1.2.2 International Value Chain

Based on the CSP value chain presented above, Figure 1.14 shows the main international players involved in each phase (either companies or other stakeholders). Some projects are led by large industrial consortia that include new entrants on the CSP market (such as Veolia Environment, CNIM, and Saint Gobain). For a single large CSP investment project, a consortium is formed under an EPC contractor that supplies the components and services for the construction of the plant. After a successful cooperation in a first project, existing relations between the companies are often used to construct new CSP plants. Over the last two years, several mergers and acquisitions have taken place in the CSP industry.

Some important market developments in recent years include:

- In 2006, Spanish Acciona acquired the majority on US CSP company Solargenix.
- In 2007, MAN Ferrostaal AG and Solar Millennium AG founded the company MAN Solar Millennium GmbH, specializing in project development, financing, and construction of solar thermal power plants. In 2010, this joint venture became part of the company Flagsol GmbH which until then was the engineering subsidy of Solar Millennium (100 percent). Since this merger, Flagsol belongs 75 percent to Solar Millennium and 25 percent to Ferrostaal. In the meantime (in 2009), a 70 percent share of Ferrostaal was sold by the German MAN holding to the Abu-Dhabi-based IPIC.
- In 2008, Sener and Masdar created a joint venture (Torresol) for their common CSP activities.

Figure 1.14 ■ International CSP Value Chain with Companies/actors for Each Sector



- In March 2009, German Siemens AG bought a 28 percent share of the Italian company Archimede Solar Energy, a technology company of vacuum receivers for parabolic trough plants. In May 2010, this share was increased to 45 percent.
- In October 2009, German Siemens AG bought 100 percent of the Israeli vacuum receiver manufacturer Solel for US$ 418 million.
- In Feb. 2010, French Areva bought 100 percent of the U.S. technology developer Ausra.
- In May 2010, Alstom invested US$55 million in Brightsource.

This chapter identifies the key players in this chain, including their function and background. The positive attitude of the existing players toward expanding their business activities in the MENA region is an important key to promoting local manufacturing, achieved through the development of their own projects in the region, and the intention to form local subsidiaries, local partnerships, and joint ventures for local manufacturing.

Assessment of key parts in the value chain

The different industries required for each phase in the value chain have specific characteristics that are described here in detail. These include, for example, business models, project experience, company size, technology specialization, etc.

In Table 1.4 the industrial and market structure for the key components and services are listed. The international industry is used here as an example for local industries to show how they could develop in the future. After a close look at the key components, secondary equipment for CSP is also evaluated according to industry characteristics. Results are important when assessing local capabilities for CSP, because international companies have required long-term experience and have undertaken large investments in R&D and technologies to reach market positions.

Materials (raw and semi-finished)

Since the most used raw materials (steel, concrete, and cement) are consumed for the construction and civil works in large volumes of 50 to 150 tons/MW, it is mostly large players in the local and national construction and steel industries who are mainly involved in supplying the CSP projects and EPC contractors. The assembly of the collectors is supplied by large local industrial companies that have a wide range of products and services. CSP is not the primary business concern of these companies due to the still limited market demand. These supply companies are often active in the building and infrastructure sectors. They also supply the automotive industry, which demands a large volume of these companies' products. Some of the raw materials are specific to the CSP plants, while other materials needed are also in demand for conventional power plants. The latter category includes products such as steel, concrete, and cement, and

Table 1.4 ■ Industry Structure and Context of Component Manufacturing and Services in the CSP Value Chain

	Industry structure	Economics and costs
Project development	• Small group of companies with technological know-how • International actors have fully integrated activities of concept engineering; often with project development, engineering, financing.	• Mainly labor-intensive engineering activities and activities to obtain permits.
EPC contractors	• Strong market position for construction, energy, transport and infrastructure projects.	• Large infrastructure companies (high turnover)
Parabolic mirrors	• Few, large companies, often from the automotive sector • Large factory output	• Large turnover for a variety of mirror and glass products
Receivers	• Two large players • Factories also in CSP markets in Spain and US	• Large investment in know-how and machines required
Metal support structure	• Steel supply can be provided locally • Local and international suppliers can produce the parts	• High share of costs for raw material, steel or aluminum

	Market structure and trends	Key competiveness factor
Project development	• Strongly depending on growth/expectations of individual markets • Activities world-wide	• Central role for CSP projects • Technology know-how • Access to finance
EPC contractors	• Maximum 20 companies • Most of the companies active on markets in Spain and the US	• Existing supplier network
Parabolic mirrors	• A few companies share market, all have increased capacities • High mirror price might decline	• Bending glass • Manufacturing of long-term stable mirrors with high reflectance • Inclusion of up-stream float glass process
Receivers	• Strongly depending on market growth • Low competition today; new players about to enter the market	• High-tech component with specialized production and manufacturing process
Metal support structure	• Increase on the international scale expected • Subcontractors for assembling and materials	• Price competition • Mass production/ Automation

	Strengths	Weaknesses	Opportunities	Threats
Project development	• Reference projects • Technology know-how	• Dependency on political support	• Projects in pipeline	• Price competition with other renewables
EPC contractors	• Reference projects • Well-trained staff • Network of suppliers	• High cost	• Projects in pipeline • Achieve high cost reduction	• Price competition with other renewables
Parabolic mirrors	• Strong position of few players • High margins (high cost reduction potential)	• Cost of factory • Continuous demand required	• New CSP markets • Barriers for market enrty	• Unstable CSP market • Flat mirror technology (Fresnel/ Tower)

(*continued on next page*)

Table 1.4 Industry Structure and Context of Component Manufacturing and Services in the CSP Value Chain *(continued)*

	Strengths	Weaknesses	Opportunities	Threats
Receivers	• High margins (high cost reduction potential)	• Dependency on CSP market • High entry barrier for new players (know-how/ invest)	• High cost reduction potential through competition	• Unstable CSP market • Low market demand • Strong market position of few players; new players to become commercial
Metal support structure	• Experience • New business opportunities for structural steel • Low entry barriers	• High cost competition	• Increase of efficiency and size	• Volatile CSP market

involves a large number of companies. In contrast, the number of companies on the world market that can supply CSP plants or CSP manufacturers with a very specific raw material (such as thermal oil) is limited.

Cost and logistical advantages are the main drivers in selecting a sub-contractor for the CSP projects in Spain or the United States. Very often the suppliers sell their products on an international level. Spanish CSP plants are built with Turkish steel or Israeli Haifa Chemicals supply salt for the storage systems.

Glass companies whose manufacturing is not centered around CSP mirrors see the potential of a good business opportunity and sell their high-class mirror products to this market. Therefore, investments often are made in markets with existing production capacities and factories. Producing CSP mirrors is constrained by the need for low-iron glass («white glass», as opposed to regular «green glass»), a glass quality required almost exclusively for this type of use. Solar grade glass can in principle be produced at any float line, provided that appropriate low-iron sand is used as the raw material.

Power block, steam generator, and heat exchangers

Since the power block unit uses many of the same components as conventional thermal power plants, large companies internationally active in converting thermal energy to electricity are also active in the CSP market. Companies like General Electric, Siemens, Alstom, ABB, and MAN Turbo are the most important players for steam turbines, generators, and power control. These high-technology companies also cover the technical side of distribution and connection to the grid. A high level of expertise is required for these components in order to reach continuous output, a large number of operating hours and, in particular, high energy-conversion efficiency. The steam turbine technology is mature, so no new revolutionary technological advancements are expected in this highly competitive and concentrated market, with companies like Siemens, Alstom, and GE controlling the major share of the global market.

Storage system

The company Sener is currently the most experienced player in thermal storage for CSP plants. It is responsible for up to 12 molten salt systems (mainly in Spain) which are either in the operation, construction, or design phase. For example, the storage system used in Andasol 1 consists of two tanks of 14m height and 38.5 m diameter with a concentrate of nitrate molten salts (60 percent $NaNO_3$ + 40 percent KNO_3). This engineering company with 5700 employees has its own very strong R&D division, on which Sener spends 10 percent of its revenues.

Flagsol had developed the molten salt thermal storage concept even before Sener entered this market jointly with Flagsol. Flagsol was responsible for the engineering, procurement, and construction of the molten salt storage of the Andasol 3 power plant (currently under commission).

In general, the molten salt thermal storage is not a technology that can be provided only by one player. The components used are standard components in chemical and energy plants. Therefore, no monopoly/oligopoly is likely. However, this might not be the case with the salt itself as a raw product. One 7.5 hour storage system for a 50 MW_{el} plant needs about 3 percent of the annual salt production of the main supplier (SQM, Chile). Recent salt price increases might be a consequence of increasing demand from the CSP industry.

For example, German Züblin AG is working on a storage concept with concrete as storage material, today at prototype status.

Finance and ownership

The large volume for the finance of CSP plants (4–8 Mio. US$/MW) is often provided by many different companies, banks, or financial institutions. On the Spanish CSP market several special purpose vehicles have been founded by a project consortium. Andasol 1 was financed in the beginning by the companies Solar Millennium (25 percent) and ACS Cobra (75 percent). In 2009, after the commission of the project, Solar Millennium sold all shares to ACS. Andasol 3 holds a share in the ownership of the special purpose vehicle "Marquesado Solar S.L." of which RWE AG, Stadtwerke Munich, Rheinenergie, MAN Ferrostaal, and Solar Millennium also share the ownership.

In Algeria, the ISCC plant was financed by a consortium of the engineering and EPC contractor Abener and Sonelgaz (NEAL).

For these first projects, the risk was consequently shared between the project developers and larger investors. The project developers tried to issue a fund to increase their limited financial resources in order to retain these shares of approximately 25 percent.

After finishing the project, the project development company very often sells its share to other owners for the operation. Large development aid institutions have played a very important role in Egypt and Morocco. The Global Environment Facility—together with its implementing agency the World Bank—has been strongly involved in the financing of CSP plants by giving grants to cover the excess costs of CSP.

As in any large investment, debt financing is an important pillar of financing CSP projects, with a share of typically 70–80 percent of the total project volume. Debt financing helps to lower the cost of capital because it is cheaper (approximately 5–7 percent p.a.) than institutional equity financing (approximately 12–15 percent p.a.). Usually, debt financing is realized by long-term bank loans or long-term bonds. The ease or difficulty of realizing debt financing depends on the banks' risk perception of the technologies. Today, parabolic trough technology is the only technology that is considered "bankable" or "proven technology" because of its long-term performance track-record.

In coming years, other CSP technologies will achieve bankability as well, through proof of performance in demonstrators and in commercial installations.

