BEUTH HOCHSCHULE
FÜR TECHNIK
BERLIN
University of Applied Sciences

Beuth Sprachenpreis 2009

Global Challenges –

Ideas and Projects Around the World Which Make a Difference

CONCENTRATED SOLAR POWER -

CLEAN POWER FROM THE DESERTS

Felix Schulze
Master Maschinenbau – Produktionssysteme
S7600570
schulze_felix@web.de

11. Sep. 2009

Contents

Introduction

For a long time, visionaries dreamt of a new form of power production in a carbon-dioxide-free way. In the 1980s, large solar power systems situated in the Sahara should convert the energy of sunlight into electricity and provide it to consumers in Europe. Costs have always been the big problem. But now scientists start a new attempt. Power plants that convert sunlight into electrical energy at reasonable cost could turn this bold idea into reality.

Requirements defined by policymakers to limit carbon-dioxide emissions and increase the proportions of electricity produced from renewable sources are the main drivers for the growth of the solar-thermal industry. [1] Ambitious climate targets set by the European Union consist of a 20% reduction in energy consumption, a 20% reduction in greenhouse gas emissions and an increase to 20% in renewable energies' share of total energy consumption by 2020. [2] It is now clear that the EU member states won't reach the target of a 20% use of renewable energies by then.[3] There are two main reasons for that. One the one hand the environment-friendly energy is not been gained where it accrues in abundance – on the Atlantic coast (wind power) and in the deserts of North Africa (sun power). On the other hand there are not enough transmission lines to transport the energy from those regions to the largest consumers.

Concentrated Solar Power (CSP) has been gaining ground worldwide with the foundation of the Trans-Mediterranean Renewable Energy Cooperation (TREC) by the Club of Rome in 2003. [4] The scientists have developed in co-operation with politicians a long-term energy plan for Europe, North Africa and the Middle East called DESERTEC. The idea behind DESERTEC is that every party gets what it needs. Europe gets clean energy, North Africa gets enough energy for the desalination of sea water and the Middle East receives economic alternatives for oil production. And it serves the global climate by reducing carbon dioxide emissions by more than 80%.

[1] (The other kind of solar power, 2009)
[2] (Europe, 2009)
[3] (EU-Länder drohen Klimaziel zu verfehlen, 2009)
[4] (Desertec Foundation, 2009)

What is Concentrating Solar Power?

Concentrating Solar Power (CSP) systems use the sun as a direct heating component to produce power. Reflective panels like mirrors or lenses are focused onto a specific spot that contains a pipe or pool of liquid. The liquid is heated up by the concentrated focus of the sun and then rotates a turbine, which cranks up a generator and produces electricity.[5]

As far back as ancient Greece, Egypt and China, making use of solar energy to condition buildings was a known art.[6] Throughout history, the same basic principles apply. Sunlight is captured for both its heat and light in order to light fires, heat houses while reducing the need for other energy sources. The concept of concentrated sunlight was also developed for military purposes to concentrate its power on a target. The first known example of a concentrating solar-powered mechanical device was a steam engine powered with sunlight developed by Augustin Mouchout in 1866.[7]

To reduce dependence on imported oil subject to politically motivated supply interruptions was the motivation in the 1970s to build the first pilot CSP plants in Spain, the USA and a few other countries.[8] The first commercial solar-thermal power plant was installed in the Mojave Desert in California which is still working fine, even today. [9]

Desert areas are highly suitable for CSP due to daily uninterrupted sunshine for much of the year. In fact, sun energy offers a high potential – each year 630,000 Terawatt-hours of unused solar radiant energy are going down on deserts in the Middle East and North Africa.[10] Europe needs only 4,000 Terawatt-hours each year by comparison.

In other words, one square kilometer desert delivers 250 gigawatt-hours energy and saves up to 200,000 tons of carbon emission. Only 0.3 % of the area of the desert in North Africa and the Middle East are enough to supply energy to whole Europe and the states bordering this area. Furthermore 1% - an area of 500 x 500 kilometers – could supply the worldwide energy consumption.

