*Tenth LACCEI Latin American and Caribbean Conference (LACCEI'2012), Megaprojects: Building Infrastructure by fostering engineering collaboration, efficient and effective integration and innovative planning, July 23-27, 2012, Panama City, Panama.*

# Concentrating Solar Power Technologies. The DESERTEC Megaproject

**Javier Muñoz-Antón**
Grupo de Investigaciones Termoenergéticas, Universidad Politécnica de Madrid, Spain, jamunoz@etsii.upm.es

**Carlos Rodríguez-Monroy**
Universidad Politécnica de Madrid, Spain, carlos.rodriguez@upm.es

**Alberto Abánades-Velasco**
Grupo de Investigaciones Termoenergéticas, Universidad Politécnica de Madrid, Spain, abanades@etsii.upm.es

## Abstract

The European strategies on energy have been searching for years to reduce the dependency of Europe from fossil fuels. Underlying this effort, there exist geopolitical, economic, environmental reasons and the reality that oil reservoirs will dry out some day. Renewable energies have become a milestone of this strategy because their huge potential has emerged after years of uncertainty. One of the better developed renewable sources, which is nearer to commercial maturity is solar-thermal energy. In this paper, the current state of this technology will be described as well as the developments that may be expected in the short and mid terms, including the thermoelectric solar megaproject DESERTEC, a German proposal to ensure energy resources to the mayor areas of the EU-MENA countries. The reader will acquire a picture of the current state of the market, of the technical challenges already achieved and of the remaining ones.

**Keywords:** Sustainability, Thermal Solar Power Technologies, HVDC, Renewable Energy, DESERTEC

## 1. Introduction

Energy is the key driver of economic and social development of our Society. Since the Industrial Revolution, the energy model is based on fossil fuels. The high energy consumption, limiting the available fossil resources and environmental effects are being detected, causing the energy sector try to evolve into what has been called a *sustainable energy model* based on renewable energy. A possible alternative is to use solar energy as a primary source and, in particular, take advantage its direct use and electricity generation.

**Figure 1: Techno-economic viability areas for Solar Thermoelectric technology (European Commission)**

The potential of solar thermal power is evident when you consider that the earth's surface receives the order of 240 million TWh / year of solar radiation that 70% is direct radiation. Taking advantage of all the arid or desert areas (7% of the surface), considering that only can be covered with solar collectors 1/3 of them about the possible effects of shadows and interception, the typical yield of conversion is 15%, and assuming that only 4% of all that she has the infrastructure to evacuate power, potential output is about 24,000 TWh / year, comparable with the 20,201 TWh of electricity consumed worldwide in 2008. (Foro de la Industria Nuclear Española, 2010). It should be take into account that the site of a plant based on this technology should be compatible with the installation of a thermal plant, which means have a sufficient cooling capacity, availability of water for operation and maintenance work, an environment low abrasion to prevent deterioration or contamination of the optics of concentration and electric grid able to evacuate the energy produced. These requirements affect the choice of location for the additional costs that may involve solving condition it with sufficient capacity and cooling evacuation.

This potential to cover part of the global electricity demand is very reasonable. The global analysis of technical and economic viability indicate that the area around the tropics called sun belt, is best placed to implement solar thermal plants (figure 1), the largest proportion of direct solar radiation received.

It is betting on an international level for the development of solar thermal technology, considered one of the most prominent of renewable and thermal power plant projects are both in developed countries, the dawn of tax and tariff benefits that promote, as in the developing countries through aid through the World Bank and other technological cooperation mechanisms. All this activity is generating a significant effort in R & D and industrial development in search of a key technology that can support its profitability in competition with other energy technologies.

## 2. FUNDAMENTALS OF CONCENTRATING SOLAR THERMAL SYSTEMS

Solar thermal systems convert solar energy into thermal energy by heating a fluid heater and transforming this energy by heat engines that can be used directly or coupled to a generator to produce electricity. The low power density of the solar resource (up to 1000 $W/m^2$ at the surface) is necessary to concentrate sunlight to reach temperatures that allow the fluid heater use in power generation cycles, so these systems are often called solar thermal concentration.

These systems consist of two main blocks (figure 2): the solar field and power cycle. Additionally, they can have storage system and hybridization system that enable the plant to continue operating in conditions close to those expected in the absence of action or when sunlight is not enough.