Political institutions

National and international policy guidelines and new energy laws on renewable energies have been an important driver for CSP projects, especially in Spain and the United States. Without governmental financial support for CSP technology, the development of CSP projects would not have been economical and bankable, due to the current higher cost of CSP technology as compared to existing conventional fossil alternatives in competitive and liberalized energy and electricity markets. Promotion by the Spanish ministry (Ministerio de Industria, Turismo y Comercio) and by U.S. federal ministries for energy has been necessary to pave the way for CSP in both countries. In both countries, research activities on all topics related to CSP have been increased. These include efficiency increases, new storage options, higher thermal temperatures, and new plant concepts.

Research & Development

Technology research institutions in the United States, Germany, and Spain have been involved in most commercial technology developments. This technology transfer from institutes to the industry usually happens through the following steps:

- Founding of new companies from institutes' staff (e.g., Novatec Biosol, Concentrix Solar or PSE from Fraunhofer ISE; CSP services from the DLR)
- Often, the industry also recruits employees from institutes to build up a high-skilled labor force of engineers and project developers (many examples from almost any institute to almost any CSP company)
- Licensed production of components (e.g., tower technology by DLR commercialized by Kraftanlagen München)

- Development of materials/components for the industry (e.g., absorber coating of Schott developed by Fraunhofer ISE)
- Testing of components for the industry (e.g., testing of the Eurotrough collector on Plataforma Solar de Almería by CIEMAT and DLR, receiver testing of Novatec by Fraunhofer ISE)

Furthermore, standardization issues in CSP technology are currently pushed forward on an international level mainly by research institutes (NREL and DLR).

Most activities in CSP started from initiatives in research institutes. All mentioned activities contributed essentially to the development of industrial products and the entire CSP sector. Many leading engineers and decision makers in CSP companies have a background in one of the leading research institutes. The market growth increased the demand for well trained staff to construct, operate, and maintain a CSP power plant.

1.3 Overview of Manufacturing Processes for the CSP Components and Systems

This section focuses on the production and assembly steps of the technology. Every CSP product for each company has specific requirements during the manufacturing, production, and assembly processes. In some cases, these steps even vary from project to project; for example, a larger project might justify the use of mass-produced components to be ordered and produced only in large volumes (especially concerning the collector support structure). Using representative examples, this section gives an overview of component production for CSP solar fields. As in section 1.1.1, the focus is set on solar collectors in parabolic trough power plants. However, some general statements on the transferability of the production steps to other technologies are also included in the different sub-sections.

The manufacturing processes described below are structured according to the following four components:

- Civil Works – Site Preparation and Foundations (section 1.3.1)
- Parabolic trough receiver – Production processes (section 1.3.2)
- Bent glass mirrors – Production processes (section 1.3.3)
- Metal structure – Production and assembly (section 1.3.4)

If local manufacturing is to take place in Northern Africa, new production capacities will have to be built up in these countries, because the current capabilities are low or non-existent. The key parameters—component costs and their typical factories—are summarized in Table 1.5. As civil works, assembly, receivers, mirrors, and mounting structure are by far the most important parts of the plant in terms of investment cost, these manufacturing processes and construction activities are assessed and described in particular detail.

Storage, which represents a high share of the total plant costs (approximately 10 percent of the investment for a 7.5 hour storage), includes a significant cost

Table 1.5 ■ Important Parameters of Manufacturing Process for Key CSP Components for European Industry and European CSP Plant

Components	Cost per entity	Typical investment in new factory	Annual output of typical factory	Share of CSP plant on annual output	Jobs created One-year job = Fulltime equivalent for one year	One-year jobs/MW	Share of labor	Energy intensity	Industries Synergies/ potential side-markets
Civil Work	—	—	—	—	250–350 one-year jobs per 50 MW	5–7 Jobs/MW	High	Low	High
Installations on the site	—	—	—	—	100 one-year jobs per 50 MW	2 Jobs/MW	High	Low	High
EPC Engineers and Project Managers	€150,000 per Engineer or Project Manager per year	—	—	—	30–40 one-year jobs per 50 MW	0.6–0.8 Jobs/MW	High	Low	High
Assembling	—	—	—	—	50–100 one-year jobs per 50 MW	1–2 Jobs/MW	High	Low	High
Receiver	€800–1000 (4 m long)	25 Mio Euro	200 MW	12–25 %	140 jobs in factory	0.3–0.7 Jobs/MW	Low	Medium	Very low
Mirror *flat* (Float glass)	€6–20 /m^2	26 Mio Euro	1 Mio mirrors 200–400 MW	~ 20 %	250 jobs in factory	0.6–1.2 Jobs/MW	Medium	High	High
Mirror *parabolic*	€25–40 /m^2	30 Mio Euro	1 Mio mirrors 200–400 MW	~ 20 %	300 jobs in factory	0.7–1.5 Jobs/MW	Medium	High	Low (if glass production is included then high)

(*continued on next page*)

Table 1.5 **Important Parameters of Manufacturing Process for Key CSP Components for European Industry and European CSP Plant** *(continued)*

Mounting structure	€45–60/m^2 €2.00/kg – €2.50/kg	10 Mio Euro	150–200 MW	30–40 %	70 jobs in factory	0.3–0.5 Jobs/ MW	Medium to High	High	Medium
HTF	€2.70–3.20 /kg	Very large	Large	Small	Not identified		Low	Medium	Low
Connection piping		—	—	—			Low	High	Medium
Storage system	$0.65/kg Salt	—	—	—	50 one-year jobs per 50 MW		Low	Medium	Low
Electronic equipment	Not identified	Medium	Medium	Small	Not identified		Medium	Medium	Medium
Reference CSP Plant (50 MW, 7,5 h storage)	7.26 M $/MW (364 M $ totally) (with 7h storage)	—	Current plants 50 MW to 100 MW	—	500 one-year jobs per 50 MW (only on the plant site)	10 Jobs/MW only on the plant site	High	Low	—

fraction related to a raw material—the salt itself—that has to be imported from countries with local resources.

The following table provides information about the importance of each plant component in terms of investment intensity as well as initial investments needed for building up production facilities for the individual components.

1.3.1 Civil Works – Site Preparation and Foundations

The maximal slope of a site for a parabolic trough plant is 1–3° (NREL, 2009). With excavators, the site is flattened to match the requirements of the collectors. The pylon foundations of the collectors require excavations of about 2 meters' depth on a square of 2.5 x 2.5 meters (Fichtner, 2009). Pylon foundations are individually designed for end pylons, drive pylons, middle pylons, and shared pylons, as well as in reinforced design for the outer areas of the field, where higher wind loads are expected, see Figure 1.15. Sometimes, an additional wind barrier has to be added to avoid large wind loads or sand pollution of the solar field. Additional civil works include all construction for infrastructure like roads to the building site or machine houses, assembling halls, engineering offices, and logistic centers as a feed stock for material and components. These works are basic construction work and not CSP specific; therefore, local companies provide this service for the installation of the plant.

Ideally the natural, non-leveled land has a slope of less than 1 percent; For PTC and Linear Fresnel collectors 3 percent is still feasible (depending on ground type). Tower and Dish technology are less sensitive to slope and can accept up to 5 percent (NREL, 2009).

1.3.2 Parabolic Trough Receiver – Production Processes

The processes referring to the technical characteristics are presented in Figure 1.16. and briefly described below. A more detailed description is given in Annex A.

Anti-reflective coating on borosilicate glass tube – The Sol-Gel Process

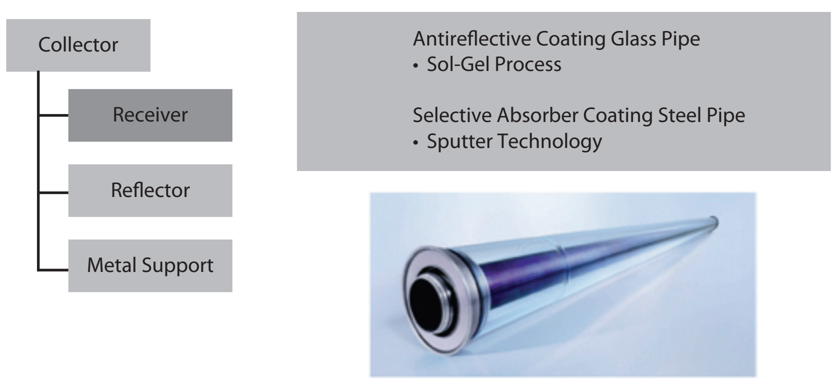
To maximize optical transmissivity of the receiver glass tube, an antireflective layer is deposited on each surface of the tube, see Figure 1.17.

The coatings consist of a varying porous structure that serves as a gradient of the reflective index from its level in air to its level in borosilicate glass. Due to this continuous gradient, the reflection can be reduced to a theoretical minimum. To coat the tube, it is dipped into an acid-modified solution containing silicon dioxide and is pulled out of it at a speed of one centimeter per second (Hel, 2008). The resulting layer has a width of 110 nanometers. The porous structure of the film can be achieved by adding a "porogen" material to the "sol-gel" solution. This compound is removed during a heat treatment after the dipping, generating pores inside the polymeric silica films. The sol-gel dip-coating technology is a widely used method for producing antireflective layers

Figure 1.15 ■ Construction Site of Parabolic Trough Solar Field At Kuraymat (Egypt) with the Foundations of the Solar Field

Source: Fichtner, 2009.

Figure 1.16 ■ Parabolic Trough Receiver PTR 70 of the Company Schott Solar

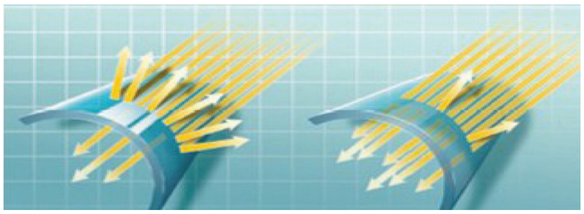


Source: Schott, 2009.

on large area glass and is also applied to solar receivers. The sol-gel process is applicable on a large scale.

The technical challenges are to achieve temperature stability and resistance to natural impacts like dirt or rain.

Figure 1.17 ■ Borosilicate Glass Tube Without Anti-Reflective Coating (left) and with Anti-Reflective Coating (right)



Source: TU Ilmenau.

Selective absorber coating – The Sputter Process

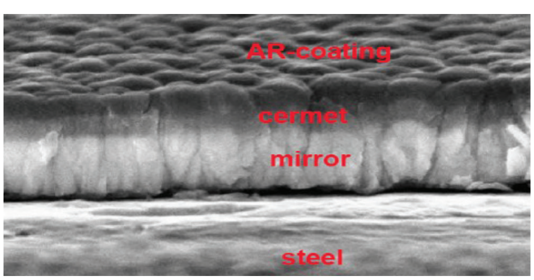
To coat the thin layers of the absorber system, precise layer compositions and precise layer thicknesses are required with high homogeneity on large surfaces. This is achievable with the sputtering technology.

