Economic analysis of the CSP industry

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Outline

Introduction

This report presents the results of an economic study on the Concentrated Solar Technology (CSP) carried out by Cerna, MINES-ParisTech and commissioned by the French Agency for Development (AFD). As compared with the Solar Photovoltaic (PV) technology, the CSP technology is still at an early development stage. Its commercial exploitation has started more recently, and the related industry is still nascent.

The purpose of the study is to analyze the technical and economic dimensions of CSP technologies, so as to highlight its current potential as a specific source of renewable energy. The study is based on an extensive review of professional technical and market reports and academic publications on this subject, supplemented by information from companies' websites and interviews. The questions addressed are the following: What are the various existing CSP technologies, their degree of maturity, cost structure and potential applications? What is their current and potential deployment in industrialized and developing countries, and what are the technical, economic and policy factors that drive it? What is the current organization and geographical repartition of the CSP industry and how are they evolving? How do competition, innovation and technology diffusion take place in this industry? Finally what is the role of French actors is this industry?

The report is structured in four Sections. Section 1 is devoted to the comparative review of the various CSP technologies. Section 2 focuses on their experimental and commercial deployment at the global scale, and the factors that drive it. Section 3 discusses the organization of the CSP industry and its on-going evolution. It includes a specific subsection on the position of the French CSP industry. Section 4 concludes by summarizing the main results of the study.

1. Concentrating solar power technologies

Concentrating solar power (CSP) technologies aim at generating electricity from sunlight. By contrast with photovoltaic (PV) technology that converts the sun's energy directly into power using the photovoltaic effect, CSP technologies produce electricity indirectly, by focusing sunrays to boil water, which is then used to generate power. In this report, we will focus on such thermal CSP, as its development and deployment have their own dynamics, involving technology-specific actors, technical constraints and opportunities, and policy schemes. We will in particular let aside the recent concentrated photovoltaic (CPV) technology, which employs sunlight concentrated onto photovoltaic surfaces for the purpose of electrical power production.

1.1. The four CSP technologies

There are four types of thermal CSP technologies, which are presented below and in Figure 1. All apply the same basic principle: reflectors (mirrors) are used to concentrate solar beams on a receptor to heat a fluid and generate steam, which in turn rotates a turbine connected to a generator, which eventually produces electricity.

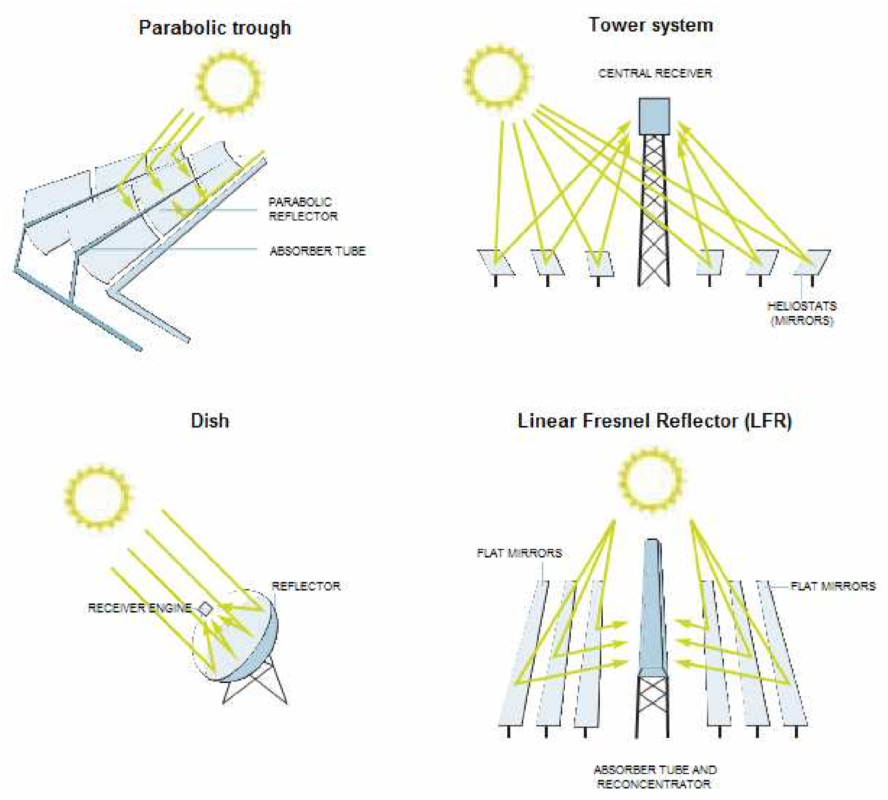
Parabolic trough
Parabolic trough technology is based on parabolic reflectors concentrating the suns rays into a receiver pipe along the reflectors' focal line. A heat transfer fluid (HTF) circulating in the receiver pipe is heated up to 400 degrees. This heat is then used to generate steam, which runs a turbine producing electricity. The system rotates to follow the sun's movements to optimize the electricity generation.

Power tower system
Power tower systems, also called central receivers, consist in large fields of sun-tracking flat mirrors to concentrate sunlight on to a receiver on the top of a tower where a HTF (water/steam, molten salts or air) is heated up to 1200°C. This heat is used to produce steam driving a turbine that generates electricity.

Dish engine
A Dish system is a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point. The sun's rays are concentrated on a Stirling heat engine generating electricity.

Linear Fresnel reflector
This technology works much like the parabolic trough systems, except that is uses flat mirrors that reflect the sun onto water filled pipes placed above the mirrors field. This generates steam which runs a turbine to generate electricity.

Figure 1: The four CSP technologies



Source: (ESTELLA, 2009)

By contrast with the PV modules, the deployment of these CSP systems is subject to geographical constraints. CSP systems firstly require direct sunrays to be efficient. Therefore, they cannot produce electricity in cloudy conditions, and pollution also significantly reduces their efficiency. Moreover CSP systems usually operate on a large scale, and are therefore better suited for on-grid applications. Their deployment is thus constrained by the proximity of the power grid – distant connection being otherwise likely to increase costs substantially. Other geographical factors, such as the erosion of mirrors caused by wind and sand, do not significantly constrain the deployment opportunities and the operating costs. However, as all electricity production plants based on steam generation, water is required for an efficient cooling system.

1.2. Thermal energy storage and hybrid power plants

Due to the intermittent availability of solar energy, a stand-alone CSP plant is not sufficient to generate base load electricity. This problem can however be mitigated by combining CSP technologies with thermal energy storage devices, and/or by hybridizing CSP plants with conventional fuel power generation units.

Thermal energy storage

Storing some of the thermal energy collected by the plant makes it possible to extend CSP production for a few hours after direct insulation is no longer available, thereby better adapting the profile of the power production to the demand, a first step toward utilisation of CSP as a base load electricity. By allowing for a greater dispachability and greater utilisation of the power block (the turbine), which will be used at its maximum capacity, it also reduces the Levelised Cost of Electricity[1] (LCE). A variety of storage systems exist, tailored to each CSP plants. It can be indirect or direct. Indirect storage uses a storage medium which is heated by the HTF. The storage medium can be tanks of molten salts, concrete modules, or phase changing mediums storing the energy in latent heat. Only the molten salts technology is currently commercially exploited, as this technology has already been proven on a large scale. Other technology could lead to reduce LEC cost but the technological uncertainty prevents developers to use it. Direct storage of the steam can also be done, adding from half an hour to one hour extra operation (ESTELLA, 2009).

Hybrid plants

Hybrid plants are a combination of CSP systems and conventional fossil fuel to run the same power block. It allows reducing the financial risk as fossil fuel technology which is very well known mitigates the technological risk. As thermal energy storage, it makes it possible to use the turbine at its full capacity, thereby improving its efficiency and reducing the LCE.

1.3. Comparison of the technologies

Table 1 draws a comparison between the four CSP technologies. The main differentiating factors concern the degree of maturity of the CSP technologies, and their potential applications.

Maturity

Maturity is a first important differentiating factor. Parabolic Trough is the most advanced technology in this respect, its first prototypes dating back from the late 19th century. With an installed capacity 1000MW (1GW) at the end of 2009, it is the only CSP technology that has proved investment and operating costs in commercial operation. However, Parabolic Trough is still at an early stage of commercial deployment as compared for instance with the PV technology (15GW in 2009). By contrast, the other three technologies are immature. Commercial demonstration of Tower technology has started only recently[2], and will require more capacity to prove investment and operating costs in commercial operation. The Fresnel and Dish technologies are even less advanced, and Fresnel is still in the demonstration stage. In each case, only a small number of demonstration projects have been carried out, and reliable information on investment and operating costs is still scant.