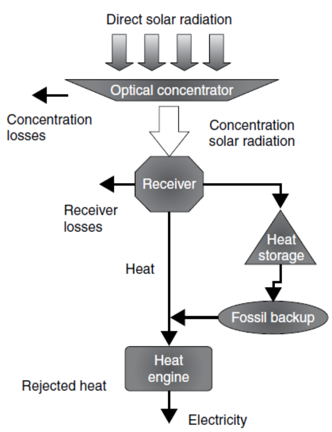


**Figure 2: Flow diagram for a typical solar thermal power plant (Romero and Zarza, 2007)**

The solar field is composed of collectors that collect and concentrate the sun's energy into the receiver, made right qualities of absorption/emission. Through it circulates the fluid to be heated. When is used different fluids in the solar field (heat transfer fluid) and the power cycle, the energy is passed from one to another in a heat exchanger. The working fluid drives a turbine or motor which is coupled to an electric generator.

The storage systems can store excess solar energy from the field when necessary. The more extended configurations have one or more tanks that store energy as latent heat sensitive or directly (when the heated fluid stores the energy itself) or indirectly (when other fluid, or system, which stores).

Hybridization systems combine the basic scheme of the solar plant with other power source. The used ones consist of fossil fuel heaters (natural gas) to heat the fluid heater well or the working fluid, the first being the most common. In some cases hybridized with central solar field larger scale, such as combined cycles, in which the solar generation is a reduced portion of the total energy, and energy is produced at the main floor (Schwarzbozl et al, 2006). This option is very attractive from the point of view of solar generation costs, but is affected by the legislation of each country. In the case of Spain and most developed countries, the benefits are granted to power generation from solar but also put a limit in the proportion of fossil energy used in the plant. This condition leaves out the special arrangements of concepts as hybridization with combined cycle, restricting the use of fossil fuel as a supplement to improve the operation of the solar.

The operation of these systems together makes the overall performance of the plant dependent on several factors, one of the main operating temperatures of each of the functional blocks described. The solar field has a yield that decreases with increasing operating temperature due largely to the increase of radiation losses, which are proportional to $T^4$. On the other hand, a high solar field temperature means better yields in the power block, which basically follows the trend of the famous law of Carnot, increasing with the difference that can be obtained between the heat sink (condenser) and the hot source (fluid heater solar field). These two trends in performance with temperature are reversed between the two main blocks, so that there will be an optimum thermal operating point for these plants. This optimum depends on the plant through the loss of solar collection system. In the case of plants based on cylinder parables, we estimate that the optimal operating temperature would be between 500-550 °C, also depending on other factors such as loss of pumping efficiency of heat transfer equipment to determine this range.

## 3. Solar thermal technologies

From a technological point of view and depending on the geometry of the solar field can be distinguished currently four types of thermal technologies (Figure 3) whose main characteristics are summarized in table 1:

- Parabolic Collectors: They are composed of rows of parabolic mirrors fitted on an axis solar tracking. The mirrors concentrate solar radiation onto the absorber tube located at the focus of the parabola, in which fluid circulates as thermal oil heater.
- Central Receiver systems: They consist in a field of mirrors fitted with two-axis tracking, called heliostats, which concentrate solar radiation onto a receiver on a tower at some point. There are several types of receptors such as external, cavity or volumetric. The first two use water or molten salts as heat transfer fluid while the latter uses air.
- Parabolic Dish systems: They consist of parabolic mirrors with two-axis tracking, concentrating the solar radiation in the focus of the parabolic dish, in which a Stirling engine is located.
- Linear Fresnel systems are formed by rows of flat mirrors located on the horizontal ground that concentrate solar radiation onto an absorber tube, each with its separate focus system, with monitoring on an axis.

The cost of electricity generation with these technologies ranges around 15-18 c€/kWh, which is one of the main obstacles to commercial development, since it is not yet competitive in a market with generation technologies that have a cost production can range from 5 to 9 c€/kWh. However, the bet that is being made for the development of solar thermal technology is in the form of grants and allowances to electricity generation is leading the development of the learning curve therefore in which factors such as R & D, the application of economics of scale and market development costs are expected to fall in the medium term to the one associated with electricity generation of the most developed sources as fossil fuels.