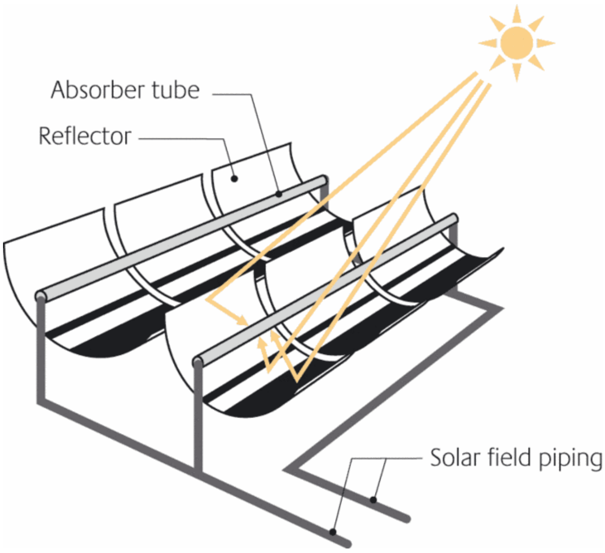
Originally, energy from the Sahara was supposed to be generated by photovoltaic cells – the transformation of sunlight into electricity by semiconductor materials. But this technique is currently not efficient enough, but also expensive. The electric power would have been transformed into liquefied hydrogen and transported by large tankers to Europe under tremendous losses. The idea was dismissed and Photovoltaic cells were replaced by Concentrated Solar Power. In the process, thousands of moveable mirrors condense light upon a tower. In this tower water is heated to generate steam which then powers a steam turbine (Solar tower). Alternatively the liquid circulates through thin tubes focused by parabolic mirrors (Parabolic trough).

[5] (Solar thermal energy, 2009)
[6] (The other kind of solar power, 2009)
[7] (Augustin Mouchot)
[8] (1973 oil crisis)
[9] (Butscher, 2009)
[10] (Spiegel - Desertec II, 2009)

Main Types of CSP systems

There are different Concentrated Solar Power technologies ranging from 10 Kilo-Watt to 200 Mega-Watt and having a broad range of applications – from Stand-alone-systems to cogeneration systems.

Parabolic trough



Picture 1 - Functional principle of the parabolic trough

The parabolic trough system is the most established form of CSP technology. Long parabolic mirrors (usually coated silver or polished aluminum) are used to focus sunlight onto liquid-filled tubes running its length.[11] Due to cost reasons the parabolic channels are uniaxially aligned to the sun.[12] The fluid that passes through the receiver becomes very hot and is then transported to a heat engine or steam generator.[13] To increase the efficiency of the power plant regular thermo oil is being replaced by water that is directly evaporated. The temperature of thermo oil can reach up to 400° C while steam can be heated up to 550° C under pressures up to 100 bar. Higher temperatures increase the energy efficiency and additionally installed heat exchanger for transmitting energy can be eliminated. Only the heated steam drives a turbine in the power plant which simplifies the setup of the plant.[14]

The receiver is the central element of a concentrated solar-thermal plant. The mirrors concentrate the sun's rays upon the receiver with up to 80 times the intensity of normal daylight. The receiver has to cope with enormous stresses and must therefore consist of resistant materials and must be extremely stable. How efficiently the receiver converts the concentrated sunlight into heat and passes it to the heat transfer medium determines the energy yield of the plant.[15]

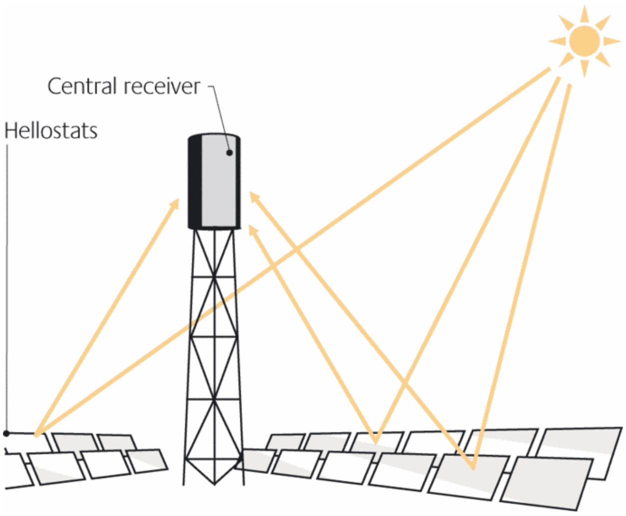
Picture 3 - Parabolic trough in Almeria, Spain

Picture 2 - Parabolic trough in Junction, California (USA)