Sputtering is based on a self-maintained noble gas discharge, known as the plasma in an evacuated chamber. First, the gas is ignited (ionized) at low pressure. Then, forced by kinetic energy supplied by electrical fields, the gas ions erode small molecular fractions from the coating material (the target) by collision (Kennedy, 2002). These fractions deposit on the substrate (the absorber), creating the sputtered layers. The different layers are formed by using different materials as sputter targets and different gases as additives to the noble gas (Zelesnik, 2002). For further description of the production techniques please refer to Annex A.

This technology-intensive procedural step is only handled by very few companies, and only two of them, Siemens (formerly Solel) and Schott, have commercial experience applying the sputtering technology to vacuum receivers of parabolic troughs.

Due to the complexity of the sputtering process, and due to the difficulty in connecting the absorber steel tube to the surrounding borosilicate glass tube

Figure 1.18 ■ Left: Exemplary Sputtered Absorber Coating (Hildebrandt, 2009)
Right: Sputtering Machinery At Fraunhofer ISE (ISE, 2010)



Source: Hildebrandt, 2009, and ISE, 2010.

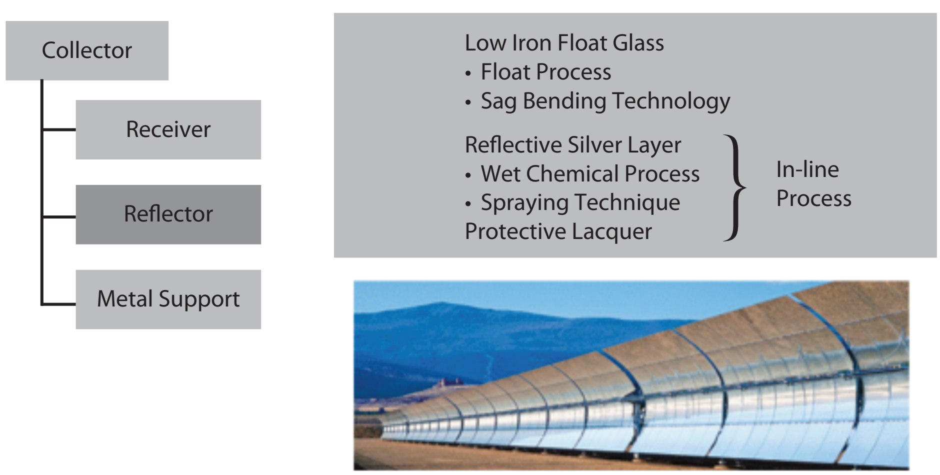
(different thermal conductivity of glass and steel normally leads to glass breakage during heating), it seems rather ambitious for MENA companies to enter the market of parabolic trough receiver technology as new entrants with no experience in coating processes. However, in the near future, it might be interesting for companies like Schott and Solel to open up local production facilities as soon as the MENA markets become more important—as they already have in Spain and in the United States.

Most Fresnel and Tower technologies also use selectively coated absorber tubes based on sputtering; the only difference is that they use different materials (both steel and coating material) to match individual requirements (mainly air stability and temperature). Companies offering vacuum receivers cannot automatically produce other coatings (with air stability and for other temperatures) because the development of an application-specific steel-coating system is necessary. The machinery and the production process, however, is in principle the same for all these applications.

1.3.3 Bent Glass Mirrors – Production Processes

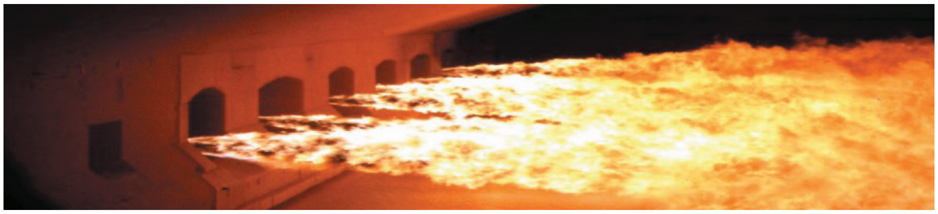
The reflector is another core component of the solar collector, as it concentrates the solar irradiation on the receiver. The optical precision is generated by exactly bent glass mirrors that are coated with a reflective silver layer. It has yet to be proven that collector systems using alternative aluminum- or polymer-based reflective materials can achieve the required long-term stability as well as reflectivity performance while still competing with the cost benchmark of the thick glass mirrors. Collectors based on glass mirrors are expected to remain the most important technology line for quite some time. That is why this report focuses on

Figure 1.19 ■ Parabolic Trough Mirrors



Source: Flabeg Solar 2010.

Figure 1.20 ■ Gas Heater of a Float Plant to Melt the Raw Materials Before the Float Process



Source: Pilkington, 2003.

the production of commercially available thick glass mirrors. Further information regarding different mirror types is given in Annex A.

Production of glass – Float process

The whole glass production is very energy demanding, mainly due to the float process, and requires large and capital-intensive production facilities. However, the raw materials—which are primarily white silicon sand, old white glass, and soda ash—are available in huge quantities and at low price. The float process is state-of-the-art technology producing large glass sheets in high quantities. The raw materials are fed into an industry-size melting oven, where they are heated to temperatures of 1600°C and thereby converted into molten glass (see Source: Pilkington, 2003).

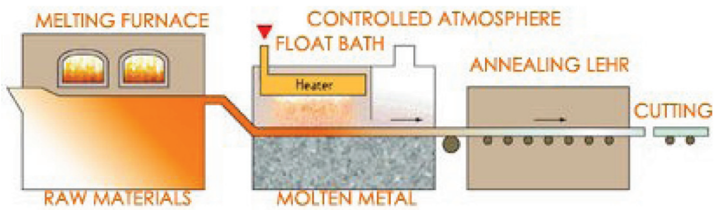
The molten glass is poured continuously from the furnace onto a shallow bath of molten tin. Due to its inferior density, the glass floats on the tin, spreads out, and forms a level surface because of its surface tension, as oil does on a water surface. The thickness of the glass sheets can be varied by the transportation speed of the glass ribbon and by the flow speed of the molten glass on the tin bath, or by stretching the glass ribbon or compressing it at its edges. Figure 1.21 and Figure 1.22 show sketches of the glass production facility.

An astonishing 75 percent of the total energy demand is due to the melting of the raw materials. The float glass processes can hardly ever be stopped during the entire lifetime of the plant, which is approximately 10–15 years. A plant produces around 6,000 kilometers of glass annually, in thicknesses of 0.4–25 mm and in widths of up to 3 meters (Pilkington, 2003).

According to Pilkington, over 380 float lines are in operation worldwide, with a combined output of about 1,000,000 tons of glass annually. In other words, the mirror glass necessary for the Andasol 1 power plant took up the production of about one week of one large float-glass production facility (see Figure 1.21 and 1.22).

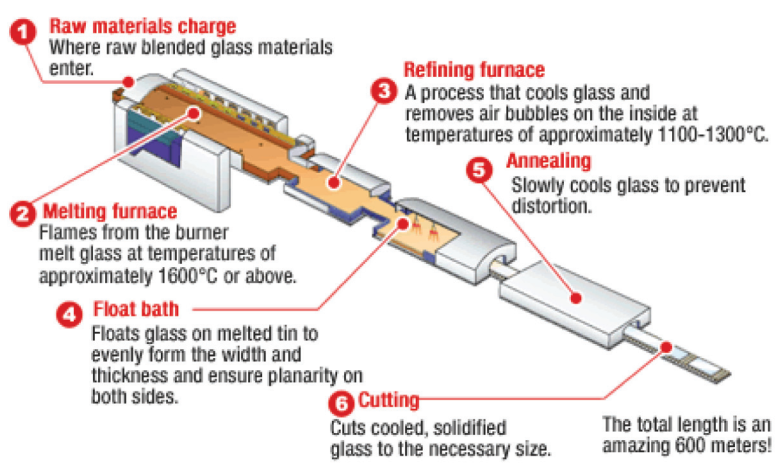
Most of these float production lines, however, do not produce solar glass, or so-called "white glass"; instead, they produce "green glass," which contains a higher fraction of iron dioxide (and therefore appears greenish at the edges). For most applications (e.g., in housing), the resulting reduction of transmittance of green glass is acceptable, but it is not so for solar applications, such as receiver glass tubes, parabolic mirrors, and the photovoltaic industry. Only recently, an increasing

Figure 1.21 ■ Sketch of Float Process: After the Melting of the Raw Materials, the Molten Glass is Poured Onto the Liquid Tin to Stretch and Form Flat Surfaces



Source: Glasstech, 2010.

Figure 1.22 ■ Sketch of Production Facility of in-Line Float Process



Source: AGC, 2010.

number of companies have been focusing on this new attractive market, mainly driven by the demand of the photovoltaic industry.

Considering the huge and complex manufacturing line (600 m length of float glass line), this process is very investment- and capital-intensive.

Bending of glass

Glass bending is a process which is mainly used by the automotive industry (for car windows). All glass bending processes are thermally driven. There are two principle options for bending glass: the sag bending process and the quench bending process. Both processes are applied by different manufacturers of parabolic trough mirrors.

As parabolic trough power plants require bent reflectors, it is necessary to bend the glass into exact shapes. The best accuracy is provided by the sag-bending technology (Flabeg, 2009). During the sag bending process, the temperature is raised to 650°C (Glaeser, 2001), to reach viscous glass condition. This temperature can be provided either by gas or by electrical heaters. Subsequently, the glass sheet is put into a precise forming bed, where the sheet adopts the parabolic form due to gravity (see Figure 1.23).

The quench bending process can only be applied to tempered glass. Glass tempering is a process in which the glass is heated up to 700°C and then shock-cooled. This induces inner tensions in the glass, which increases mechanical stiffness and is applied for security reasons (so that breakage will result in small pieces with round edges).

Today, the bending process can be performed by a single machine, allowing for highly automated production. Even the integration into another production line is possible, due to the modularity of the bending process.

Turning a glass sheet into a mirror – Wet chemical spraying

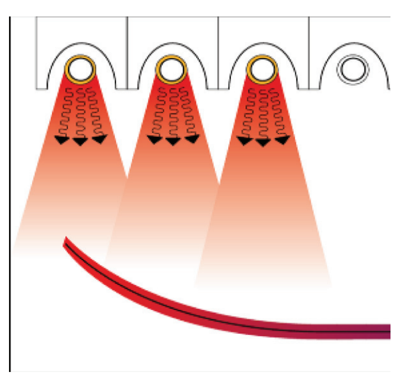
This process is applied to coat the bent glass sheets with reflective silver and necessary protective layers.