Parabolic trough | Fresnel | Central receiver | Parabolic Dish

**Figure 3: Concentrated solar thermal technologies. Source: Plataforma Solar de Almería web page**

In the cost structure of this type of plant, the investment is the key point, as the primary resource is free, at a cost of operation and maintenance of approximately 10% of the total. The investment required to install such plants depends on many factors, mainly the configuration, being near of 3-5 €/W of installed power.

**Table 1: Main features of current solar thermal technologies. Source: Protermosolar, 2011**

| | | **Parabolic trough** | **Central Receiver** | **Parabolic Dish** | **Fresnel** |
|---|---|---|---|---|---|
| **Solar field** | **Collectors** | Parabolic Cylinder | Heliostats | Parabolic mirrors | Flat mirrors |
| | **Collectors tracking** | 2D | 3D | 3D | 2D |
| | **Receiver** | Absorber pipe | Exterior<br>Cavity<br>Volumetric | Cavity | Absorber pipe |
| | **Heat transfer fluid** | Thermal oil | Water (W)<br>Molten salts (MS)<br>Air (A) | Hydrogen or Helium | Water |
| | **Temperatures margin $T_{in}$-$T_{out}$ (C)** | 290-390 | 290-565 (W)<br>110-700 (MS)<br><1100 (A) | <750 | 140-270 |
| **Block of power** | **Thermodynamic cycle** | Rankine | Rankine<br>Brayton | Stirling | Rankine |
| | **Power range** | 30-320 MW | 10-200 MW | 5-25 kW | 1.4-200 MW |
| **Thermal energy storage** | | Molten salts double tank | Direct, molten salts double tank, solid | Under development | Under development |

## 4. STATE-OF-THE-ART

### 4.1 SOLAR THERMAL PLANTS WITH PARABOLIC-TROUGH

The plants with this technology are the most widely deployed and most industrial development, providing the largest source of global solar electricity (Romero et al 2007). Currently there are near of 20 plants of this technology in commercial operation in Spain in operation since November 2008 in Spain, 50 MW each. Ion table 2 the reader can read the historical main plants that uses parabolic-trough collectors. This story begins with the DCS plant in Spain and the SEGS (Solar Energy Generating Systems) plants (Kearney, 1999).

Avoiding the collectors improvements and the ones attached to the absorber tubes from the first plant (Price, 2002), the configuration of the solar field has remained largely unchanged. All plants have used thermal-oil as heat transfer fluid, being the only change the temperature range reached: the first plants, DCS (Distributed Collector Systems) and SEGS I, reached 300 °C and 315 °C respectively, making it impossible to obtain higher efficiencies in the thermodynamic cycle. The following ones, changing the thermal-oil, reached 400 °C (Duffie and Beckman, 1991). Maximum operating temperature of the thermal-oil is one of the major technological limitations to achieve higher final yields. The R&D efforts in this area are oriented to improve the temperature constraint by the use of other fluids, such as molten salts or pressurized gas.