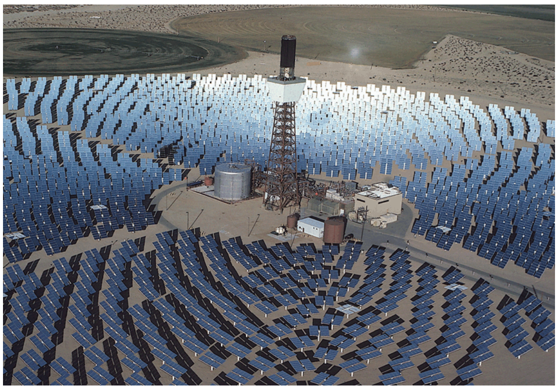
[11] (Fischedick, 2007, p. 45)
[12] (Parabolic trough)
[13] (Fischedick, 2007, p. 45)
[14] (Butscher, 2009, pp. 87-88)
[15] (Butscher, 2009, p. 86)

Central Receiver Systems (Solar Power Tower)

Higher temperatures up to 1,000° C can be achieved with Solar Power Towers (CRS – Central Receiver System). Hundreds of movable mirrors (heliostats) are usually arranged around a Solar Tower with a height of 50 to 150 meters.[16] They follow the path of the sun and concentrate the solar radiation on a receiver, installed at the top of that solar tower.[17] The receiver is usually made of porous ceramic elements through which incoming ambient air flows. In passing through the receiver, the air is heated to around 700 to 850 degrees Celsius. The steam generated there drives a turbine, which produces power via a generator.[18] It is possible to achieve pressures and temperatures similar to modern coal-fired power stations.[19] Modern CRS use sun-tracking software to coordinate the movement of all the mirrors via optical sensors.[20]



Picture 4 - Functional principle of the solar tower



Picture 5 - Solar Tower Power Plant in Almeria, Spain

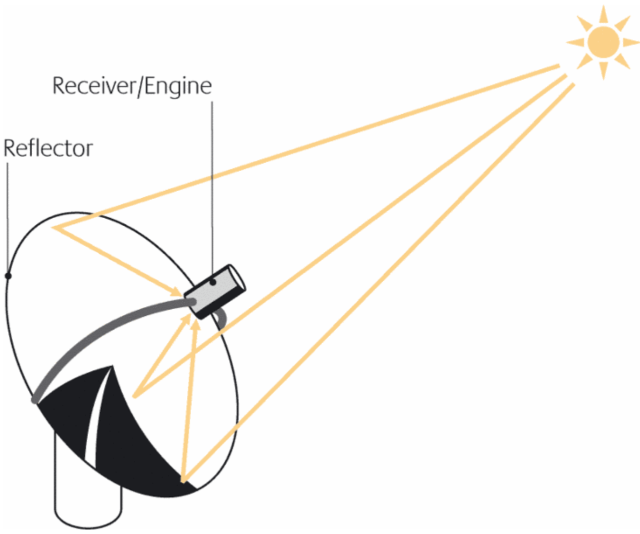
With new developed extreme temperature resistant receiver components made of ceramic, Solar Tower technology possesses a concentration factor up to 500.[21] The resulting high circle process temperatures offer higher efficiency compared to parabolic through and other CSP technologies. Air as heat carrier is available endlessly, costs virtually nothing and is completely save in environmental terms. The Solar Tower plant concept can be deployed easily on uneven ground offering a definite advantage over parabolic trough plants which require plane surfaces.[22] However, Solar Tower Systems are less advanced and not thoroughly tested in the field than their parabolic trough counterparts.

Furthermore, the generated high temperatures achieved with the Solar Tower can be used beyond power generation. The heat energy being collected can be stored chemically using liquid salt. In that way solar power is made available around the clock. Surplus energy collected during the midday is being stored in heat accumulators and is taken back under a cloudy sky or during the night to enable the power station to operate at full power for up to 7.5 hours after the sun has set. [23]

[16] (Butscher, 2009, p. 89)
[17] (Solar Power Tower)
[18] (Jülich)
[19] (Kempkens, 2009, p. 19)
[20] (Solar thermal energy, 2009)
[21] (Butscher, 2009, p. 89)
[22] (Solarturm Jülich)
[23] (Kempkens, 2009, p. 20)