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[1] LCE is a cost of generating electricity for a particular system. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital. A net present value calculation is performed and solved in such a way that for the value of the LEC chosen, the project's net present value becomes zero. This means that the LEC is the minimum price at which energy must be sold for an energy project to break even.

[2] While the first very large scale Trough installation (>50MW) is in operation since 2007, the first Tower installation reaching this scale will be completed in 2011

Table 1 Comparison of the CSP technologies in 2009

	Parabolic trough	Tower	Fresnel	Dish
Installed capacity in 2009 (MW)	1000	70	8	0.5
Maturity	• Commercially proven investment and operating costs	• investment and operating costs need wider scale proof in commercial operation	• Recent market entrant, only small projects operating	• Operational experience of first demonstration projects
Application	on-grid	on-grid	on-grid	off-grid/on-grid
Operating Temperature (℃)	350-550	800-1200		750
Plant efficiency	14%	25%		30%
Hybrid compatible	Yes	Yes	Yes	No
Other advantages	• Lowest materials demand	• Storage at high temperatures • Better options to use non-flat sites	• Lower manufacturing costs of flat mirrors	• No water requirements • Easily manufactured
Other disadvantages	• The oil-based HTF restricts operating temperatures to 400℃, resulting in moderate steam qualities			• Projected cost goals of mass production still to be proven

Source (ESTELLA, 2009)

Applications

Tower, LFR, and Parabolic Trough require large-scale installations to run a steam turbine. As a consequence they are appropriate for on-grid application only. By contrast, the Stirling engine of dish units makes it possible to use them on a stand-alone basis, which makes their use possible for off-grid as well as on-grid application. However, in contrast with the other three technologies, the Dish technology cannot be combined with fossil fuels and does not allow for heat storage, which prevents its use for the production of base load electricity.

The technical specificities of each technology also make them more or less competitive for specific applications. As compared with Parabolic Trough, the Tower technology allows storage at a higher temperature – which improves its efficiency – and can be more easily deployed on non-flat sites. The Fresnel and Dish technologies potentially have a cost advantage over Trough and Tower. This must however be balanced with their commercial immaturity in a context where the scale of deployment will drive a large part of the cost decrease. Dish Stirling engine does not require water cooling, while all the technology need water cooling to function at their best efficiency, dry cooling being less efficient.

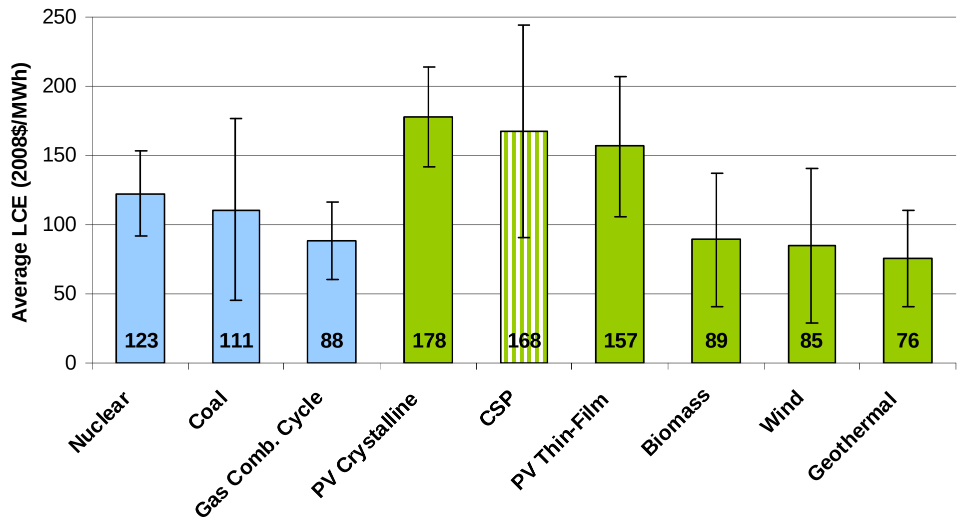
1.4. The cost of CSP electricity

The cost of CSP energy shows important variations from country to country and, within each country, from location to location according to sun energy availability. For example the Levelised Prices of Electricity (LEC) of Parabolic Trough was reported to be 170 $/MWh for an irradiation 2700 kWh/m2,y and 230 $/MWh for an irradiation 2000 kWh/m2,y in 2005 (Dersch et al. 2005). Moreover the LECs depend on other key parameters, such as the size of the plant or the cost of capital. The lack of standards for those parameters also explains why LEC differ from one study to another.

Up to now, most of the available cost information concerning CSP is related to parabolic trough plants in the US as it represents the major part of plants currently in operation. Tower technology is today more expensive but it is expected to be cheaper than trough technology in the short term as more progress remains to be made in technology and scale (Charles et al. 2005).

Figure 2 displays the comparison between the LCE of CSP (with horizontal stripes) and other conventional and renewable energy sources in 2009, based on June 2009 Lazard LCE analysis. Since those LCE vary according the installations, average LCEs have been supplemented with intervals of confidence for each technology. CSP turns out to be the most expensive energy source with PV. However, those two solar technologies are also the one having the biggest cost decrease potential. According to industry sources (see, e.g. CSP Energy outlook 2009) the price has been reduced by around 17% for each doubling of installed capacity, and this trend is expected is expected to continue. Factoring in installation previsions, CSP LCE expected to decrease from 15-23 €cents/kWh in 2009 to 10-14 €cents/kWh in 2020. This cost decrease is driven by higher components production capacities and larger plant scales leading to scale economies, increased competition among the suppliers, and new technologies from learning by doing in the operating plants and the firms R&D. Parity with gas-fired plants is expected around 2020, this figure depending on the countries and the quantity of new CSP installations.

Figure 2. Average Levelised Costs of Electricity (2009)



Source: Lazard (2009)

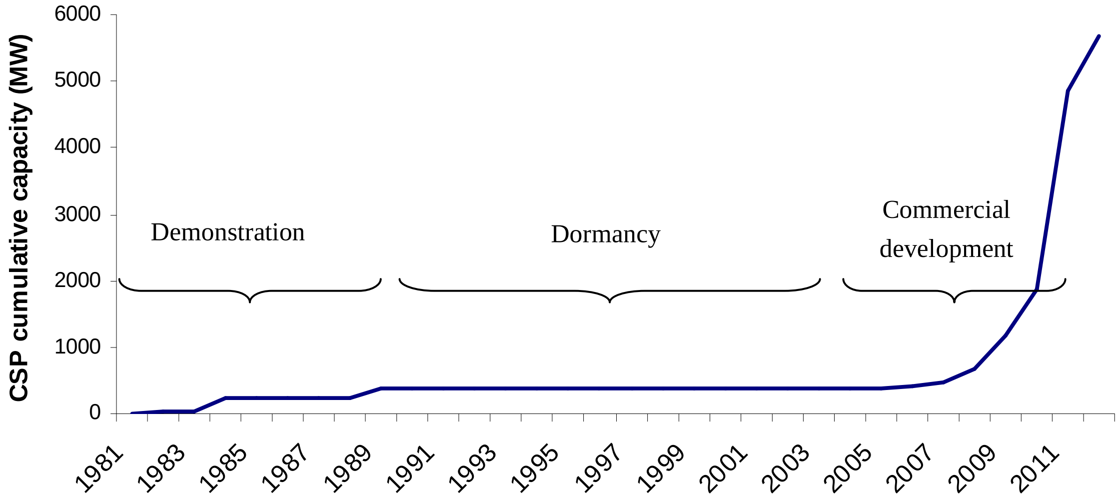
Moreover LEC is not the only parameter to consider for the profitability of installing a power plant. The adequacy of the demand curve and the supply of the plant is also very important, the price of the electricity being much higher during the daily pick of demand. In countries suitable to CSP, it often corresponds to the afternoon when the air con is used, and when CSP electricity production is also high.

2. CSP deployment

2.1. Global deployment of CSP technologies

There have been three stages in the CSP development, as illustrated by the evolution of the global CSP cumulative capacity on figure 3[3]. A first demonstration stage took place between 1981 and 1991. It roughly corresponds to the installation of 9 demonstration plants (called SEGS I to IX) in the U.S.A. by the Israeli company Luz. These nine plants, called SEGS I to IX, all use the Parabolic Trough technology and total up 367MW of installed capacity. A few Tower plants have also been installed in US (Solar One, 10MW), Russia (C3C-5, 5MW), France (Thémis, 2.5MW), Italy, Japan and Spain (1MW) but their capacities are not significant. This first phase has been followed by a long dormant stage, during which CSP installation has been interrupted too place for 14 years. Deployment resumed in 2005 with an important boom. Annual growth rates have been above 40% since them, signalling the beginning of a real commercial development.