**Table 2: Parabolic trough more representative plants. Source: Protermosolar, 2011**

| | Location | Year | Net Power (MW) | SOLAR FIELD $T_{in}$ (ºC) | SOLAR FIELD $T_{out}$ (ºC) | THERMAL ENERGY STORAGE | HYBRIDIZATION SYSTEM | BLOCK OF POWER |
|---|---|---|---|---|---|---|---|---|
| **DCS** | Spain | 1981 | 0,5 | 220 | 300 | Termocline with oil | - | - |
| **SEGS I** | U.S. | 1985 | 13,8 | 240 | 315 | Direct storage, with two thermal-oil tanks with 3 hours capacity | Natural gas over-heater | A |
| **SEGS II** | U.S. | 1986 | 30 | 231 | 316 | NO | Steam boiler | A |
| **SEGS III** | U.S. | 1986 | 30 | 248 | 349 | NO | Steam boiler | A |
| **SEGS IV** | U.S. | 1986 | 30 | 248 | 349 | NO | Steam boiler | A |
| **SEGS V** | U.S. | 1987 | 30 | 248 | 349 | NO | Steam boiler | A |
| **SEGS VI** | U.S. | 1988 | 30 | 293 | 390 | NO | Steam boiler | B |
| **SEGS VII** | U.S. | 1988 | 30 | 293 | 390 | NO | Steam boiler | B |
| **SEGS VIII** | U.S. | 1989 | 80 | 293 | 390 | NO | Thermal-oil heater | B |
| **SEGS IX** | U.S. | 1990 | 80 | 293 | 390 | NO | Thermal-oil heater | B |
| **Saguaro** | U.S. | 2006 | 1 | 120 | 300 | NO* | NO | - |
| **Nevada Solar One** | U.S. | 2007 | 64 | 318 | 393 | Molten salts indirect storage with 30 minutes capacity | Thermal-oil heater | B |
| **Andasol** | Spain | 2008 | 50 | 292 | 392 | Molten salts indirect storage with 7.5 hours capacity | Thermal-oil heater | B |
| **Puertollano** | Spain | 2009 | 50 | 291 | 391 | NO | Thermal-oil heater | B |
| **Alvarado** | Spain | 2009 | 50 | 291 | 391 | NO | Thermal-oil heater | B |

*Thermocline storage system pending.
A = Rankine without reheating
B = Rankine with reheating

### 4.2 SOLAR THERMAL PLANTS WITH CENTRAL RECEIVER

These technology emerged in the 80's as test plants of this in Spain, Italy, Japan, Israel, France, Russia and the U.S.. The evolution has driven this technology to commercial plants (table 3): GEMASOLAR (Protermosolar, 2011), PS10, PS20 (Osuna et al, 2004) and Jülich (Hennecke et al, 2007) currently provide energy. The SSPS, CESA-1 in the PSA and SPP-5 operate as centers for testing new components (Romero et al, 2002). The rest are currently inoperative. With the experience of these plants, the technology is being developed in several research lines:

- Saturated steam
- Molten salts as heat transfer fluid and storage media
- Air with volumetric receiver and a solid media (stones, ceramic…) as storage media
- Volumetric receiver with pressurized air

**Table 3: Central receiver more representative plants. Source: Protermosolar, 2011**

| Heat transfer fluid | Plant | Location | Year | Power (MW) | Storage system |
|---|---|---|---|---|---|
| Na Liquid | **SSPS** | Spain | 1981 | 0,5 | Direct by Na liquid |
| | **Rockwell** | U.S. | 1981 | 2,5 | NO |
| Water | **Eurelios** | Italy | 1981 | 1 | Molten salts and water |
| | **Sunshine** | Japan | 1981-1984 | 1 | Molten salts and water |
| | **SOLAR ONE** | U.S. | 1982-1988 | 10 | Thermocline tank with sand and stones. Thermal oil as heat transfer fluid |
| | **Arco Solar** | U.S. | 1982 | 1 | No |
| | **CESA-1** | Spain | 1983 | 1 | Indirect in molten salts tanks |
| | **SPP-5** | Russia | 1985 | 5 | Direct with steam |
| | **Weizmann Institute** | Israel | 1989 | 2 | |
| | **PS10** | Spain | 2007 | 11 | Direct with 4 tanks of saturated steam with 50 min capacity |
| | **PS20** | Spain | 2009 | 20 | - |
| Molten salts | **Themis** | France | 1983-1986 | 2,5 | Direct. Molten salts dual tank with 6h capacity |
| | **MSEE** | U.S. | 1984-1985 | 0,75 | Direct. Molten salts dual tank with 3h capacity |
| | **GEMASOLAR** | SPAIN | 2011/ | 19.9 | Direct. Molten salts dual tank with 15h capacity |
| | **SOLAR TWO** | U.S. | 1996-1999 | 10 | Direct. Molten salts dual tank with 3h capacity |
| Aire | **TSA** | Spain | 1991 | 2,5 | Themocline storage in Alumina pebble |
| | **DIAPR** | Israel | 1994 | 0,2 | SDSDSDDS |
| | **Jülich** | Germany | 2009 | 1,5 | Ceramic material storage |

### 4.3 PARABOLIC DISH SYSTEM

Currently solar technology uses parabolic dishes with Stirling cycle engines, which is the thermal system with higher performance, which can minimize investment costs and therefore the price of electricity produced.