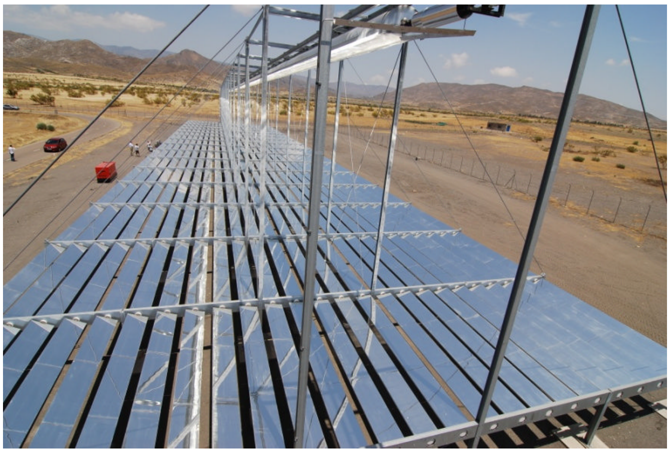
Parabolic dish

A Parabolic dish (or Dish-Sterling System) uses only one large, reflective, parabolic dish and a separate receiver connected to an aggregate to generate electricity[24]. A gas is alternatively heated and cooled down to power a generator. The parabolic reflector, receiver and generator are automatically turned along two axes towards the sun for maximum efficiency. A concentration factor of 1,000 to 10,000 can be achieved due to higher concentrated sunlight. Several parabolic dishes can be interconnected modularly to a small but flexible power plant park in order to generate electricity for villages in remote areas in developing countries.[25] A biogas plant can be added to secure a steady supply of energy.



Picture 6 - Functional principle of the solar dish

Picture 8 -Solar parabolic dish



Picture 7 - Fresnel reflector in Almeriá, Spain

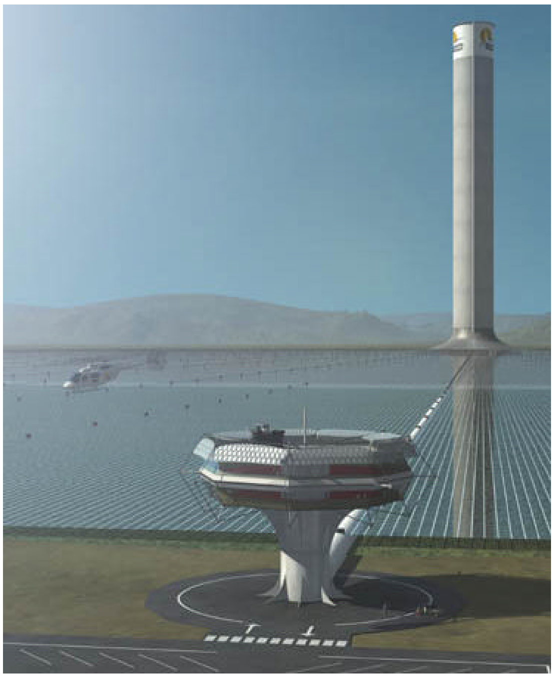
Fresnel reflectors

The large parabolic curved mirrors of a parabolic trough are replaced by many small mirrors that are only slightly curved. Due to small mirrors and a shared receiver between several mirrors, Fresnel reflector power plants can be manufactured at considerably lower cost.[26] Fresnel plants are not as efficiently as parabolic trough because they concentrate less light on average. But this disadvantage can be compensated by installing additionally secondary mirrors to focus more sun light on the receiver.

[24] (Dish-Sterling, 2009)
[25] (Fischedick, 2007, p. 46)
[26] (Solar thermal energy, 2009), Fresnel reflectors

Solar chimney power plant

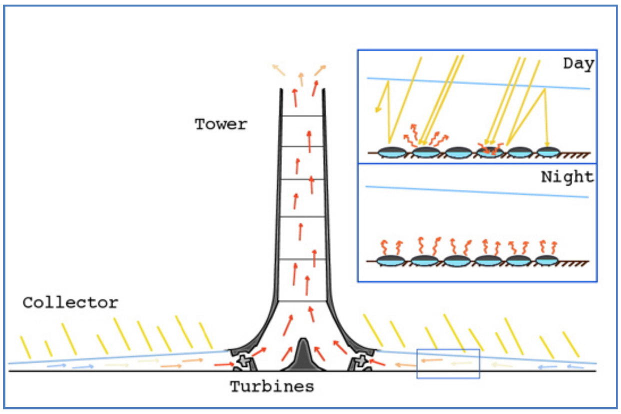
Other forms of solar-thermal power plants that work without concentration of direct solar radiation are solar chimney power plants (or Solar Updraft Tower). The sun's radiation is used to heat a large body of air in a kind of greenhouse which lets light in, but does not let heat out. The upright tower covers one square kilometer at its base and is surrounded by a greenhouse made of polycarbonate and polymer. The heated air flows upwards through a chimney via air ducts at the bottom. Before reaching the chimney the heated air mass flows through one or more wind turbines with a turbo generator attached to it in order to create electricity. The vacuum effect caused by temperature differential continually draws in more air. The bigger the solar upright tower and its surrounding solar collection area the more volume of air can flow through and the more energy can be generated. To power 100,000 houses, a 1000 meter tall tower and 20 square meters greenhouse are required, yielding around 100 Megawatt of power.