Figure 3. CSP cumulative installed capacity and stages of the industries' development



Source: (ESTELLA, 2009) and http://www.nrel.gov/csp/solarpaces/

The demonstration plants deployed before 1991 were then mainly based on the Parabolic Trough technology, and marginally on Tower technology. New projects installed from 2005 to 2009 were also almost exclusively based on the Parabolic Trough technology, reflecting its more advanced maturity as compared with the other technologies. This is illustrated in Table 2, which shows the installed capacity and market share of each technology in 2009, and their estimation for the 2010-2012 period. Interestingly, the deployment of the Tower and Parabolic Dish technologies are expected to take off over this period (from 6% and 0% of total CSP capacity in 2009 to 14 % and 18% of planned installed capacity in the 2010 -2012 period), thereby substantially eroding the domination of the

[3] The 2010, 2011, and 2012 figures feature future installations resulting from projects in development or proposed. Those predictions are reliable as it requires several years to install a CSP plant.

Trough technology (from 93% to 64 %). By contrast, the LFR technology remains too immature to reach the commercial scale in the short term.

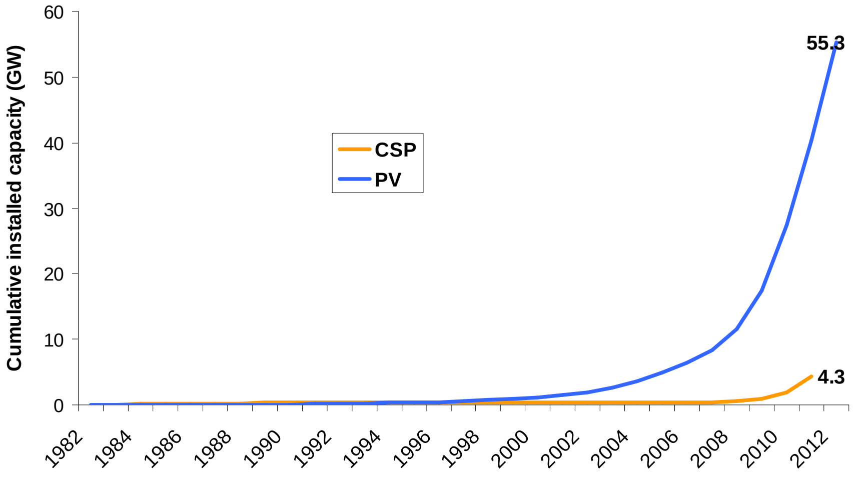
Table 2 Installed and future capacity by technology type in 2009

TECHNOLOGY TYPE	Cumulative Installed capacity in 2009 (MW)	Approximate from 2010 to 2012 (MW)
Parabolic trough	1,098 (93%)	2,866 (64%)
Solar tower	71 (6%)	645 (14%)
Dish	0	800 (18%)
Fresnel	8.4 (1%)	177 (4%)
Total CSP	1177	4,488
Total PV	17,356	38,000

Source: National Renewable Energy Laboratory website (http://www.nrel.gov/csp/solarpaces/) and (ESTELLA, 2009)

It is worth noticing that the deployment of CSP technology remains very limited as compared with the evolution of PV capacities over the last decades. Figure 4 compares the cumulative installed capacities of PV versus CSP between 1982 and 2012. It shows that the large-scale deployment of PV capacity has started around 2000, nearly a decade before that of CSP. The PV industry has then experienced a fast growth and an accelerated maturing process. As a consequence, the PV installed capacity is expected to be more than ten times that of CSP in 2012. This counterfactual highlights the growth potential of CSP in the next decades, the drivers of CSP cost decrease being related to cumulative capacities as well as for PV. However it also raises questions as to the causes of the late start of CSP deployment. It is indeed not obvious that PV technology was more mature than CSP technology is the 1990's. Other factors must be considered that concern the geographical and policy drivers of CSP deployment.

Figure 4. CSP versus PV cumulative installed capacities (1982-2012)



Source National Renewable Energy Laboratory website (http://www.nrel.gov/csp/solarpaces/), (ESTELLA, 2009), EPIA (2009)

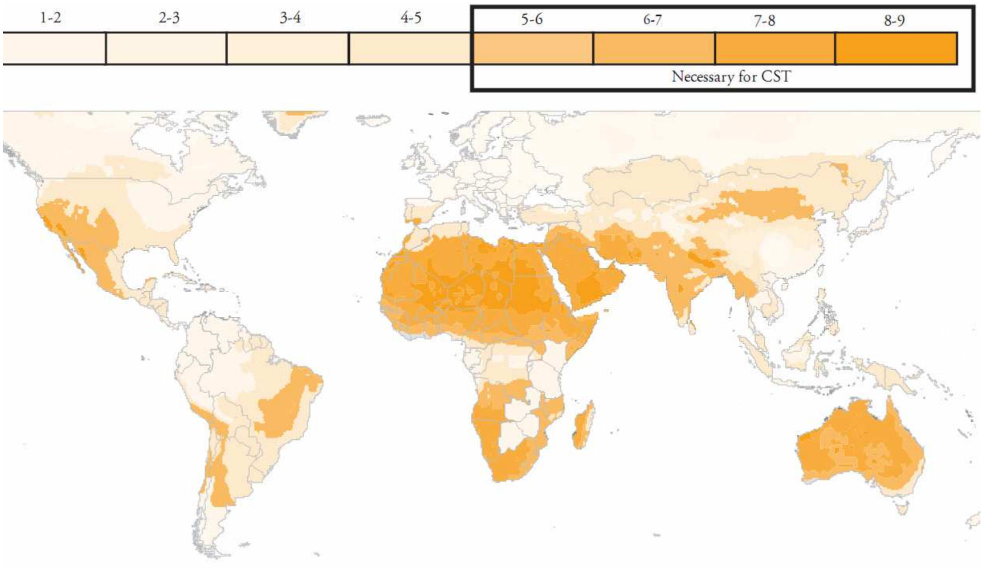
2.2. The drivers of CSP deployment

Like for PV, the LCE of CSP technology is higher than those of conventional energy sources (see Figure 2 above). Policy measures such as feed-in tariffs are thus necessary to trigger their deployment until further cost decreases make it possible to reach grid-parity. In addition, the possibility of deploying CSP installations is also constrained– much more strongly than for PV – by geographical factors.

Geographical conditions

The geographical extension of CSP installation is indeed naturally limited by the important amount of direct sunrays required. Direct sunrays shall not be deviated by clouds, fumes or dust in the atmosphere so as to reach the Earth's surface in parallel beams for concentration. Suitable sites for CSP deployment are those that get a large quantity of such direct sunrays - at least 5 kilowatt hours (kWh) of sunlight radiation per square metre per day. The best sites receive more than 2,800 kWh/m2/day.

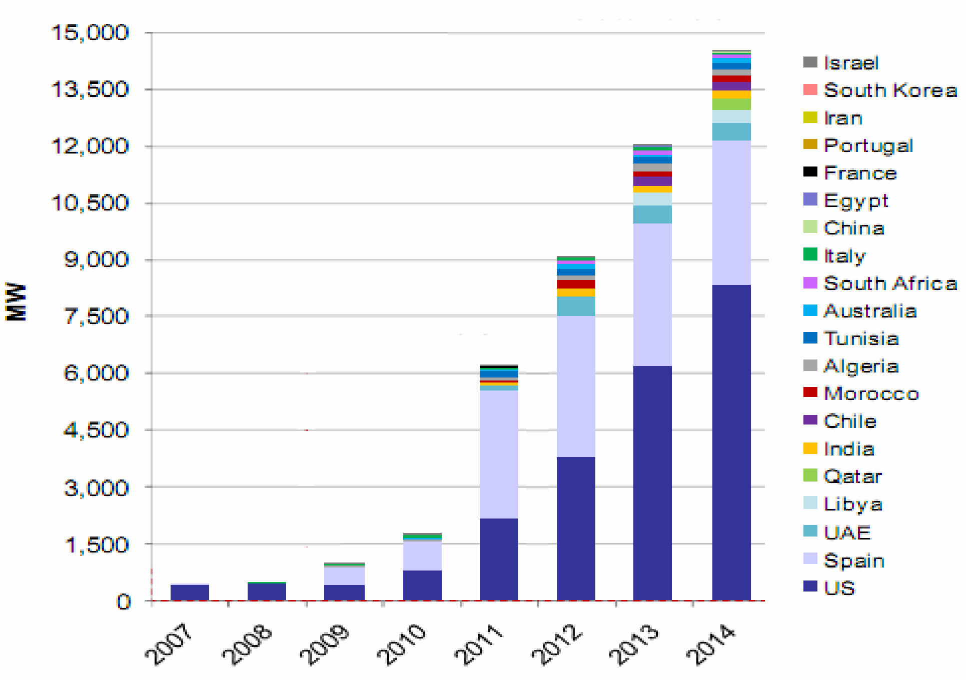
Figure 5. Global Direct Normal Solar Radiation (kW/m2/day)



Source World Resources Institute (2009)

Figure 5 shows the direct normal solar radiation repartition in the world. The most appropriate regions for CSP deployment are those without large amounts of atmospheric humidity, dust and fumes. They include steppes, bush, savannas, semi-deserts and true deserts, ideally located within less than 40 degrees of latitude north or south. Consequently, the most promising areas of the world include countries in both the developing (Chile, Northern Africa, Middle East, Brazil, and parts of India and China) and industrialized worlds (Southwest US, Australia, and Spain).