**Figure 4: DISTAL system in the „Plataforma Solar de Almeria‟, Spain**

**Figure 5: "Puerto Errado 1" Solar thermal powerplant in Murcia, Spain**

This technology, like the rest of the applications of concentration revised, was initiated at the beginning of the 70 United States, after the oil crisis that promoted the search for alternative sources of energy. The development until 1984 was very important, obtaining that year the higher performance in a solar electric conversion process, 29.4%

(Duffie and Beckman, 1991). Unlike other solar thermal technologies concentration, these systems can be competitive from units of about 10 kW, because they are not associated with a thermal cycle based on turbomachinery. In fact, the power range of designs to date ranges from 3 to 50 kW. Figure 4 shows one of the prototypes that have been implemented at the Plataforma Solar de Almeria (DISTAL).

Currently there are some ambitious plans for developing plants based on this technology in the U.S., as the Calico-Solar One, Solar-Two Imperial Valley and Maricopa, with a projected total installed capacity of more than 1500 MW of electricity, produced by more than 60,000 units of this technology.

### 4.4 Fresnel receivers

At the moment, this technology is becoming stronger in solar thermal applications. It is characterized by a lower concentration efficiency than the parabolic trough and lower temperatures in the receiver, but has lower cost and is easier to operate. This gives a higher techno-economical feasibility. Its application is clear on low-medium temperature (under 400ºC), and in the case of use for steam generation presents a number of interesting characteristics, such as no use of moving parts, that avoids the leaks founded in experiments with steam and parabolic-troughs (Zarza et al. 2004).

Fresnel concentrators are formed by flat mirrors aligned with the receiver axis, each mirror reflects the solar radiation directly over the tubes of the receiver (figure 5). Above this receiver, a parabolic structure is incorporated to collect part of the reflex to increase efficiency; this is due to the fact that the Fresnel flat mirrors have less ability to concentrate than other 2D systems, such as parabolic. A collector of this technology can be seen in figure 5. There are currently several ongoing projects of Fresnel plants, among them Puerto Errado (1.4 MW) in Calasparra (Murcia) and Liddell (Australia) with 35 MW thermal in a hybridization with a combined cycle. The United States has the Kimberlina project in Bakersfield (California), with a net capacity of 5 MW (SolarPACES).

## 5. A renewable energy megaproject – The DESERTEC initiative

Solar energy received in the deserts of tropical and subtropical regions is the most abundant energy source that can be found on the Earth's surface. The DESERTEC concept has been elaborated in order to extract from the deserts, with the existing technology, the resources to meet the energy and water needs of inhabitants in large geographical areas in a clean and environmentally friendly way.

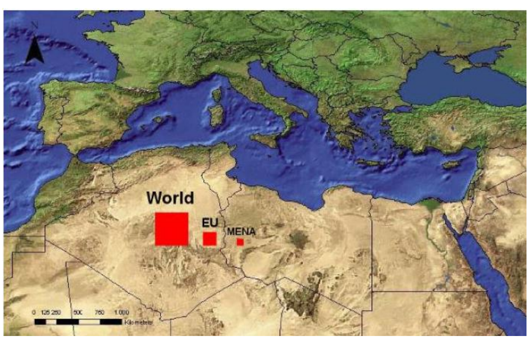


**Figure 6: Left: The red boxes covered surfaces would be enough to satisfy the electricity consumption of the World, EU and MENA countries (Desertec Foundation, 2008).**


**Figure 7: Concept of a „EUMENA Supergrid" based on HVDC power transmission as "Electricity Highways" to complement the conventional AC electricity grid, as developed by TREC in 2003.**

Cooperation among Europe, the Middle East and North Africa (the EU-MENA region) is proposed for the production of electricity and desalinated water through thermo-solar power plants together with wind farms in the deserts of the MENA region. These power stations can cover the increasing demand for electricity and for the energy required to desalinate water in the MENA region and produce clean energy which could be transmitted to the European continent by means of High Voltage Direct Current (HVDC) transmission lines with a transmission loss of only 10-15%.

From a geopolitical point of view, the implementation of the DESERTEC concept would be significantly easier in counties such as Australia, China, India, the United States and México.