Picture 9 - Solar Updraft Tower in Australia

As an advantage, Solar Updraft Towers also work at night and in cloudy or rainy spells as well. Not only the air but also the ground beneath it is heated up during the day to such a degree that in the night time it re-radiates the heat back again keeping the air warm and flowing towards the chimney all the time, even though some efficiency is lost compared to peak times during the day.

Interestingly, instead of a desert developing underneath the solar collecting area because of the high temperatures, a quit luxuriant plant growth was fostered due to the "greenhouse effect" which produces large quantities of condensation during the night.[27] This potential of transforming desert land into arable land by building large greenhouse could be linked with other programs such as establishing farmland in remote and dry areas.



Picture 10 - Functional principle of the Solar Tower

Picture 11 - Productive Landscape within the Greenhouse

[27] (Infranet Lab, 2009)

Future Development

Solar-thermal technology is being carefully observed by politicians and energy companies likewise. The use of solar energy in solar-thermal plants is a key issue considering how to ensure the European energy supply in a cost-effective, reliable and climate-friendly way.

In 2004 the government of Spain passed a law to promote this technology, which has been booming in Spain since then. Currently there are more than 100 projects with a total capacity of more than 2 gigawatt planned to be built, under construction or have been completed. Not only in Spain but also in other regions of the Mediterranean, the use of solar-thermal energy is being pursued with growing verve. Algeria, Egypt, Morocco, Israel and Greece and the southwest of the USA are all eager to build more solar-thermal plants.

This year a project named DESERTEC[28] was launched by a consortium of 20 companies aiming to cover 15 % of the power consumption of Europe by investing 400 billion Euros in solar-thermal plants in North Africa and transporting the gained energy with low-loss transmission lines to Europe.

In order to satisfy Europe's total energy consumption it would be necessary to built solar-thermal plants covering an area of about 20,000 square meters in the deserts of North Africa.[29]

To further increase the efficiency of a solar-thermal plant, the extracted air coming from the gas turbine can be reused to power a second turbine. With the help of thermal storage or adding gas lighting (hybrid power plants) the annual operating hours and hence also the efficiency of the plant can be raised[30]. Often natural gas supplies additional energy. But it is planned to replace fossil fuels with solar power completely. Furthermore, the use of gas turbines eliminates the use of cooling water completely. Water was needed to condense steam into liquid water so far. The prospect of utilizing solar energy in combined power plants is an important step towards making solar-thermal power generation competitive. In the long term this may be the most attractive concept with the highest efficiency.

High levels of synergy effects are also achieved by combining power generation and other generated products (desalination, air-conditioning, energy recovery). Even the old idea of producing hydrogen as fuel for coming full cell vehicles or as a basic material for the chemical industry is getting one step closer. Instead of obtaining hydrogen through the electrolysis of water and electrical power, heat from solar-thermal plants could be used to split water molecules into oxygen and hydrogen – completely carbon-dioxide-free. For this purpose, metal oxide is being heated up to 1,200° C with concentrated solar radiation.

Still, cost reduction is the key issue which needs to be tackled in order to further spread the use of CSP technology. Higher overall efficiency and the manufacture of low cost components are crucial elements and additional research is needed.

[28] (Spiegel - Desertec, 2009)
[29] (Spiegel - Desertec II, 2009)
[30] (Fischedick, 2007, p. 47)

Pros and Cons

Solar-thermal power stations have several advantages over solar-photovoltaic projects.

Pros

Size – Solar-thermal power stations are normally built on a much larger scale than photovoltaic panels and therefore their costs are much lower in the long run. They achieve an efficiency rate of 25 to 30 %, similar to those of photovoltaic cells. In addition, the size of CSP plants can match many fossil fuel based plants enabling an investment far less than that required to install the equivalent wattage of photovoltaic cells.