Figure 6. Installed capacity by country



Source Emerging energy research (2009)

Against this background, the past and current deployment of CSP capacity has taken place only in industrialized countries. As illustrated in Figure 6, past commercial investments actually only took place in the United States and Spain, in comparable proportions. Deployment is only starting in the developing world, and in very small proportions as compared with the on-going trend in the U.S.A. and Spain. The observe discrepancy between the potential and actual deployment is mainly due to the difference of incentive policies used to develop the CSP installation.

Policy conditions

As often for new technologies, and for most of current renewable energies such as wind or PV, the price of CSP electricity is too high to compete with traditional energy sources. This would prevent any development of the industry, market decisions following short-term views, while it can be profitable in the longer term, especially if environmental externalities are taken into account. Therefore governments create incentive policies to enhance the development of the industry. Some, as pollution taxation, aim at correcting market failures such as environmental externalities. Others directly aim at stimulating a specific industry.

The measures aiming at directly stimulating the CSP industry are upstream measures such as public R&D or demonstration projects, or downstream measures stimulating the market. Among those downstream measures, besides different tax credit like in the US (30% Investment tax credit, refundable), the two other instruments that have been proven efficient are Feed In Tariff (FIT), and Renewable Portfolio Standard (RPS), where the financial burden falls upon the utility customers rather than the tax payers, as the extra cost is charged to the power network users.

- In Europe, FIT set fixed guaranteed prices at which power producers can sell renewable power into the electric power network: it's an obligation for electricity suppliers to buy renewable energy. Such FITs are implemented in Portugal, Spain, Greece, France, Italy, and Germany for solar power. However Spain is the only country having enough sun power to install CSP plants, in the other countries those FIT essentially benefit to the PV industry.

- In the US, RPSs require that a minimum percentage of power sold or power capacity installed be provided by renewable energy sources. In both cases the extra cost is charged to the power network users. For example, in California, utilities have to sell electricity with 20% of renewable by 2017, in Nevada, 15% by 2013, and in New Mexico, 10% by 2011. To reach those goals, the Utility Firms have to negotiate Power Purchase Agreement (PPA) with owners of renewable energy plants such as CSP plants.
- The other countries where solar resource is suitable have not significant CSP installations because they lack of efficient incentive policy. The US and Spain are the only countries combining adequate solar resource and effective incentive policy (other European countries have incentive policies that works for PV but not the adequate solar resource).

The various incentive policies carried out in each country also explain why the commercial deployment has started earlier for PV technology than for CSP. During the early stages of PV development, the market was chiefly driven by two countries – Germany and Japan – which were the first ones to set strong incentive policies for solar energy. However, direct solar radiation in these two countries is not sufficient to make CSP technology profitable, which explains why only PV benefited of those incentive policies. The CSP industry started its commercial development only in 2006 when US and Spain, having enough direct solar radiation for CSP technology, started implementing strong incentive policies.

Further deployment of CSP, especially in developing countries, will in turn depend on the implementation of appropriate incentive policies. This is illustrated in Table 3, which summarizes the potential for CSP deployment in 2020 according to two different policy scenarios (IEA, 2007; CSP Energy outlook 2009). The first (business-as-usual) scenario only takes into account existing policies and measures, while the second one also factors in policy measures that were either under way or planned in 2009[4]. Although the results should be considered with caution, they suggest an important impact of enhanced policies, with a cumulative capacity in 2020 ten times higher in scenario 2 than is scenario 1. The difference is due to enhanced deployment in the U.S.A., but also to stronger deployment in Asia, Middle East and Latin America.

[4] The second scenario also assumes increased investor confidence in the sector due to a successful outcome of the current round of climate negotiations.

Table 3. Worldwide allocation of CSP capacity in 2020: business-as-usual versus enhanced policies

	Share of world cumulative capacity		
	2010	2020 Scenario 1 (business as usual)	2020 Scenario 2 (enhanced policies)
WORLD	0.9GW	7.3 GW	68.6 GW
Europe (EU 27)	41.4%	42.0%	10.0%
North America	57.7%	24.0%	37.0%
Latin America	0.0%	1.5%	3.2%
Developing Asia	0.0%	0.0%	3.8%
India	0.0%	0.4%	4.0%
China	0.0%	0.4%	12.0%
Middle East	0.5%	8.4%	13.0%
Africa	0.0%	15.2%	5.8%
OECD Pacific	0.3%	6.5%	4.1%

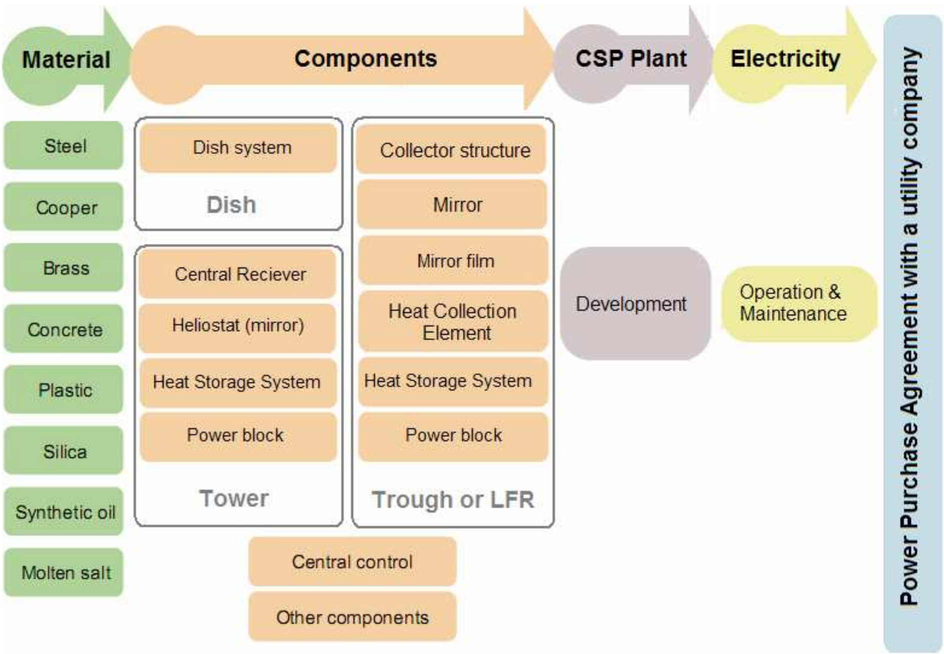
Source: CSP Energy outlook 2009, National Renewable Energy Laboratory website (http://www.nrel.gov/csp/solarpaces/)

3. Organization of the CSP industry

3.1. The supply chain of the CSP industry

CSP is in competition with fossil fuel and other renewable sources of energies – including PV technologies – for the generation of electricity. It however relies on a specific technology, entirely different even from solar PV, with its own constraints and opportunities. Therefore, the production and installation of CSP power plants is organized as a specific industry, which we can analyze as such. Since the CSP technology is far from having reached full maturity yet – the first U.S. demonstration plants dating back only from the 1980's – it is important to keep in mind that the CSP industry is still nascent. It can be expected to grow and change significantly in the future in the trail of wider CSP deployment, as did the solar PV industry during the last decade (De la Tour et al., 2010).

Figure 7. CSP industry supply chain



Source Authors

Figure 7 depicts the supply chain of the CSP industry, from the raw materials that are used to manufacture the components of the CSP plants, to the development and exploitation of these power plants. Raw materials are commodities and therefore do not affect the organization of the core of CSP industry. On the other extreme, the energy market is the locus of competition of CSP with other forms of power generation.

Four links can be identified:

- The raw materials are used to manufacture the components of the CSP plants. They are commodities, and therefore they do not affect the organization of the core of CSP industry.