First, the parabolic bent glass sheets have to be cleaned by a polishing and washing machine using only dematerialized water (Glaeser, 2001) to guarantee a perfectly clean glass surface (in nano scale). After that, the sheets have to be silvered, which is achieved through a spraying process.

The solutions containing the silver nitrate and the reducing agents (which are prepared, stored, and applied separately) are pumped to spraying guns to spread the mixture onto the pane surface (Glaeser, 2001). The layer is generated immediately, as soon as the liquids mix and hit the glass surface. It is very important to avoid reducing the silver nitrate solution with the reducing agents before it proceeds from the guns to the flat glass pane; otherwise the mirror surface may contain corns.

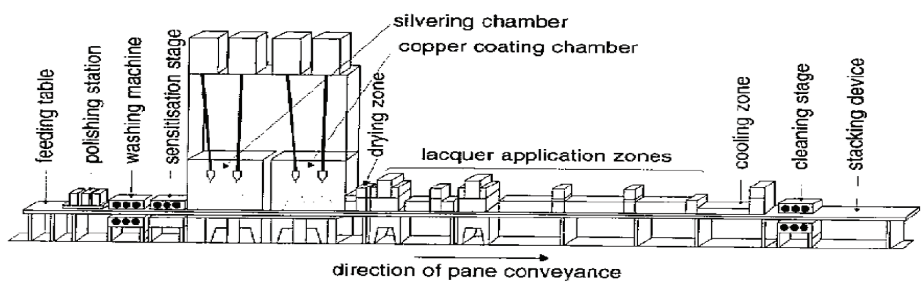
The next step after the silver layer generation is to deposit a protective copper layer on the reflective coating in a separate chamber. After that, the system is dried by radiant heaters and finally coated with special lacquers to be able to resist the impacts of nature in desert-like areas during the whole life-time of the CSP power plant. The entire coating of silver mirrors is carried out as an in-line process (Glaeser, 2001). In-line silvering plants have a length of approximately 200m. To

Figure 1.23 ■ Precise Radiant Heater for Sag Bending



Source: Glaston, 2010.

Figure 1.24 ■ Silvering of Glass Mirrors and Application of Protective Layers



Source: Glaeser, 2001.

operate a modern plant, a large amount of demineralized water and a steady energy supply is necessary.

Solar Towers and Linear Fresnel collectors use flat glass mirrors (see *Source:* Saint Gobain, 2010). This means that the bending process (and in some cases also the glass tempering)[2] can be omitted. The pads for the fixation of the mirrors to the trough mirror support structure can also be omitted for flat mirrors. Companies offering bent parabolic mirrors typically also offer flat glass mirrors. The reverse is not true. A company which is able to produce only flat glass mirrors has to invest significant efforts to learn the processes for bending and coating the glass.

1.3.4 Metal Structure – Production and Assembly

After the receiver and the mirrors, the metal support structure is the third core component of the solar collector. There is a large variety of collector structures on the market today; some examples of different structure types are compiled in Table A.1. As competition among the CSP collector providers increases and the market conditions toughen, cost-efficient concepts based on mass production and standardized components increase their market share. That is why the involved engineering companies develop concepts based on fewer different parts and faster production assemblies. Today, there is still huge cost-saving potential regarding this component, as the whole assembly and construction process is not nearly as developed as modern automotive equivalents.

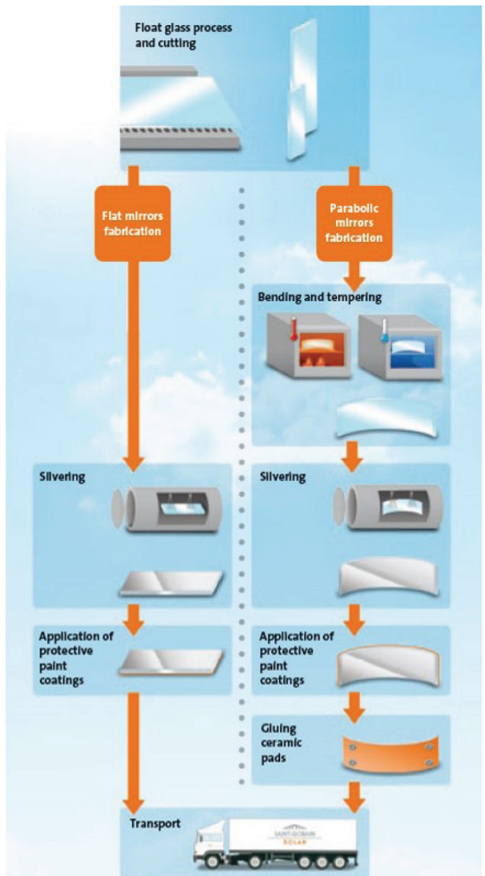
The mounting procedures of the different collector systems vary, and details of the structure and the assembly are usually proprietary know-how of the companies. For example, the production and the assembly of the steel structure

[2] The tempering of the glass results in mechanically more stable glass sheets which, on the other hand, break into small glass pieces, in case of breakage (security glass). Both tempered and non-tempered glass is provided by the CSP mirror industry and is used in both trough and Fresnel technologies. (E.g. Flabeg uses non-tempered glass.)

of the Spanish company Sener (Sener Trough), using stamped cantilever arms (Sener, 2007), are described here, according to their chronological steps:

- Galvanizing process
- Stamping process (cantilever Arms)
- Welding process
- Jig assembly

Figure 1.25 ■ Construction of Solar Glass Mirrors



Source: Saint Gobain, 2010.

Galvanizing process

The steel structure is protected against corrosive influences such as humidity from wet cooling, nightly condensation, and high air salinity in coastal areas. To provide protection against these threats, different well-known applications are available. All CSP collector types using steel structures need to apply such a protection against corrosion.

Hot dip galvanization (a metallurgical process) is the most common protection method, coating steel with a thin zinc layer during a dip coating process. During the coating, the metal is put into a conductive liquid, and then an electrical current is connected, see Source: Sener, 2007

Via an electric field, the zinc molecules are transported to the metal and form a protective layer on it. The zinc coating prevents corrosion of the metal by forming a physical barrier. When exposed to the atmosphere, zinc reacts with oxygen to form zinc oxide, which further reacts with water molecules in the air to form zinc hydroxide, and later with carbon dioxide to form zinc carbonate. This thin layer is impermeable, tenacious, and insoluble, protecting the deeper layers from corrosion.

This hot dip galvanization results in a very thin coating that prevents corrosion of the metal support. The advantage of this process is its low cost and ease of application compared to other protective coatings like lacquers.

Figure 1.26 ■ Hot Dip Galvanizing of a Whole Torque Tube

Source: Sener, 2007.

Stamping: Cantilever arms

Stamping techniques allow manufacturing of a high number of identical pieces able to fulfill resistance and stiffness requirements, as well as increased accuracy requirements. To stamp the cantilever arms and the absorber tube supports from pre-galvanized steel sheets requires a massive stamping machine (Casteneda, 2006). It has to be sufficiently strong to stamp even thick steel sheet accurately. Its adjustment is optimized to reduce material waste. Because of the pre-galvanizing of the steel, no later corrosion protection has to be applied. Repeatability and geometrical accuracy of the stamped pieces is very high, so it is possible to fix the mirrors directly to the metal support during the jig-assembly (see below), eliminating the necessity for further intermediate attachments, which had to be used to fix the mirror to the metal support structure in earlier collector constructions. Figure 1.27 shows a stamped cantilever arm of the SenerTrough.

This mass production achieves cost reduction of 30 percent compared to existing solutions (Casteneda, 2006), and this figure can be improved even

Figure 1.27 ■ Stamped Cantilever Arm by Sener; the Design was Developed to Reduce Material and Energy Demand

Source: Casteneda, 2006.

further if a growing demand allows for bigger machinery and cheaper purchase prices.

Stamping is not the only approach to mass production of cantilever arms; the same results can be obtained by laser-based or water-jet cutting methods. The HelioTrough collector by Flagsol employed yet another alternative, though still based on cantilever arms and a torque tube. This new concept, which Flagsol developed with their earlier Skal-ET collector, is based on the utilization of mass-produced standardized components (rectangular bars) that can be assembled into arms by robots.

There are also other feasible support structures that are completely different from the cantilever arm concept in combination with a torque tube (see Table A.1); for example, the SkalET collector installed in the Andasol projects uses a steel framework instead of the stamped arms described above.

Welding process

The well-known welding process is still important in the collector assembly. Older concepts like the Skal-ET relied even more on welding techniques, as the whole torque box was welded. However, due to unavoidable precision faults and thermal stress of the welded components, new concepts try to use alternatives to welding processes (e.g., through plug connections). Use of screws is also avoided where possible.

Collector assembly and Installation

Usually, the collector is assembled on-site in a jig assembly line. This concept uses highly accurate jigs to connect the torque tube, the cantilever arms, and the mirrors (Casteneda, 2006). To guarantee low transport costs, the jigs are located in an assembly hall close to the solar field.

The real manufacturing process of the collectors is managed efficiently: the workers put the different parts on their predetermined positions on the jig, check the geometric verification, and weld, screw, or plug them together, see Source: Sener, 2007

According to information from the Andasol 2 project where the jig assembly is applied to assemble the Skal-ET collector, four or more collectors (12 meters each) were assembled per hour per jig.

This basic process allows the employment of a fairly low-skilled workforce. Of course a certain introduction phase is necessary, but after that, the construction reaches a high output level.

In an advanced configuration, the whole process is operated by robots instead of people, to improve constant quality. Using this method, once the cantilever arms are welded to the torque tube, the points to fix the mirrors to the cantilever arms are in the right position without any human error (Casteneda, 2006).