The technology required to implement this project is already available and has been in use for several decades. The current requirements to reduce greenhouse gas emissions and the urgent need to ensure the security of supply of electricity in the MENA region and in continental Europe turn this initiative into an outstanding possibility for the potential development of this area.

Solar thermal power plants are more suitable than photovoltaic farms due to their manageability and storage capacity, which makes them capable of providing power 24 hours a day. In case of using photovoltaic plants in the MENA region there would have to be sufficient pumped storage in central Europe to store energy and be able to operate at night, but it would take more power lines or using such energy for less hours per day.

The transmission of electricity through High voltage direct current lines is much more efficient than hydrogen as an energy carrier. With such lines transport losses would be limited to about 3% per 1000 km. of line. Therefore, although the total losses between MENA and Europe would be in the range between 10-15%, these losses would be compensated by the fact that MENA radiation levels are much higher than those in southern Europe. Additionally, seasonal variations are much lower in these countries than in Europe.

All the technology necessary to implement the DESERTEC concept exists and has been operating for decades. HVDC transport lines with a capacity of up to 3 GW over long distances are being built for many years by ABB and Siemens. In July 2007 Siemens was awarded in a tender the construction of a system of 5 GW in China. In the World Energy Dialogue 2006 in Hannover, Germany, representatives of both companies confirmed that the construction of the transmission lines needed to complete the DESERTEC concept represents no problem.

The Solar thermal power plants are being used commercially since 1985 in Kramer Junction, California. New plants with a capacity of more than 2,000 MW are currently under construction or planned. The government of Spain established conditions for generation in solar thermal electrical plants and delivering the electricity to the network: a 25-year guarantee for payment of 27 c€ / kWh providing a major boost to the promotion of these plants in that country. In places with higher solar irradiation it would be possible to implement these plants with lower premiums in the feed-in tariffs. If in the coming decades there is an increase in thermal power plant construction production costs could go down to 4-5 c€ / kWh. As prices of raw materials needed for solar thermal plants increase more slowly than fossil fuel prices, these plants could be competitive sooner than expected.

**Table 3: EU-MENA electric conexion development by High Voltage Direct Current (HVDC) and the installed power by Concentraded Solar Power Plants (CSP) in the scenario TRANS-CSP 2020-2050 (Desertec Foundation, 2008)**

| Year | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| **Transfer Capacity (GW)** | 2 x 5 | 8 x 5 | 14 x 5 | 20 x 5 |
| **Electricity Transfer (TWh/yr)** | 60 | 230 | 470 | 700 |
| **Capacity factor** | 0.60 | 0.67 | 0.75 | 0.80 |
| **Turnover Billion €/yr** | 3.8 | 12.5 | 24 | 35 |
| **Land Area (km x km) CSP** | 15 x 15 | 30 x 30 | 40 x 40 | 50 x 50 |
| **Land Area (km x km) HVDC** | 3100 x 0.1 | 3600 x 0.4 | 3600 x 0.7 | 3600 x 1 |
| **Investment (Billion €) CSP** | 42 | 143 | 245 | 350 |
| **Investment (Billion €) HVDC** | 5 | 20 | 31 | 45 |
| **Electricity cost (€/kWh) CSP** | 0.050 | 0.045 | 0.040 | 0.040 |
| **Electricity cost (€/kWh) HVDC** | 0.014 | 0.010 | 0.010 | 0.010 |

**Comment [JMA1]:** Cheking billion

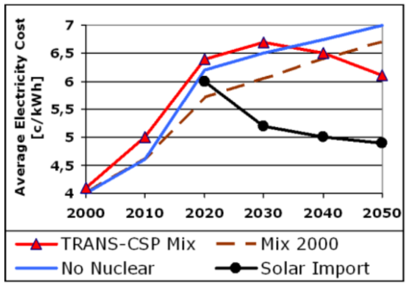


**Figure 7: Produced energy future cost estimation for Germany (Desertec Foundation, 2008)**

### 5.1 MEASURES TO BE TAKEN FOR THE REALIZATION OF THE DESERTEC CONCEPT

The thermal power plant construction has begun (Andasol 1 and 12 more plants, including the PS10, Spain and Nevada Solar One in the U.S.). There are projects in Egypt, Algeria, Morocco, Jordan and Libya. Morocco is implementing a law of feed-in tariffs for electricity generation using renewable energy to boost especially wind energy. In the EU there is discussion about a super network High Voltage Direct Current for Europe (Euro-Supergrid) while plans are realized for offshore wind turbines in Northern Europe. The European Union wants to implement a Mediterranean Solar Plan for the Mediterranean which could be the framework for realizing the DESERTEC concept in EU-MENA.