- The various components of CSP plants account for around 80% of the installation cost of a CSP plant (Müler & Steinhagen 2008). They are therefore the main driver of the LCE, and a critical link in the organization of the CSP supply chain.
- Project development is another key link of the CSP supply chain. Since there is no fuel cost involved in the CSP LCE, the initial investment (components and indirect costs) indeed represents more than 99% of the LCE (Charles et al. 2005). This represents a huge investment (400 million USD for a 50MW CSP plant in Spain with heat storage) which, combined with the uncertainty on the technology and on the incentive policies, raises substantial barriers to entry.
- The Operation and Maintenance (O&M) of the plant represent less than 1% of the LCE (Charles et al. 2005). They are carried out by the developer or by a firm trained by the developer. The electricity is then sold to a utility company trough a Power Purchase agreement (PPA) or a feed in tariff, setting a price at which the electricity will be bought for a defined amount of time.

The CSP technology is chiefly structured around two segments – the manufacturing of components and the project development – that play the key role in the success of CSP deployment. We therefore focus the subsequent analysis on these two segments.

3.2.CSP plant development

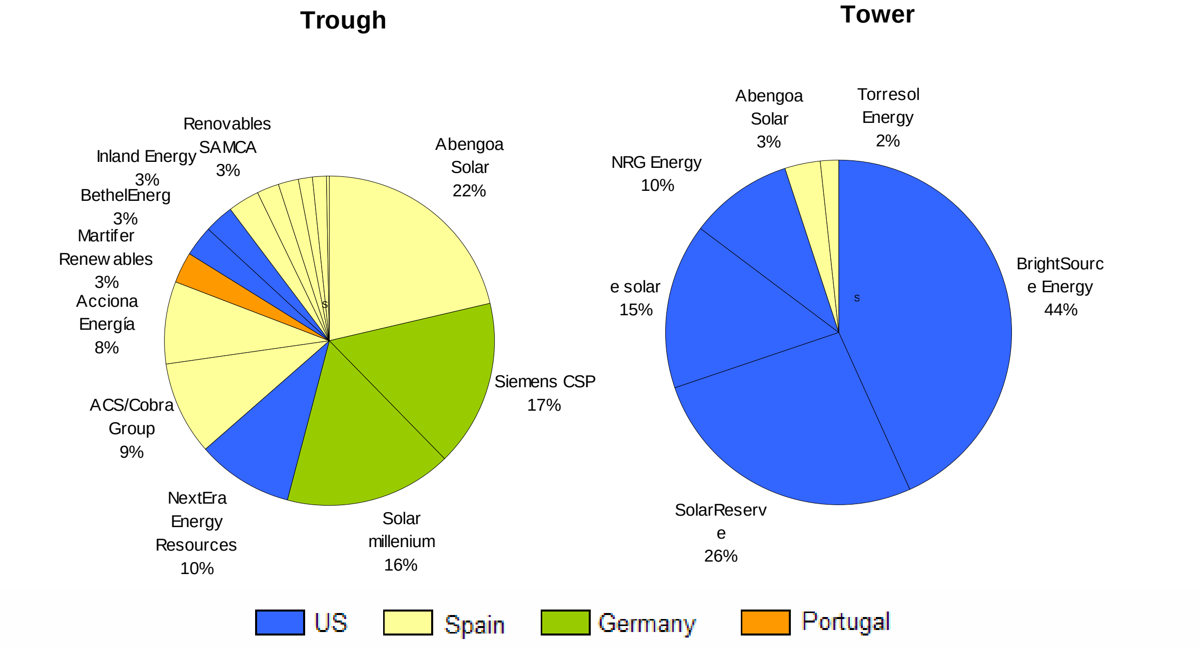
The installation of a CSP power plant requires both technical and financial resources. It is usually organized around specialized CSP developers that provide technical expertise on CSP technologies. These firms are however too small to bear the long-term investment (400 million USD for a 50MW CSP plant in Spain with heat storage) required for a CSP plant, in a context of uncertainty on the technology and the incentive policies. Against this background, the development of CSP plants is usually supported by a consortium of several companies, combining complementary expertise and resources:

- A developer, bringing the expertise and know how in CSP technology, and sometimes manufacturing some components.
- A major construction company, which will be the Engineering, Procurement and Construction (EPC) contractor, taking the leadership of the consortium and guaranteeing the price, performance, and schedule of the project. Only big companies can provide such guarantees, and in most of the cases from the country where the plant will be installed.
- Investors which can be public utilities, banks etc.

CSP development market concentration

Figure 8 represents the main developers in the Tower and Trough technologies and their expected market shares in 2012, the colours representing the countries where they are localized. It is based on the plants already installed or the projects in development or proposed. Those predictions are reliable as it requires several years to install a CSP plant. There are also other companies involved in this segment, but as they have not installed commercial scale CSP plant yet and do not plan to do so before 2012, they are not represented. You can refer to annex 1 to have a list of those companies.

Figure 8. Trough and Tower main developers, and market shares for the expected cumulative installed capacity in 2012



Source 1 National Renewable Energy Laboratory website (http://www.nrel.gov/csp/solarpaces/) and authors' research

The development of plants using the Trough technology involves a large number of actors. However, the three biggest firms represent 57% of the expected Trough installations in 2012, so that the market remains concentrated according to usual economic standards (with a HHI[5] of 0.13). This does not mean that the industry is not competitive for it is still immature and thus expected to develop. There are for instance several new entrants currently developing small demonstration projects that are not reported on Figure 8. The geographical repartition of developers reflects the countries where CSP technology has already been deployed. Spanish firms will have developed 49% of the Trough plants in 2012, German and U.S. firms accounting respectively for 33% and 17%.

The development of plants based on the Tower technology involves different actors that are much more concentrated. The three biggest firms represented 85% of the market in 2012 (with a global HHI of 0.29). The geographical concentration is even more stunning, US firms being expected to have developed 95% of the Tower CSP plants installed in 2012. The other two technologies involve even fewer developers: Areva (ex Israeli company Ausra) and Tessera Solar (subsidiary of the US company Tessera) are almost in monopoly positions in respectively the LFR and Dish industries.

Rather than a lack of competition, the significant concentration of CSP project developers reflects the immaturity of the CSP technologies. This is clearly confirmed by comparing the technologies: the number of identified

[5] The Herfindahl-Hirschman Index (HHI) is defined as the sum of the squares of the market shares of the largest firms within the industry, where the market shares are expressed as fractions. The result is proportional to the average market share, weighted by market share. As such, it can range from 0 to 1, moving from a huge number of very small firms to a single monopolistic producer

developers for each technology is indeed proportional to their respective maturity – with Parabolic Trough ahead of the other technologies, Tower in an intermediate position, and LFR and Dish technologies as laggards.