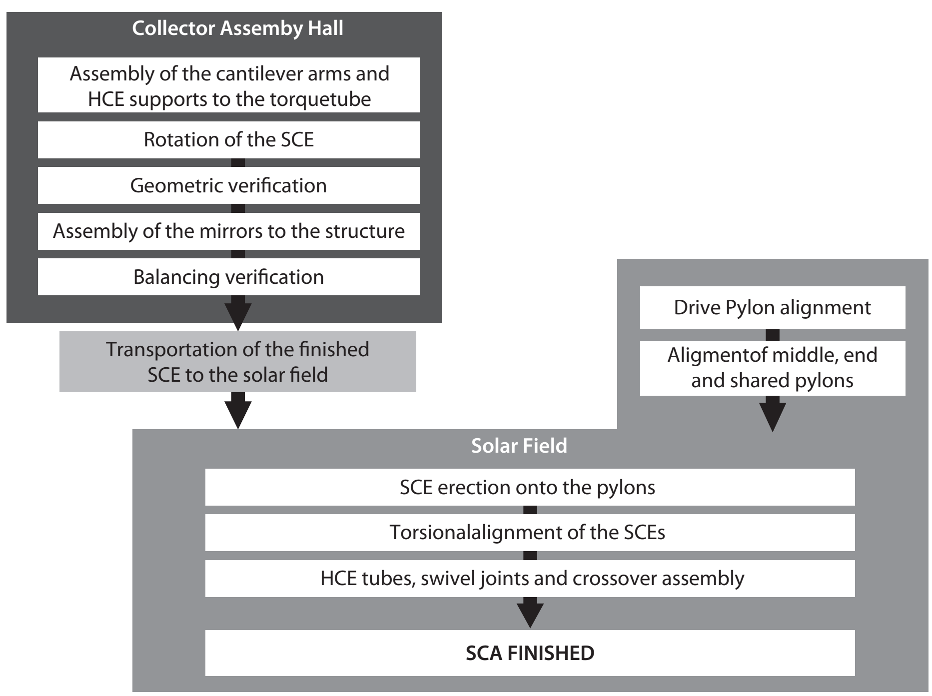
Siemens applies still further automation by introducing robot-based manufacturing, inspired by the vast automation of car production; this reduces the work force but keeps to the jig-assembly model.

Figure 1.28 ■ Sener Jig Assembly

Source: Sener, 2007.

Once the collector is completed, it is transported directly to its designated location in the solar field using trucks. In the field, the collectors are installed by a special vehicle or a crane. The correct alignment is ensured via specialized optical equipment.

Figure 1.29 ■ General Assembly Process for the Solar Field, SCE: Solar Collection Element, HCE: Heat Conducting Element, SCA: Solar Collector Assembly



Source: Authors; Casteneda (2006).

After the jig-assembly it is important to coordinate the subsequent logistics to align the collectors in the solar field. This complex process is very prone to bottlenecks, as a strict construction sequence is necessary. Casteneda (2006) gives a broad overview of the different steps needed to install the whole solar field. The solar collector installation process is generally divided into two parts: 1) the single solar collector production in an assembly hall close to the future solar field, and 2) the solar field installation. During the collector assembly, the jig method described above is used. Before the solar field installation, the pylons that support the collector have to be precisely aligned.

After the correct alignment, the solar collectors are fixed with exactness to the pylons and measured once more. Finally, the heat conducting elements (receiver tubes) are installed, and the piping can be connected.

Only a few steps can be done simultaneously; most assembly steps cannot be performed before the preceding activity is complete. That is why it is essential to coordinate the different process steps rigidly, leaving no room for error. As already mentioned, the structural properties of each collector are very product-specific. Therefore, there must always be an individual assessment—from company to company and even from project to project—to determine the extent to which steel structure mounting principles are applied. At least a minor share will always consist of labor-intensive standard steel/aluminum construction; however, in some cases, a high degree of automation reduces the labor-intensive activities of mounting and assembly.

1.3.5 Complexity Assessment and Technological Barriers

The selection of production processes can be further categorized according to general complexity and investment intensity. This will give a broad overview of which manufacturing process of CSP components can most easily be adapted by local industry or international industry for local manufacturing, and will consequently stand the best chance of being manufactured in MENA countries in the short- and mid-term future.

Today, on-site jig-assembly, antireflective coating, and galvanization seem to be the production activities most likely to be performed in MENA countries. However, it is very difficult to give a clear final judgment, since a production complex is never based on one single process. Nevertheless, this overview is based on recent production technologies. It is therefore likely that this graph will undergo a continual change during the development of a competition-based CSP market.

Only recently, the U.S. government has given a loan guarantee (US $1.45 Billion) to Abengoa to realize a 260 MW_{el} CSP power plant in Arizona (Solana). One condition of this grant was to utilize a maximum share of American components. For this reason, Abengoa raised the local share to 70 percent, and a new mirror production facility is planned.

For the first large commercial plant, Andasol 1 in 2006, the share of Spanish supplies was below 50 percent. Now, four years later, the new plants use more than 75 percent local supplies (personal communication Protermosolar).

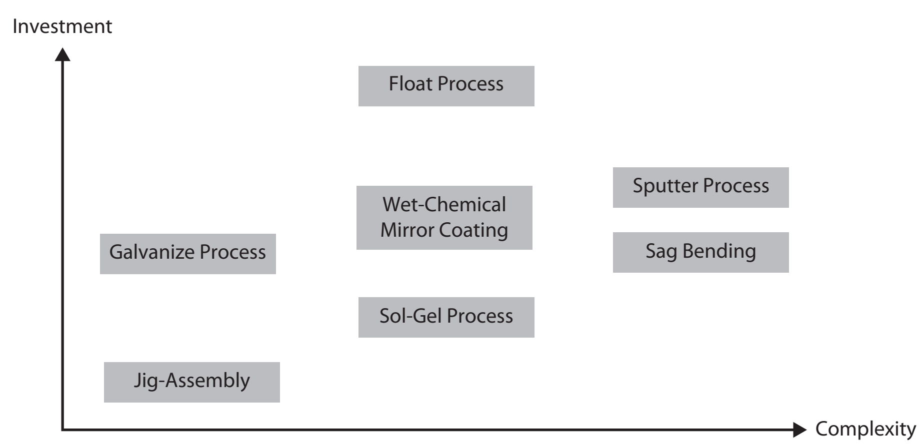
Similar developments should be supported in MENA countries. Even though their technological level cannot be compared to the United States, some production steps could be performed in the target countries. Early adopters in MENA (e.g., the Kuraymat project in Egypt) already perform the whole jig-assembly close to the solar fields. A next step could be the galvanizing process, and later the mirror production, which are both locally present but not yet in the necessary quality and quantity. Another important step towards including MENA countries is Joint Ventures of CSP companies. For instance, Flabeg erected a whole mirror production in the United States, and every German CSP company has a Spanish and American subsidiary to be regarded as a local, and not as an intruder looking for government subsidies. A good example is Egypt, where almost the entire erection of the CSP power plant was managed by a local company. It is important to include local companies, because local companies usually have good understanding of the local institutional and market content.

For each manufacturing process or service, some barriers and bottlenecks may presnt problems for local MENA industry looking to enter the CSP market. These barriers have to be minimized with the presentation of special roadmaps and action plans for each component regarding current MENA potential, analyzed further in chapter 3.

1.4 Cost Analysis for the Main CSP Components

Today, CSP markets and CSP projects evolve where a political framework ensures some kind of financial incentive. It is virtually impossible to determine the real cost of electricity from CSP, because the cost of electricity equals the electricity tariffs paid; this is the case, at least, in Spain, which is currently the primary world market for CSP. When there is a difference between internal cost and tariff,

Figure 1.30 ■ Complexity Versus Investment-Intensity for CSP Production Processes



Source: Fraunhofer ISE.

Table 1.6 ■ Technical and Economic Barriers to Manufacturing CSP Components

Components	Technical barriers	Financial barriers	Quality	Market	Suppliers	Level of barriers
Civil work	Low technical skills required	Investment in large shovels and trucks	Standard quality of civil works, exact works	Successful market players will provide these tasks	Existing supplier structure can be used for materials	**Low**
EPC engineers and project managers	Very highly skilled professionals: engineers and project managers with university degrees		Quality management of total site has to be done	Limited market of experienced engineers	Need to build up an own network	**Medium**
Assembly	Logistic and management skills necessary Lean manufacturing, automation	Investment in assembly-building for each site, investment in training of work force	Accuracy of process, low fault production during continuous large output Low skilled workers	Collector assembly has to be located close to site	Steel parts transported over longer distance Competitive suppliers often also local firms	**Low**
Receiver	Highly specialized coating process with high accuracy Technology-intensive sputtering step	High specific investment for manufacturing process	High process know-how for continuous high quality	Low market opportunities to sell this product to other industries and sectors	Supplier network not strongly required	**High**
Float glass production (for flat and curved mirrors)	Float glass process is the state-of-the-art technology but large quantities and highly energy intensive Complex manufacturing line Highly skilled workforce to run a line	Very capital-intensive	Purity of white glass (raw products)	Large demand is required to build production lines	Supplier network not strongly required	**High**
Mirror *flat* (float glass)	Complex manufacturing line Highly skilled workforce to run a line	Capital-intensive	Long-term stability of mirror coatings	High quality flat mirrors have limited further markets Large demand is required to build production lines	Supplier network not strongly required	**High**

(*continued on next page*)

Table 1.6 Technical and Economic Barriers to Manufacturing CSP Components *(continued)*

Mirror *parabolic*	*See flat mirrors* Plus: Bending: highly automated production	*See flat mirrors* + bending devices	*See flat mirrors* High geometric precision of bending process	Large demand is required to build production lines Parabolic mirrors can only be used for CSP market	Supplier network not strongly required	**High**
Mounting structure	Structure and assembly are usually proprietary know-how of companies Standardization/automation by robots or stamping reduces low skilled workers, but increases process know-how	Automation is capital-intensive Cheap steel is competitive advantage	For tracking and mounting: stiffness of system required	Markets with large and cheap steel Transformation industries are highly competitive	Raw steel market important	**Low**
HTF	Chemical industry with large productions. However, the oil is not highly specific	Very capital- intensive	Standard product, heat resistant	Large chemical companies produce thermal oil	Not identified	**High**
Connection piping	Large and intensive industrial steel transformation processes Process know-how	Capital-intensive production line	High precision and heat resistance	Large quantities	Not identified	**Medium**
Storage system	Civil works and construction is done locally Design and architecture Salt is provided by large suppliers	Not identified	Not identified	Low developed market, few project developers in Spain	Not identified	**Medium**
Electronic equipment	Standard cabling not difficult Many electrical components specialized, but not CSP specific equipment Equipment not produced for CSP only	Not identified	Not identified	Market demand of other industries necessary	Often supplier networks because of division	**Low**

the actors (e.g., the EPC contractor) adjust their margin. In Spain, the electricity price paid for CSP roughly amounts to at least 27 €ct/kWh, based on a funding system, subsidizing the electricity production (and not the plant installation). Such a feed-in system proves to be the most effective funding scheme when a fast capacity addition is required, because it provides the necessary financial security for investments.

In Spain, many companies have entered the CSP market, including large companies from conventional business sectors such as utilities and construction. This high market response can be considered a sign that CSP pays off well with the Spanish level of remuneration. For the above mentioned SEGS plants, electricity generation costs of 11 to 18 $ct/kWh have been published, but with approximately 30 percent higher solar irradiation (on an annual level) than good Spanish sites. The real cost of CSP today depends on site and suppliers. Some CSP suppliers even claim to have already reached break-even cost with fossil energies, but this has not yet been verified in non-subsidized markets.