In order to make these ambitious plans attractive to the private sector it is necessary to count on the Initial support by governments. Thus by 2050 a capacity of 100 GW for export could be achieved (installed capacity equivalent to 100 nuclear power plants) in the countries of the MENA region, after discounting its own demand. According to existing data with support of less than 10 billion Euros, this program could be launched before 2020 and it would make possible that this form of power generation to compete with the generation of electricity from fossil fuels without subsidies. Given the current market developments of oil and natural gas the competitiveness of this solar thermal could be reached even earlier.

Public investors could cover the financing of transmission lines and processing centers, but also banks and other private investors would be willing to provide the necessary funding if given the right circumstances. Enabling this process requires the implementation of a policy of premium rates as well as guarantee funds for investments and to expand these funds for the energy produced in the MENA region. It would also be possible that the implicit financing of the feed-in tariffs could be achieved through "Loans for Renewable Energy", which could be acquired by European countries to meet their objectives of climate protection or, even better, to overcome them. At the same time care has to be taken in order not to hinder the expansion of renewable energies in Europe which constitute the main contributor in the energy mix proposed by the TRANS-CSP 2050 scenario.

The decision on the fate of the energy generated in the MENA countries depends largely on each individual country. For example, Morocco's own demand is so great that it has established a credit system for solar and wind power. Tunisia and Algeria, however, show a greater interest in exports. When the Southern European countries begin to import electric power from the MENA region there will be an effect on other countries in Europe, which will no longer be obliged to produce as much energy for these countries with power deficits. This would result in less pressure for construction of new conventional plant and allow more time to extend the introduction of renewable energies. In any case, the construction of a HVDC network cannot wait any longer because the planning, the licensing process and the construction of such lines require a fairly long period. It is for these reasons that the feasibility studies have to start as soon as possible

## REFERENCES


Foro de la Industria Nuclear Española, 2010. www.foronuclear.org

Romero M, Zarza E. "Chapter 21: Concentrating Solar Thermal Power" of Kreith F, Yogi Goswani D. *Handbook of Energy Efficiency and Renewable Energy*. CRC Press, 2007

Schwarzbozl P, Buck R, Sugarmen C et al. (2006). "Solar gas turbine systems: Design, cost and perpectives" Solar Energy.Vol 80, pp 1231–1240

Plataforma Solar de Almería http://www.psa.es

Deloitte (2011), *Impacto macroeconómico del sector solar termoeléctrico en España*, Protermosolar.

Romero M, Buck R, Pacheco J. (2002) "An Update on Solar Central Receiver Systems, Projects, and Technologies". Int. J. Solar Energy Eng. Vol.124, pp 98-108

Kearney D, (1999) "Solar Electric Generating Stations (SEGS)". IEEE Power Engineering Review.

Duffie J. A. and Beckmann W. A. (1991). *Solar Engineering of Thermal Processes*, 2nd edition, John Wiley, New York

Osuna R, Fernández V, Romero S. et al. (2004) "PS10: A 11-MW solar tower power plant with saturated steam receiver" In Proceedings 12th SolarPACES International Symposium.

Hennecke K, Schwarzbolzl P, Koll G et al. (2007) "The Solar Power Tower Jülich-A solar thermal power plant for test and demonstration of air receiver technology". In Proceedings of ISES World Congress 2007 (Vol. I – Vol. V) Solar Energy and Human Settlement

Zarza E, Valenzuela L, León L, Hennecke K, Eck M, Weyers D, Eickhoff M (2004) "Direct steam generation in parabolic troughs: Final results and conclusions of the DISS project", Energy, Volume 29, Issues 5–6, Pages 635-644

SolarPACES, Solar Power And Chemical Energy Systems, 2008: http://www.nrel.gov/csp/solarpaces/

Desertec Foundation, http://www.desertec.org/


### *Authorization and Disclaimer*