Know-how diffusion and emergence of new developers: the role of Luz

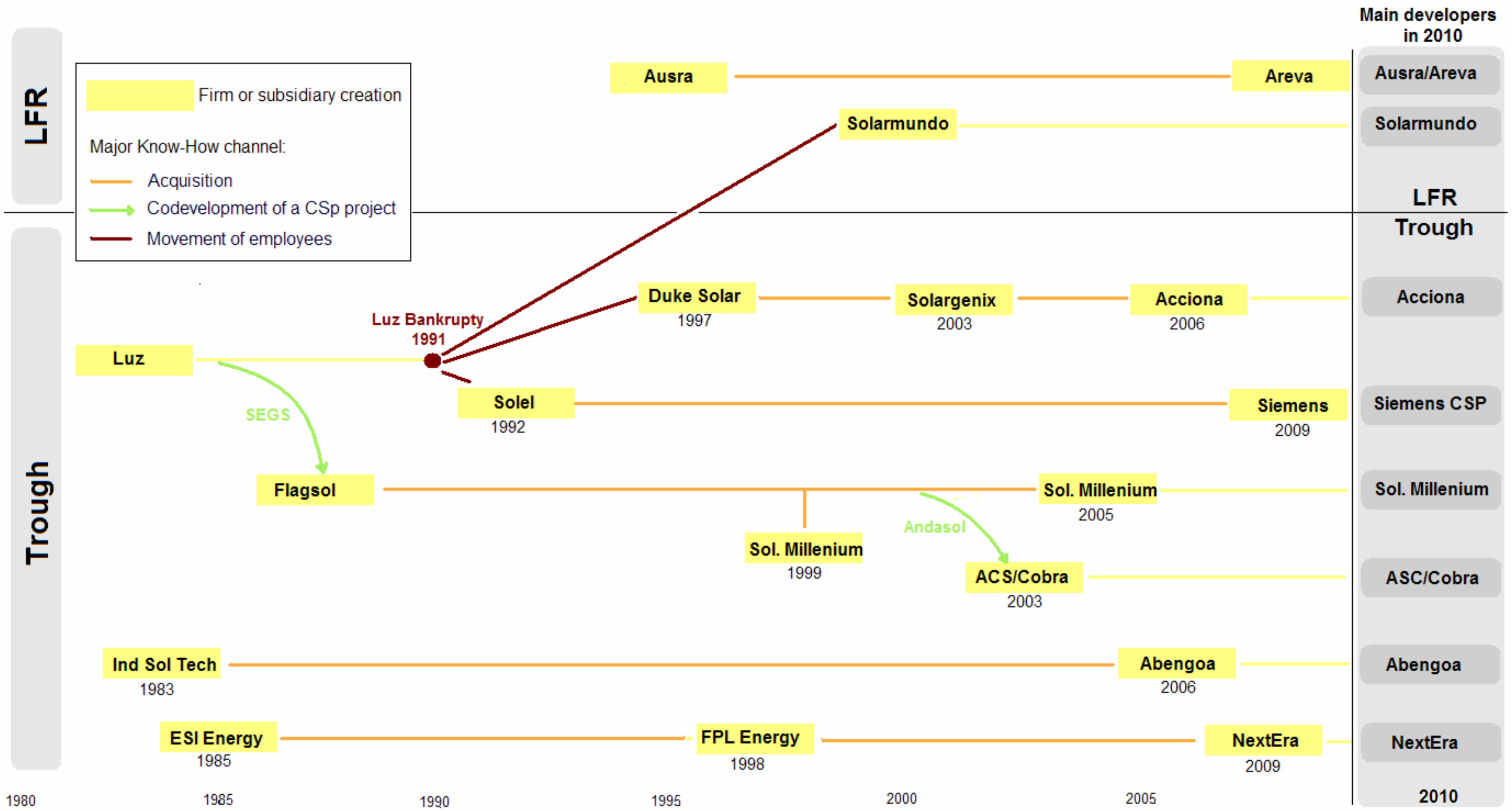
Parabolic Trough offers the most advanced example of emergence of new developers as the technology improves in maturity and becomes more widely adopted. Interestingly, this trend can to a large extent be related to the progressive diffusion of technical know-how originating from the pioneer developer of this technology in the early 1980's, the Israeli-US company Luz. This company successfully developed and constructed the first SEGS CSP plants in California between 1981 and 1991, thereby accumulating experience that would later benefit the rest of the industry.

Figure 9 summarizes the history of CSP developers in relation with Luz, and illustrates more generally the process of emergence of new developers through technology diffusion. In 1991, LUZ filed for bankruptcy, being unable to finance the construction of its tenth plant due to delays in the signing of the California solar property tax exclusion. The know how accumulated by Luz in one decade then spread all over the world through acquisitions but also the circulation of workforce, leading to the creation of several new CSP firms:

- Solel Solar Systems bought the assets in 1992 and could thus be called the « successor » of Luz. It is based in Israel and financed by Pixy Investment (H. Wenzlawski 2003). Its core technology is the HCE. It is in 2010 the only HCE manufacturer with Schott. Solel has been bought by Siemens in 2009 and is now called Siemens CSP.
- Acciona Solar Power was created in 1997 by key executives from Luz (it was initially named Duke Solar, and then Solargenix Energy after successive acquisitions). Its core technology is the SCA, the structure of the trough collector system.
- Solarmundo has been co-funded by the former president of Luz. It develops plants using the LFR technology.

Project co-development has been another channel of the diffusion of the know how accumulated by Luz. Before it went bankrupt, Luz co-developed a CSP project with Flagsol (which later became Solar Millenium) during the 1980's. In turn, later project co-development involved the transfer of know how form Solar Millennium to ASC/cobra, which has now become the second CSP developer in Spain.

Figure 9. History of the developers market



Source Authors researches

Entry of new developers: barriers and recent trends

The emergence of new developers, as well as the growth of current developers, will be related to the continuation of CSP deployment, and therefore depend to a large extent on the adoption of incentive policies in the countries where CSP can be an efficient source of energy. However, there are other barriers to entry, related to the technology maturity, the access to expertise and access to capital.

Technology uncertainty is an important barrier that will progressively be alleviated as CSP technologies become more mature. This is especially the case for the more mature Trough technology, and to a lesser extent for the Tower technology – which investment and operating costs are currently in the process being commercially proven. Although some technologies developed by historical actor such as Luz stand as references in the industry, there are however no official standards yet guaranteeing a good quality, which is a deterrent for financial investors. This forces new players to build costly demonstration plants before developing large commercial scale plants. It also slows down some new technologies development as new storage systems or LFR systems as they have not been proven commercially interesting.

There is no patent or secret high technology process preventing a new firm to enter the market, but rather some know how required to install the CSP plants. This know how is generally acquired through the development of demonstration plants. As illustrated by the past process of diffusion of the expertise initially acquired by Luz, it can however also diffuse between firms trough project co-development (e.g. the construction company ASC/Cobra having co-developed Andasol with solar millennium and developing project now on its own), joint ventures (e.g. Masdar acquiring Seners' experience through their JV Torresol), or acquisitions (e.g. Areva buying Ausra).

The huge investment required to install a CSP plant (400 million USD for a 50MW plant) remains an important barrier for small firms, all the more so as policy and technology uncertainty is a deterrent for financial investors. Against this background, major international companies seem to play an increasing role, as illustrated by the acquisition of Solel by Siemens, or Ausra by Areva. Such large companies have indeed the financial strength to carry out long term a sustainable development in the long run. In line with this entry of big companies, another trend features integration between developers and EPC contractors, leading to the emergence of larger developers. Such integration can result from acquisitions of pure developers by EPC contractors (e.g. Areva buying Ausra), or from a learning by doing process whereby the EPC contractor co-develop the CSP projects (e.g., ASC/Cobra with Andasol) before developing their own project as a second step. With the know-how and the financial strength being gathered, such integrated actors can propose turn-key power plants with development, EPC and O&M services, and guarantee.

These evolutions do not seem to modify the geographical repartition of the industry, which remains located in industrialized countries with a single exception: Masdar in Abu Dhabi. Israel, where the pioneer firms Luz and Solel were coming from, is now loosing ground. By contrast large companies from Germany (Siemens) and France (Areva) are entering the market through acquisitions. Abu Dhabi's company Masdar owns 40% of Terresol, a Joint Venture (JV) with the Spanish Sener which has developed three Tower plants in Spain. Masdar is now developing CSP firms on its own in Middle East, and its first plant, Shams 1, is expected to start production in 2010. Masdar, Japan's Cosmo Oil Company and the Tokyo Institute of Technology have launched an advanced CSP Central Tower research and development project at Masdar City[6].

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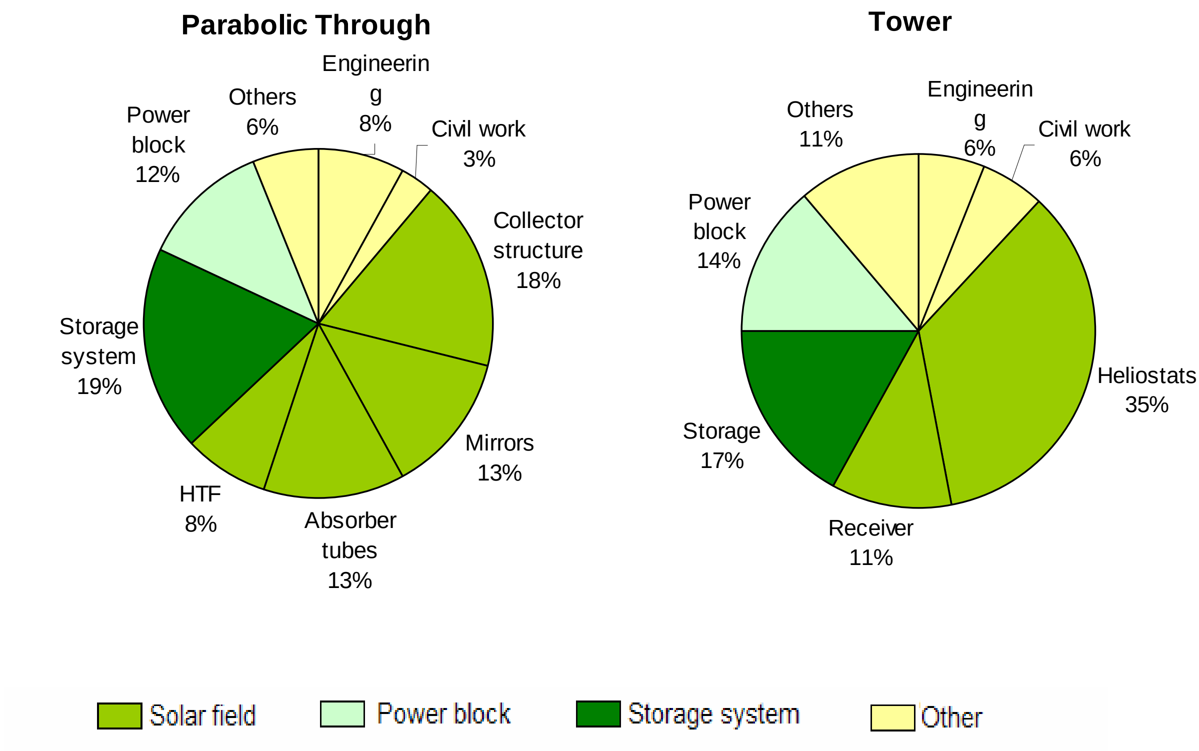
[6] http://social.csptoday.com/weekly-brief/weekly-intelligence-brief-january-18-25