This section describes the typical cost structure of a CSP plant. Like the previous sub-sections, this section focuses on data from parabolic trough technology, which is the most commercially advanced. Like any other industry, CSP business actors are not willing to disclose internal information on cost structures in an unlimited way. Still, some commercial cost information has been made available, which is analyzed and referenced in this section. Solar Tower and Fresnel Systems technologies are constructed from the same basic components as the parabolic trough technology. Spanish projects (PS10 and PS20) and the Novatec Fresnel 30 MW plant use the same feed-in tariff regulations for selling the electricity to the market.

Fresnel systems show a similar cost structure, although the cost for the mirrors and steel structure is lower. On the other hand, this cost advantage is counterbalanced—at least in part—by lower plant efficiency caused by lower optical efficiencies and a lower working temperature.

Solar Towers require an extra investment in the tower itself, but also involve lower costs for piping and mirrors in combination with higher possible temperatures. Further evaluation of total costs is made difficult by the small number of existing projects, but the similarity of the production process implies comparable outcomes for local manufacturing, although the simplicity of flat mirrors—both for towers and for Fresnel collectors—should be highlighted again at this point.

Unlike conventional power generation systems, the bulk of the electricity generation costs of CSP plants are dominated by the initial investment, which accounts for approximately 80 percent of the electricity generation cost (Morin, 2009). The remaining 20 percent represents the cost of operation and maintenance of the plant, and of plant insurance.

1.4.1 Total Investment for a Parabolic Trough Power Plant

This chapter presents cost information for a parabolic trough power plant of the Andasol 1 design, i.e., with a rated power of 50 MW_{el} and a storage capacity of 7.5

hours. The cost for each component is depicted in the following table to identify the potential revenues that could be earned if this component or service were executed by a local manufacturing, engineering, or construction company. These revenues will remain local earnings that will benefit the region. The individual cost parameters will be used later to calculate the share of local manufacturing in an ongoing ISCCS project in the region (see section 2.2.3) and to calculate the future economic benefit to be gained if local manufacturing is increased by direct and indirect support.

The cost information refers to a selling price of a turn-key parabolic trough power plant of US$364 million. This price is based on calculations for Spanish CSP plants with volumes of €300 million, but this price was reduced here to €280 million because price reductions are predicted by many experts in interviews and by technical and economic reports. This reduced price is not published officially in Spain because the Spanish feed-in tariff offers attractive revenues for investment costs with volumes of €300 million.

One must note that a plant using storage of this size uses a solar field which is 75 percent larger than a trough power plant without thermal storage. This increases the specific investment of $/kW, which is a number that is often referenced when looking at energy technologies. In CSP, the specific investment is of no relevance, because storage increases the energy production. Storage can therefore reduce the cost of electricity of the plant, which is a much more relevant decision criterion.

Component costs in Table 1.7 correspond to prices at which an EPC contractor buys the components. Labor in this table only considers labor during construction of the power plant (and not during manufacturing of the components). Most of this is low-skilled labor to be provided by locals.

As mentioned above, this table confirms that the components of the solar field (with 550,000 m²) are the most capital-intensive part of the plant (38.5 percent). The price of a collector is mainly determined by the cost of the receiver (7.1 percent), the reflector (6.4 percent), and the metal support structure (10.71 percent). The solar field piping (5.4 percent) and the HTF (2.1 percent) also amount to a considerable investment.

To install these components and build the whole power plant, it is necessary to employ a workforce of around 500 people (Andasol 1), while more advanced concepts rely on fewer workers (see Table 1.10 for exact numbers). These employees include blue collar workers, logisticians, and construction managers. The total labor costs therefore range around 17 percent.

The blue collar workers assemble the collectors and are responsible for the ground and construction works of general building infrastructure. Consequently they represent the majority of the workforce. Nevertheless, the logisticians have to provide the whole transport system, which has to be resistant to costly bottlenecks. The overall management is provided by experienced specialists to ensure on-time and cost-efficient planning.

If storage is included, 10 percent of total investment is due to this system. However, storage also affects other costs, because a storage plant is usually equipped with a much larger solar field.

Table 1.7 ■ Estimation of the Investment Cost of an Andasol-like Power Plant with a Rated Power of 50 MWel, a Thermal Storage Capacity of 7.5 hours, and a Solar Field Size of 510 thousand m²

	Cost for Reference Power Plant in Euro	Cost for Reference Power Plant in US$	Relative Value of plant
Labor Cost Site and Solar Field	**48.0 Mio €**	**62.4 Mio $**	**17.1%**
Solar Field	8.7 Mio €	11.3 Mio $	3.1%
Site Preparation and Infrastructure	16.3 Mio €	21.2 Mio $	5.8%
Steel Construction	7.0 Mio €	9.1 Mio $	2.5%
Piping	4.9 Mio €	6.4 Mio $	1.8%
Electric installations and others	11.1 Mio €	14.4 Mio $	4.0%
Equipment Solar Field and HTF System	**107.9 Mio €**	**140.3 Mio $**	**38.5%**
Mirrors	17.8 Mio €	23.1 Mio $	6.4%
Receivers	19.9 Mio €	25.9 Mio $	7.1%
Steel construction	30.0 Mio €	39.0 Mio $	10.7%
Pylons	3.0 Mio €	3.9 Mio $	1.1%
Foundations	6.0 Mio €	7.8 Mio $	2.1%
Trackers (Hydaulics und Electrical Motors)	1.2 Mio €	1.6 Mio $	0.4%
Swivel joints	2.0 Mio €	2.6 Mio $	0.7%
HTF System (Piping, Insulation, Heat Exchangers, Pumps)	15.0 Mio €	19.5 Mio $	5.4%
Heat Transfer Fluid	6.0 Mio €	7.8 Mio $	2.1%
Electronics, Controls, Electrical and Solar Equipment	7.0 Mio €	9.1 Mio $	2.5%
Thermal Storage System	**29.5 Mio €**	**38.4 Mio $**	**10.5%**
Salt	14.3 Mio €	18.6 Mio $	5.1%
Storage Tanks	5.1 Mio €	6.6 Mio $	1.8%
Insulation Materials	0.5 Mio €	0.7 Mio $	0.2%
Foundations	1.8 Mio €	2.3 Mio $	0.6%
Heat Exchangers	3.9 Mio €	5.1 Mio $	1.4%
Pumps	1.2 Mio €	1.6 Mio $	0.4%
Balance of System	2.7 Mio €	3.5 Mio $	1.0%
Conventional Plant Components and Plant System	**40.0 Mio €**	**52.0 Mio $**	**14.3%**
Power Block	16.0 Mio €	20.8 Mio $	5.7%
Balance of Plant	15.9 Mio €	20.7 Mio $	5.7%
Grid Connection	8.1 Mio €	10.5 Mio $	2.9%
Others	**54.6 Mio €**	**71.0 Mio $**	**19.5%**
Project Development	8.1 Mio €	10.5 Mio $	2.9%
Project Management (EPC)	21.6 Mio €	28.1 Mio $	7.7%
Financing	16.8 Mio €	21.8 Mio $	6.0%
Other costs (allowances)	8.1 Mio €	10.5 Mio $	2.9%
Total Cost	**280. Mio €**	**364. Mio $**	**100.0%**

Table 1.8 ■ Cost Estimates for Individual Parabolic Trough Components

Element	Cost estimate	Unit
Parabolic Mirror ("conventional" thick glass mirror)	28–40	€ per m^2 of collector aperture
Steel structure (material)	50–65	€ per m^2 of collector aperture
Vacuum receiver	200–300	€ per m receiver length
Thermal oil	3.0–7.0	€/ l
Parabolic Trough Collector (incl. installation)	200–240	€ per m^2 of collector aperture
Solar Field installed (incl. connection piping, HTF & HTF system)	230–290	€ per m^2 of collector aperture

Source: authors
Note: As in Table 8, component costs in this table correspond to prices at which an EPC contractor would buy the components. The collector and solar field cost correspond to net cost, including labor but excluding costs for engineering, project management, financing, and margins for profit as well as risk.

Up to 20 percent of cost can be attributed to the category "Others," which includes project development (2.9 percent), project management (7.7 percent), financing (6 percent), and risk allowances (3 percent). This cost block is strongly project-related and can be changed quickly according to project characteristics.

The following table compiles information on ranges for component costs of parabolic trough power plants. Only key components are shown. Obviously, the prices depend on manufacturer, project size, market situation (e.g., oligopoly), country, and other criteria. Following the table are additional remarks respecting individual sub-systems and components.

Metal structure cost

The cost of the metal support structure is a combination of material cost, process cost, design cost, and galvanization cost. For the Andasol 1 project, the total cost of the metal support structure was €30 million. Solarel Energy, a company that produced the steel structure of the Skal-ET (SMI, 2010), published material cost of €1,000/ton (Solarel, 2010). Using these numbers and the total amount of steel in the solar field, 31 percent of the €30 million were spent on the material itself.

The general steel cost composition of similar constructions can be derived from Evers (2000), where 38 percent of the cost of a steel structure accounts for raw steel price. Hence, there price of steel will have some influence on plant cost and on cost of electricity from CSP.

Receiver cost

The essential parts of a state-of-the-art receiver are a coated stainless steel pipe and a borosilicate glass envelope. A standardized borosilicate glass tube (100–149 mm) comes to €9.85/kg. The total cost of a 4m long glass tube is around €94 (Doening, 2010). Following the data of SolarMillenium, Archimede Solar, and Schott, the absorber tube is made of stainless steel SS316 (Arc, 2008). Such tubes, with a diameter of around 70mm and a length of 4m, cost about €190 (Doening, 2010). Hence, the combined raw material price of the absorber is €71/meter, disregarding the negligible amounts of material for the absorber and the anti-reflex glass coating as well as the getter material. Process costs for these components are unlikely to justify this high add-on. Hence, this receiver component seems to offer great cost reduction potential once a really competitive market evolves.

1.4.2 Running Cost of PTC Plants – Operation and Maintenance, Insurance, and Fossil Fuel Cost

One part of the running cost of the plant is the insurance. The insurance cost is determined by what is to be assured and secured financially. Usually, 0.5–1 percent of the initial plant investment is paid as annual insurance cost.

The larger portion of the running cost is the operation and maintenance (O&M) cost of the plant. Operation and maintenance costs of power plants that have been put into operation since the CSP renaissance in 2007 have not been made publically available. However, a very comprehensive study assessed the detailed structure of the O&M cost and activities of the Californian SEGS plants at Kramer Junction (Cohen, 1999). The following table summarizes the main findings of this study, which aimed at assessing and improving the O&M activities in the Kramer Junction power plants (SEGS III-VII).