3.3.Component manufacturers

The Dish and LFR technologies still being at an early development stage, there has been no feedback yet from demonstration plants that would make it possible to assess their cost structure. Consequently, we will focus the discussion on the more mature Parabolic Through and Tower technologies, for which reliable information on costs is already available. Figure 10 represents the cost breakdown of a CSP plant installation for these two technologies. As already mentioned, the prices of the components (solar field, storage, and power block) account for around 80% of the cost of a CSP plant installation in both cases. This component cost is evenly spread between 4 to 6 core components according to the technology. Hence there is not one particular bottleneck in the cost structure of these technologies, and all components offer a significant potential for further cost decreases.

Figure 10. Cost structure of Tower and Parabolic trough in 2008 (source: Müller-Steinhagen, 2008)



Market concentration

It is expected that future cost reductions will be driven by innovation and the development of competition in each component market as the scale of CSP production increases. Observing the past and current competition in these markets provides a first hint about potential competition in the future. Table 3 displays an approximation of the market shares of component suppliers, based on the plants in operation or in development for which the identity of component suppliers is available[7]. For every element, the proportion of installed capacity for which information was available is précised under the component's name. First generation plants (before 2005) have not been taken into account to represent situation of the current market. The small number of suppliers in each

[7] Indeed, while information on the projects' developer is always disclosed, information on the component manufacturers is not available for all the projects. If it doesn't give an exact market share repartition, it is nevertheless interesting to look at those figures as it gives a good approximation of the market concentration and the major actors.

component market suggests that these markets are still very concentrated, thereby reflecting the relative immaturity of the industry. Companies which have not a significant activity are not represented but you can refer to annex 1 to have a list of those companies.

The most mature technology – Parabolic Trough – is also the one in which suppliers are the most numerous. The least concentrated segment is the Solar Concentrator Assembly (SCA), which consists in building the structure of the collector holding the other core components. The other core components are the mirrors and the Heat Collection Element (HCE) – the tube that absorbs the heat. For those last two core components, concentration is higher than for the SCA. This may be due to technological barriers to the manufacturing of curved mirrors and especially HCE. Indeed the manufacturing process remains secret and is only mastered by Siemens CSP (ex Solel) and Schott.

Table 3. CSP components manufacturers and market shares

Trough		
SCE 32%	Solar Millennium (DE)	41%
	Acciona Solar Power (SP)	20%
	Abengoa Solar (SP)	13%
	Cobra (SP)	11%
	Ingemetal (SP)	8%
	Solel (IL)	4%
	Iberdrola (SP)	3%
	Parker-Hannefin (US)	0%
HCE 26%	Solel (IL)	58%
	Schott (DE)	42%
Mirror 45%	Flabeg (DE)	80%
	Rioglass (SP)	17%
	Solel (IL)	3%

Tower		
Receiver 72%	Babcock Power (US)	61%
	Pratt & Whitney (US)	37%
	Sener (SP)	2%
Heliostat 42%	Pratt & Whitney (US)	63%
	eSolar (US)	25%
	Abengoa Solar (SP)	8%
	Sener (SP)	4%
Dish		
Dish 100%	Stirling Energy Systems (US)	100%
LFR		
Receiver 99%	Areva (FR)	99%
	Novatech Solar	1%
Drive 99%	Areva (FR)	99%
	KKK-Siemens	1%

Source National Renewable Energy Laboratory website (http://www.nrel.gov/csp/solarpaces/) and authors' research

The stronger concentration of component suppliers for the other three CSP technologies reflects their lesser maturity. Several suppliers exist for the tower technology, but this market is still very concentrated for the core technologies (heliostats and central receiver) – the three main identified suppliers accounting for more than 90% of the installed capacity. As regards the least mature technologies, Dish and LFR, the component suppliers we identified appear in a monopoly position (Stirling Energy Systems for the Dish technology and Areva for LFR).

Like for developers, it is worth noticing that the CSP components manufacturers are located in the countries where CSP plants have already been installed: Spain (SP), Germany (DE), and U.S.A. In the Trough industry, the market for SCE is dominated by Spanish and German companies. The market for HCE and mirrors is dominated by German firms. U.S. companies account for almost controls all the supply of Tower components, the remaining market shares being detained by Spanish firms. U.S. firms also control the Dish manufacturing market. The market for LFR components appears as a recent exception, since the leading identified equipment supplier is the French Areva, which acquired the US firm Ausra in February 2010.

Entry of new manufacturers: barriers and recent trends

Since the small number of components manufacturers mainly reflects the early age of the CSP industry, it does neither necessarily imply that the CSP industry is not competitive, nor that competitive pressure will not increase in the future. The various CSP technologies are indeed substitutable with each other, and therefore they are subject to cross-technology competitive pressure. Similarly, the prices of CSP components are likely to be disciplined by the competition of other forms of energy generation, including large solar PV. Finally, the larger number of suppliers in the Parabolic Trough segment suggests that further technology deployment is likely to trigger the entry of new competitors in the concerned countries.

Potential barriers to entry include technological barriers and market visibility. CSP core technologies are either new (DISH, LFR), or difficult to imitate (HCE, mirrors, central receiver). However, there are no important CSP components protected by valid patents (H. Wenzlawski 2003) that could prevent further use or development by other industry participants. The technology is then rather protected by secrecy or lead time. Given the limited maturity of the technologies and the weak visibility on incentive policy schemes in many countries, market uncertainty still constitutes an important barrier to entry, especially for small firms. Against this background, it may indeed be easier for large firms or their subsidiaries to sustain long-term investments in the sector.

Depending on the segments, component suppliers currently include specialized firms as well as large multinational companies such as Siemens, Areva or Pratt & Whitney. While the smaller firms are usually historical actors of the sector or , large companies are either well-known specialists that have entered the market for components (Siemens, or more recently Saint Gobain for the mirrors) or long-term investors that enter the market for CSP technologies through the acquisition of specialized firms (such as Areva in the LFR technology). Following the example of the solar PV industry, it can be expected that new component manufacturers will enter the market – and contribute to cost reductions through enhanced competition – as CSP deployed goes on, thereby enabling large scale production of standardized components.

3.4. The CSP industry in France

The French involvement in the CSP industry started in the 1980's with the construction of Themis, a 2.5 MW demonstration plant in Targasonne, in the south west of France. It has been operating from 1983 to 1086 but the project has been then left ahead. The French industry has not benefited of this early know-how and no French firm has been involved in the CSP business until recently. As of today, the French CSP industry is still nascent as compared to the U.S.A. and Spain, where the main CSP plants are located, but also compared to Germany were as in France, there is not enough direct solar radiations. This last point proves that it is possible for a country to develop a CSP industry even if there is no national market. The Mediterranean Solar Plan (MSP) and Desertec might be an occasion for French energies companies having high financial capabilities to accumulate know-how in the solar industry.

Components

St Gobain is the only French firm that has been really active in the CSP components manufacturing. It has already been supplying heliostats (flat mirrors for tower plants), and built in 2009 a new production line to manufacture parabolic mirrors to for Trough projects. St Gobain aims at providing 30% of the post 2010 trough market. It entered the DeserTech consortium in mars 2010.

Areva, a big French international firm having its core business in nuclear plants development, EPC, and O&M, bought Ausra in 2010. Ausra, start-up created in 2006, was the world leader in the LFR CSP technology. This acquisition was based on the synergy of Areva having an important expertise in steam generation, electricity production from turbine, and energy storage due to its nuclear activities, and Ausra's LFR technology and know-how concerning CSP installation. Besides, Areva will bring the financial strength necessary to attract investors that were reluctant to sign several hundreds million dollars contracts with the small firm Ausra (70 employees). Areva’s objective is to make global and comprehensive offers combining Ausra’s LFR technology, Arevas expertise in energy storage, and Areva’s worldwide experience in EPC and O&M services. Areva also tried to buy Solel in 2009, but they lost the bid which was won by Siemens.

Thermodyn, based in France, produces steam turbines for the CSP industry. Although located in France, it is a now a subsidiary of General Electric Oil & Gas.

Babcok Wanson, a French company, has been active in the industrial boiler and heat process business since 1898. It belongs to the French group CNIM. The company started in 2010 the construction of a prototype of LFR module at La Seyne sur Mer. The prototype should be ready for operation in May 2010.

Other firms plan to enter the CSP market but none is actively involved yet. Alstom, the world's third-biggest coal-fired power-plant builder manufactures turbines that are too big for the CSP industry. But the group is interested in this market and, like Areva, also tried to buy Solel[8]. Alstom plans other acquisitions and is already members of ESTELA, the European CSP industry association. It funded the venture capital Aster Capital with Schneider Electric to take minority interests in innovative start-ups based in Europe, North America and Asia[9].

Development

Having bought Ausra, Areva is now a leading developer in the LFR CSP technology.

Solar Euromed, an engineering consultant company, has been created in 2007 by a former employee of Alstom who had worked on several CSP projects and has a good knowledge of electricity generation from steam. It is developing a 12 MW LFR project in Corsica called Alba Nova 1, which will be completed in 2011. This demonstration plan aims at proving the commercial interest of the technology. Solar Euromed also signed an 8 billion dollars contract with Sudan to develop, build, and operate a 2 GW installation. This should be ready in ten years, with the first MW produced in 2012.

EDF also have some interests in the Industry. EnXco, an Edf Energies Nouvelles’ subsidiary, is currently in late stage discussions with leading CSP technology providers, and is actively exploring the potential of a number of private and federal land sites for the development of solar energy plants[10] in the US.

R&D

The Commissariat à l’Energie Atomique (CEA) carries out researches on some core technologies such as heat transfer materials and heat storage. The Centre National de Recherche Scientifique (CNRS), together with Total and EDF, rebuilt the Thémis Tower plant to develop new technologies. This old plant is now a research project called Pégase. Total is also doing some research on core components, as is Euromed. R&D does not concern

[8] http://www.bloomberg.com/apps/news?pid=20601090&sid=aiCHEHhciIKQ

[9] http://www.renewable-energy-sources.com/2010/01/20/alstom-and-schneider-electric-with-venture-capital-fund-for-innovative-technologies-for-energy-and-environment/

[10] http://www.enxco.com/solar_energy_csp.php

much the industrial application, for the French industry is not active yet. It rather concerns core components or new technologies (as high temperature receptors). There is a first stage of upstream research and then demonstration plants as in the Pégase project, or the LFR project from Euromed in Corsica.

4. Summary

There are four different types of thermal CSP technologies, all of which consist in focusing sunrays to boil water, which is then used to generate power. They are meant to operate on-grid in power plants, and can be combined with heat storage devices of fossil fuel power generation units so as to generate base-load electricity. By contrast with solar PV technologies, these technologies are still immature. The most mature one, Parabolic Trough, has already commercially proven investment and operation costs. The Tower technology is still in this commercial demonstration stage, while the two remaining technologies – Dish and Fresnel – have not started demonstration of large scale projects yet. The levelised cost of electricity (LCE) of these technologies is close to that of solar PV, and thus neatly above the cost of conventional fossil-fuel and renewable energies. However, the cost of solar energies are also the ones having the biggest decrease potential, this drop being correlated to the installed capacity increase. Solar PV and then CSP are expected to reach grid parity before 2020 according to the deployment forecasts. By contrast with PV, CSP operation however requires direct sunrays to be efficient, which limits the geographic areas where they can be exploited.

Although the first demonstration plants date back to the 1980s, the commercial deployment of CSP has started only very recently (1177 MW in 2009, as compared with more than 17 MW for large PV). It mainly concerned the more mature Parabolic Trough technology (93% of installed capacity in 2009), although the Tower and Dish technologies are expected to gain market shares in the next two years (respectively 14% and 18%). So far, CSP deployment has taken place essentially in two industrialized countries: Spain and the U.S.A. Indeed these two countries are the only ones combining attractive policy schemes and sufficient sun exposition (direct sunrays). Future CSP deployment in some developing countries (Chile, Northern Africa, Middle East, Brazil, and parts of India and China) will depend on the adoption of policies such as fee-in tariffs.

Large up-front investments required for the plant installation account for more than 90% of the CSP LCE. They mainly reflect the cost of components (80% of the installation cost). Against this background, the CSP industry is structured around two key categories of actors: component manufacturers, and the consortia – associating expert CSP developers, construction companies and financial investors – that take in charge the development of the plants. These firms are localized in the industrialized countries, especially the United Stated and Spain, which already started operating CSP plants. Both developers and project developers are strongly concentrated, what reflects the immaturity of the technology rather than a lack of competition. Recent trends feature an increase in the number of players in the most mature technology segment (Parabolic Trough) along with the entry of large equipment (Siemens), energy (Areva) or construction (ASC/Cobra) companies, mostly from industrialized countries. These companies are able to acquire the required technological know-how through acquisitions or joint project development, and are better equipped to undertake long term investments in a context where the uncertainty on technology maturity and policy support are a deterrent for financial investors.

Despite the early development of a demonstration plant in the 1980’s (that was subsequently abandoned), the French CSP industry is only starting its development. In 2010, Areva (LFR technology) and Saint Gobain (mirrors) are the two most prominent actors, but their involvement in CSP is recent.

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Annex: List of main companies involved in CSP

Source: CGGC (2008) and Emerging energy research (2010)

CSP Developers

- *Technology Promoters and System Integrators*

Abengoa Solar
ACS Cobra
Aries Solar Termoeléctrica
Areva (Ausra)
BrightSource Energy
eSolar
Grupo Sener
Lloyd Energy Storage Ltd.
NOVATEC Biosol
Siemens CSP Ltd. (formerly Solel Solar Systems)
SkyFuel
Solar Millennium
SolarReserve
Solare XXI
Stirling Energy Systems (SES)

- *Global Utilities/Independent Power Producers*

Acciona Energía (Acciona Solar)
Cogentrix Energy
Iberdrola
NextEra Energy
NRG Energy

- *Global Project Developers*

Albiasa Solar
Ibereólica
Grupo SAMCA

EPC contractors and Consultants

ACS Actividades de Construccíon y
Servicios SA (Grupo Cobra)
Bechtel Corp.
Fichtner AG
Fluor Corp.
Lauren Engineers & Constructors
Lahmeyer AG
Ferrostaal AG
Sacyr Vallehermoso SA
Techint Group
United Research Services Corp. (URS)
WorleyParsons Ltd

Component manufacturers:

- *Parabolic trough and LFR*

3M
Abengoa
Alanod
Acciona Solar Power
Alcoa, Inc.
Archimede Solar Energy SpA
Areva (ex Ausra)
Cristaleria Espanola
Enertol Santana
Glaston Corp. (Kyro Oyj Abp.)
Glavarbeg
Gossamer Space Frames
Hydro Aluminum Extrusion Americas (Norsk Hydro ASA)
Industrial Solar technology
Naugatuck Glass
Panaltec
Pilkington
Radco Industries
Dow Chemicals
ReflecTech
Rioglass Solar
Ronda Reflex srl
Saint Gobain
Schott
Siemens (ex Solel)
Solargenix
Soalar Millennium (ex Flagsol and Flabeg)
Sopogy

- *Tower*

BrightSource Industries Israel
(BrightSource Energy)
Lockheed Martin Corp.
SolarReserve (United Technologies)

- *Dish*

Infinia Corp.
Stirling Energy Systems

Power Block and Balance Of the Plant (BOP) Suppliers

3M
Aalborg Industries Group A/S
ABB Ltd
Alfa Laval
Alstom SA
Bertrams Heatec AG
Dow Chemical Co.
Emerson Electric Co. (Emerson Process Management)
Flowserve Corp.
Friatec AG
General Electric Co. (GE) Oil & Gas
GEA Group AG
Haifa Chemicals Ltd. (Ferquisa SA)
Holtec International
MAN Turbo AG
Ormat Technologies
Parker Hannifin Corp.
Siemens Power Generation
SPX Cooling Technologies
Radco Industries
Solutia, Inc