As can be seen in Table 1.9, replacement of receivers and mirrors is among the largest cost positions. The reason for this is—in both cases—glass breakage.

Table 1.9 Summary of Total Annual Costs for Parts and Material for Solar Field Maintenance

Parts and Materials					
	Unit Cost $	% replace	SF size= 500,000 m^2/unit	m^2 \$/m^2-yr	\$K/yr
Mirrors	100	0.5	2	0.250	125.0
HCEs	700	3.0	22	0.963	481.7
Sun Sensor	150	0.5	545	0.001	0.7
LOCs	200	0.5	545	0.002	0.9
Ball joints	2100	0.5	273	0.039	19.3
Hdr. Drive	6000	0.5	545		27.5
Miscellaneous	assumed as 5% of total equipment costs above				33.6
TF Pump Seals	1200	2 per year	500000	0.005	2.4
HTF Makeup	4,221,423	1	500000	0.084	42.2
Water	demineralized water for mirror washing				243.3
Nominal -KJ					**976.5**
With 30% higher material costs and cheap water					**1034.9**
With only cheap water					**810.1**
With only higher material costs					**1196.5**

Source: Cohen, 1999.
Note: "KJ" stand for Kramer Junction, the reference plant in California

Figure 1.31 ■ Left: Conventional Cleaning Methods (Cohen, 1999), Right: Water-Efficient Cleaning Using a Cleaning Robot of Fresnel Collector by Novatec Biosol (Novatec, 2010)

Source: Cohen, 1999 and Novatec, 2010.

The receiver glass tube breakage through thermal expansion problems may have been solved since then by adapting the thermal expansion of glass and metal (see section 1.1.3). Glass breakage in the solar field could also be significantly reduced by stiffer collector sub-structures. Another cost position is water for mirror washing (see Sources: Cohen, 1999 and Novatec, 2010).

Looking at staffing, the study by Cohen presents different scenarios for nominal (=optimal) O&M procedures and "reduced" O&M activities, both for a developed country and for a developing country (see Table 1.10).

Parabolic trough technology has not yet achieved a significantly higher degree of automation in the operation procedures than what was described by Cohen (1999). However, the technology improvements described above reduced the need for frequent replacement of components. Therefore, the staffing level shown in Table 1.10 will be reduced by approximately 30 percent in today's trough plants.

In addition to the personnel explicitly dedicated to the operation and maintenance of the solar field, plant personnel for the operation of the power block for the plant administration is needed. A typical 50 MW trough plant requires about 30 employees for plant operation (Dersch, 2009).

Depending on the hybridization of the plant, fuel costs are also part of the running cost. For example, according to Spanish legislation, co-firing of 10–12 percent is allowed. For this, normally natural gas is used.

In the course of the operation and maintenance improvement program described in Cohen (1999), the total O&M cost could be reduced from an initial 4 $ct/kWh to below 2.5 $ct/kWh by improving the O&M procedures (both cost and plant performance). Today's O&M cost should be lower than this, due to improvements in technology and processes (cleaning, glass breakage, and others).

Table 1.10 ■ Staffing for Solar Field Operation and Maintenance Plan, for Developed Countries (above) and for Developing Countries (below)

Staffing Developed Countries (e.g. U.S., Europe) For SF size = 500000 m² OH rate								
		Nominal #	**Reduced #**	**Level**	**Rate, $K/yr Direct**	**35% Burdened**	**Annual $K Nominal**	**Reduced**
Solar Field Manager		1	0	Senior	50	67.5	67.5	0.0
Maintenance	Supervisor	1	1	Skilled	45	60.8	60.8	60.8
2 shifts	Welder	1	1	Skilled	40	54.0	108.0	54.0
(4 10h days)	Mech Tech	2	1	Exper'd	35	47.3	189.0	47.3
	I&E Tech	1	1	Skilled	40	54.0	108.0	54.0
Lead Mrror	Wash Supervisor	1	1	Skilled	45	60.8	60.8	60.8
1 shift	Equip. Opers.	4	2	Exper'd	35	47.3	189.0	94.5
Field Operator (status)		5	3	Exper'd	30	40.5	202.5	121.5
		20	13			**Total**	**985.5**	**492.8**

Staffing Developing Countries							
		Nominal #	**Reduced #**	**Level**	**Burdened Rate, $K/yr**	**Annual $K Nominal**	**Reduced**
Solar Field Manager		1	1	Senior	20.3	20.3	20.3
Maintenance	Supervisor	1	1	Skilled	18.2	18.2	18.2
2 shifts	Welder	2	1	Skilled	15.2	64.8	16.2
(4 10h days)	Mech Tech	4	2	Exper'd	14.2	113.4	28.4
	I&E Tech	2	1	Skilled	16.2	64.8	16.2
		4	2	Unskilled	8.5	68.0	17.0
Lead Mrror	Wash Supervisor	1		Skilled	18.2	18.2	0.0
1 shift	Equip. Opers.	6	3	Exper'd	14.2	85.1	42.5
Field Operator (status)		10	5	Exper'd	12.2	121.5	60.8
		31	16		**Total**	**574.3**	**219.6**

Source: Cohen, 1999.

In a nutshell, the O&M strategy has to find an optimum middle ground between a highly efficient solar power production and low operation and maintenance cost, which are normally contrary goals. In most cases, however, working on high plant performance pays off because of the high investment cost share of a CSP plant.

1.4.3 Future Cost Reduction Potential

Cost reduction through research and development

A high number of R&D activities in the field of CSP are underway. An overview of the R&D fields, including recommendations on funding R&D in CSP, is given in Ecostar (2005). Table 1.11 shows an excerpt of current R&D activities in the

Table 1.11 ■ Excerpt of Current Research and Development Activities in Solar Thermal Power Generation (Parabolic Trough)

Innovation	State of the Art	Aim	Solutions
New Heat Transfer Fluids	Synthetic Oil	Higher temperatures, cost-reduction, reduce environmental risks	Direct Steam Generation (cheap water & no heat exchangers), molten salt
New Storage Concepts	Molten Salt (Oil)	Cheap storage material, high heat capacity, low freezing point, isothermal heat transfer (for evaporation)	Latent heat storage (esp. for DSG), thermocline storage, new storage materials such as concrete, sand or others
New Mirror Materials	Curved Glass Mirrors	cost reduction, high reflectivity	Metallic reflectors, coated polymer film with integrated support
New Collector Concepts	PTC with 5–6 m aperture	Cost reduction, high efficiency, high optical accuracy	Variety of collector substructures, different collector widths (1–10 m); lean Fresnel-Collectors

field of line-focusing collectors. All technology developments that are shown in Table 1.11 aim at improving CSP components and sub-systems with respect to cost and/or efficiency.

A recent study, carried out by the European CSP-industry association Estela and by AT Kearney (Estela, 2010), figured out the latest cost reduction potential by interviewing the existing CSP industries regarding technology improvements and effects of economics of scale. The results are shown in the following table. Overall LCOE will decrease by 45–60 percent by 2025, according to AT Kearney. Economies of scale, overall plant efficiency increase, and technology improvements are the main drivers for this development. Many components will contribute to these technology improvements by values of 15 to 25 percent.

Cost reduction through economies of scale – Increasing the plant size

This sub-section goes beyond the assessment of the cost reduction by economies of scale through increased market size on the component level (as in Table 1.12), and assesses cost reduction potential on the power plant level.

Today, most of the finished and constructed CSP power plants have a capacity of 50 MW. This is mostly due to the Spanish feed-in law RD-661/2007, which restricts the maximal electrical output to 50 MW. In terms of economies of scale, 50 MW is not at all the optimal plant size. Current U.S. project developments all aim at much higher plant capacities around 200 and 250 MW. In Kistner (2009), the effect of plant size on specific plant investment is assessed, see Figure 1.32.

The thorough reader of this study might note that the values given in the reference case of Figure 1.32 top) correspond well to the data given in the right column of Table 1.7. The reason for this is that the authors of this study (Kistner, 2009) work for Ferrostaal, who jointly with SolarMillennium, Flagsol, and Duro Felguera act as general contractors for the Andasol 3 power plant.

Table 1.12 ■ Cost Reduction Caused by Technology Improvements, Economies of Scale (Plant Size) and Efficiency Increase of the CSP Plant

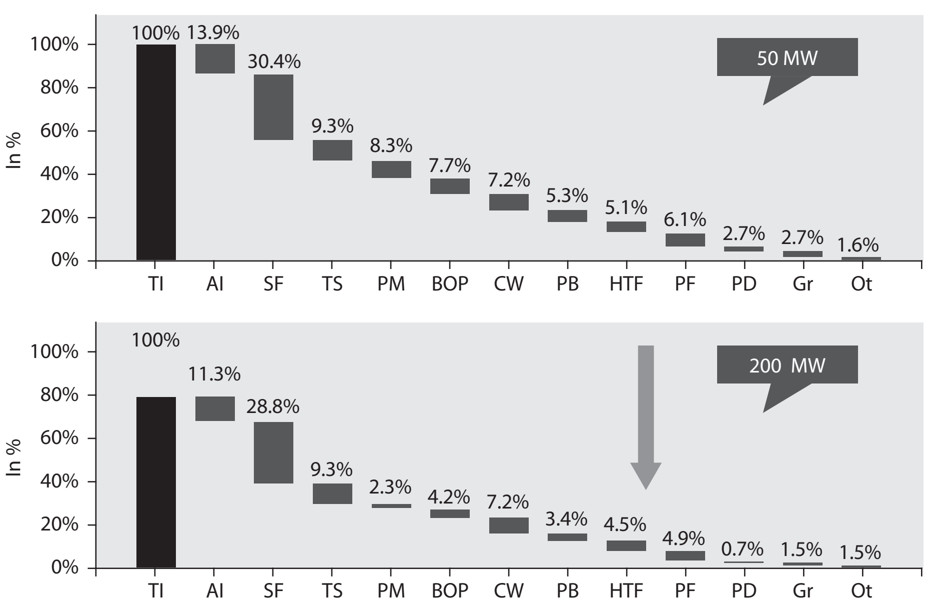
Levelized cost of electricity reduction	2025
Total plant LCOE	45–60%
Economies of Scale	21–33%
Efficiency increase	10–15%
Technology Improvements	18–22%

Technology Improvements	Mirrors parabolic	Mirrors flat	Receivers	Steel structure	Storage Tank	Molten salt
2020	25%	25%	25%	30%	20%	15%

Source: Estela, 2010

Kistner came to the conclusion that the specific cost for a parabolic trough power plant with 50 MW and 7.5 h of storage can be cut by 12.1 percent at 100 MW and by 20.3 percent at 200 MW. The study shows that the relative contribution of the different cost shares to the economies of scale is very different. The biggest economy of scale can be realized in Project Management (PM), Balance of Plant (BOP), Power Block (PB), and grid access (Gr). The specific cost can be cut by 20–25 percent in these areas. The specific cost of Project Management

Figure 1.32 ■ Economies of Scale: Decrease of Component Cost with Increased Plant Size



Abbreviations: Total Investment (TI), Allowances (AI), Solar Field (SF), Thermal Storage (TS), Project Management (PM), Balance of Plant (BOP), Civil Works (CW), Power Block (PB), Heat-Transfer Fluid (HTF), Project Finance (PF), Project Development (PD), Grid Access (Gr), Other (Ot)

Source: Kistner, 2009.

drops by 47 percent at double capacity (100 MW) and by 72.3 percent at four times capacity. The specific Project Development cost declines by 33.4 percent and 74.1 percent respectively. Hence, these cost items almost remain constant in absolute numbers, independent of the plant size. Since costs of solar field and storage depend on the plant size, only small changes can be observed regarding the Solar Field, the Heat Transport Fluid, and the storage, as material cost is the dominant cost fraction in these areas.

Similar to Kistner, Acciona came to the conclusion that an augmentation of the capacity from 50 MW to 120 MW would result in specific cost savings of 13 percent overall (Nieto, 2009).

Cost reduction through efficient supplier markets and economies of scope

It is more promising to analyze the capital cost than the enhancement of efficiency in terms of total cost reduction. Short term improvements can be obtained by raising the standard plant size from 50 MW to over 100 MW and reducing the construction period.

Today, CSP markets and projects evolve where a political framework ensures a financial incentive. It is virtually impossible to determine the real cost of electricity from CSP, because cost of electricity equals the electricity tariffs paid. In case there is a difference between internal cost and tariff, actors (e.g., EPC contractors) adjust their margins. In Spain, the electricity price paid for CSP roughly amounts to 31 €ct/kWh. Subsidizing the electricity production—in contrast to subsidizing the plant installation—gives adequate incentives to produce large amounts of electricity over the lifetime of the plant.

In Spain, many companies have entered the CSP market, including large companies from conventional business sectors such as utilities and construction. This high market response can be considered a sign that CSP pays off well with the Spanish level of remuneration. For the above mentioned SEGS plants, electricity generation costs of 11 to 18 $ct/kWh have been published, but with approximately 30 percent higher solar irradiation (on an annual level) than good Spanish sites. The prices of the power purchase agreements that are realized in the U.S. market today are not publically available; according to semi-official information, they are in the same spectrum (11–17 $ct/kWh), but include subsidy schemes (such as state loan guarantees, investment tax credits, or production tax credits).

Today, the real cost of CSP depends on site and supplier. Single CSP suppliers even claim to have already reached break even cost with fossil energies (Novatec, 2010b); however, this has not yet been verified in non-subsidized markets.

Another result of the analysis of the present CSP market is the necessity of a market-driven value chain to allow for more competition. This seems very logical, as current component suppliers like Schott Solar have EBIT-margins around 20–25 percent (2008) in CSP. In comparison, in the PV industry, which produces under much more evolved competitive conditions, EBIT-margins are around 6 percent and below. This competition raises the need to differentiate products from competitors' by using more advanced technologies or offering a lower price, which CSP has not yet achieved.

Standardization, combined with mass production, offers large potentials for relevant cost reductions.

Compared with other renewable energy technologies, the installed capacity of CSP is still relatively small. Learning processes in mass production and project management, which are already realized in PV and wind energy, have not been reached. A learning curve that began in the early 1990s was stopped by lack of governmental support.

Following the introduction of the new Spanish feed-in tariffs, a second technology roll-out has started recently. With additional new markets like the United States showing a high competitive pressure, it will be a matter of only a few years before CSP costs will drop considerably. New cost-efficient collector concepts using light designs, a high degree of automation, and a high degree of standardized components will realize this foreseen cost-reduction. Compared to electricity from wind power and photovoltaic, CSP can provide electricity on demand through thermal storage, which will also pay off in the form of higher electricity prices that can be realized through dispatchability. After a market introduction phase a few years from now, CSP technology will no longer depend on subsidies, and will be—at the very least—cost-competitive in the market of peak and intermediate load power, and possibly, in the long run, also with base load power.

1.5 Conclusion of Chapter 1

This chapter presents a review of CSP technologies with respect to technology description (section 1.1), description of the industry (section 1.2), analyses of production processes (section 1.3) and cost (section 1.4). The main results can be summarized as follows:

The **CSP market** is mainly driven by the markets in the United States and Spain, but first projects are also under construction or in status of commissioning in North Africa: in Morocco, Algeria, and Egypt. By the middle of 2010, over 800 MW of CSP plants were in operation world-wide; the electricity producing plants have doubled their capacity with new installations since 2007, after the installation of the SEGS plants in California.

Today, parabolic trough technology is commercially the most mature technology, and the only widely bankable CSP technology. Therefore, the focus throughout this study is set on this technology. However, most findings for local manufacturing are also applicable to other CSP technologies, because working principles, materials, and production processes do not significantly vary. Most trough, Fresnel, tower (and partially dish) technologies consist of steel structures, glass mirrors, and absorber tubes using a sputtered selective coating. All systems track the sun, have high optical/geometric accuracy requirements, use high-temperature materials and processes, and have electric generators that need to be coupled to the electric grid. Nevertheless, receiver technologies are quite different between the different CSP concepts, with different degrees of complexity. For example, it could be argued that the receiver technology used in Linear Fresnel technologies is simpler to produce and hence more easily produced locally. However, this requires a more in depth investigation of this key component than possible in this study.

Beyond parabolic trough plants, Fresnel, tower, and dish technologies are about to achieve commercial maturity through the installation of the first fully commercial power plants, and after having installed first prototype power plants (which were in most cases financed by the companies that developed the technologies). Due to considerable advances in all four types of CSP technology, future calls for tenders should not be restricted to one specific technology. In turn, all technologies matching minimum requirements (including experience) should be admitted. Increasing competition will allow innovative and cost-efficient technologies to prove their potential, will bring down the cost of CSP and—maybe the most important point—will help to realize more CSP capacity with a given amount of financing in the MENA region.

This chapter gives in-depth analysis of a selection of important **production processes,** their general manufacturing parameters (e.g., labor and energy intensity), technology complexity, and investment intensity, to give a broad overview of which manufacturing processes of CSP components can be most easily adapted by local industry or international industry for local manufacturing. These products will consequently have the highest chance of being manufactured in MENA countries in the short- and mid-term future.

In the next section, the **cost of CSP** and the contributions from individual components of the CSP value chain were reviewed through an analysis of Spanish CSP plants. A reference plant with 50 MW and storage was evaluated with an investment of US$364 million. The components of the solar field are the most capital-intensive and the largest part of the value chain (38.5 percent). The price of a collector is mainly determined by the cost of the receiver (7.1 percent), the reflector (6.4 percent), and the support structure (10.7 percent). Total labor costs range around 17 percent. Although the components of the solar field are the most capital-intensive and largest part in the value chain, there are opportunities for local manufacturing and services all along the value chain.

Based on the complexity level and the potential for local manufacturing, as well as the share of added value in the CSP value chain, a number of key components and services are identified as the most promising and worthwhile to foster local manufacturing in the MENA region. These key components are support structure, mirrors, and receivers; key services range from assembling and EPC to O&M.

Cost reduction of solar thermal power plants will be important for future success in the MENA region. This will be achieved by:

- an increasing amount of plants being built through sustainable and reliable markets,
- competitive market mechanisms, including all—and especially innovative—CSP technologies, and
- further research and development.

Unlike wind power and photovoltaic, CSP can provide electricity on demand through thermal storage, which will also pay off in the form of higher electricity prices that can be realized through dispatchability. After a market introduction phase a few years from now, CSP technology will no longer depend on subsidies, and will be—at least—cost-competitive in the market of peak and intermediate load power, and possibly in the long run also with base load power.

In order to understand whether **local manufacturing in the MENA region** has a reasonable chance, it was important to conduct a detailed analysis of the CSP value chain; that is, the technologies and services involved, the production processes, and the main industry players behind the technologies. Companies in the value chain show a high potential for participation in future MENA CSP markets and are already involved in the ongoing CSP projects in the MENA region.

The following points summarize the findings of today's status of the CSP industry:

- A growing CSP industry can be identified in Spain, the United States, and also in the MENA market. Effects of new investments in large scale production, increased project capacities, and technology know-how (e.g., Siemens, Abengoa, Acciona, Schott Solar, Solar Millennium, Bright Source, Iberdrola) are observed.
- International companies are strongly concentrated in Spain, the United States, and Germany.
- A growing market has been identified for all phases (raw materials, components, engineering, EPC contracting, operators, owners, investors, and research institutions) across the entire value chain.
- In Spain, many companies from non-energy sectors could start new business activities in the CSP field very quickly.
- Some sectors and companies, like receiver suppliers, are strongly dependent on the CSP market demand and growth. Other firms have built their production and manufacturing capacities on the demand of other markets (CSP is a niche for them).
- Some components (Piping, HTF, electronics, power block) are not produced by companies with large CSP know-how or background, because this equipment is used for many other applications, such as chemical, electronic, and fertilizer (Nitrate salts) industries.
- High technological know-how is required for some components—especially mirrors, receivers, and equipment for the power block—which makes it difficult for new players to enter the market. However, a trend toward more competition, including new players, can be noted in all fields.
- Well-established players for mirrors and receivers opened up new production facilities in the current CSP markets in Spain and the United States at short notice.
- These players will very likely build up production facilities also in the MENA region if the market size becomes large enough (see scenarios in Part II of

this report). Sustainability of the CSP market is crucial for this because the specific output of a single component factory is high. Such sustainable markets will have to be facilitated by policy related measures (Trieb, 2010).

Local manufacturing can take place if technical and economic requirements for local and international industry are fulfilled. Most important is a sustainable CSP market, which will have to be facilitated by political measures. Investments for new local production capacities are related to market size, as the specific output of a single component factory is often high.

However, high technological know-how and advanced manufacturing processes are necessary for some key components, such as parabolic mirrors or receivers, which nevertheless offer the highest reward in terms of value added.

Local manufacturing potential in the MENA region may be realized by the following strategies: local construction works, manufacturing of components by local, regional, and international companies, and support by local subsidiaries of international CSP industry.