Costs – The usage of mirrors reduces the costs compared to more expensive photovoltaic cells. Solar-thermal plants are low-tech and reliable and need also less high-maintenance. A broken mirror does not interfere with the operation of the facility and is easily replaced. Few large mirrors are now replaced by a large number of smaller and less expensive mirrors in order to lower the costs of maintenance. The use of computers enables an accurate and automatic tracking and redirection of sunlight than was ever possible before.[31] Further reduction of the cost of solar power to below 8 Cents per kWh is possible with new innovative hybrid systems that combine large CSP plants with conventional natural gas combined cycle or coal plants.[32]

Flexibility – Solar-thermal plants can be installed in hybrid applications enabling day and night operation. Furthermore their varying in size – from 10 kilo watts to 200 mega watts – enables CSP plants to adapt well to decentralized generation systems and to be connected to existing regional power generation. Since solar-thermal plants produce both heat and electricity, they can replace all or part of the energy requirements in some industrial applications.

Benefits – CPS plants are risk-free, they cannot explode, no nuclear waste or harmful carbon-dioxide emissions occur. Neither oil nor uranium is needed for operating theses plants.

Compatibility – Conventional turbines can be used to generate electricity from heat. Even much of the equipment now used for conventional power plants running on fossil fuels can be used for CSP plants. This integration into today's electric utility grid could make solar-thermal systems the most cost-effective solar option for large-scale electricity generation.

Prospects – CSP technology can be exported to developing countries. Not only Europe would benefit from this clean energy source but also states in the Middle East and North Africa would receive an area-wide and reliable power supply considering the estimate that their energy demand will have tripled by 2050. 68% of the generated solar energy are planned to remain in the producing countries and 13% are being used for the desalination of sea water or for generating cold or steam in the industry. According to the planned concept only 19% are exported to Europe.

[31] (Solar Power Tower)
[32] (The other kind of solar power, 2009)

Cons

Requirements – CSP systems are area-dependent. Best results can be achieved under really hot conditions and when the demand is high. Accordingly desert areas are best suited for large solar-thermal plants.

Because solar-thermal plants are thermal power plants and need a difference in temperature, cooling water in large quantities is required. Especially in desert environments big problems could be the result. But dry cooling instead of using water is increasingly used in new and planned plants. Also one major obstacle is the lack of transmission lines when building CSP plants in remote regions.

Reliability – In order to guarantee a steady supply of electricity the generated heat needs to be stored and converted to electric power. Normally the thermal energy can be stored in the form of hot, molten salt and therefore enabling to generate steam, and thus electricity, even when the sun is not shining. On average with 360 days of sunshine in the Sahara a solar-thermal plant delivers more reliable electricity than a coal kiln which needs to be periodically shut down for maintenance. The operators of CSP plants in Spain are already able to announce 30 hours in advance how much electricity and when they can deliver based on the actual weather forecast.

Costs- The relatively high costs of building a new solar-thermal power plant and the current economic climate of obtaining financing for CSP projects could result in delays of building new CSP projects. In addition, current CSP plants operate with costs around 20 cents per kWh and cannot compete with conventional power plants. But studies showed solar-thermal power to be viable with attainable costs of less than 10 cents per kWh in 15 to 20 years. [33]

Experimental Character – The total expenditure of projects like DESERTEC are very difficult to calculate.[34] Risks and imponderables are mainly based on assumptions that may not be accurate. Worldwide there are only a handful of CSP plants that are older than 20 years and can be used for long-term studies and experiences. Difficulties that are expected to arise as a consequence of hard desert climate include periodic occurring sand storms that could damage or destroy these plants. The costs for purchasing materials and through continuous abrasion could increase sharply.

Political Dependence – For maximum efficiency CSP plants need to be implanted in politically unstable countries in North Africa and the Middle East. The relationship between those is historically charged. However, the use of Solar-thermal technology could stabilize the relationships to these countries according to TREC. After all, both sides depend on each other. Employment and water supply in the energy-producing countries depend on the export of electricity.

Terror attacks - The few transmission lines could be targeted by terrorists and Europe's energy supply would be at risk. To be on the safe side, the DESERTEC concept plans to build many small solar-thermal plants with a capacity of 50 to 200 Megawatts at 20 locations instead of a few large ones. They cover whole North Africa from Morocco to Saudi-Arabia and are connected with several power lines to spread the risk.

[33] (Butscher, 2009)
[34] (Spiegel Online - Desertec III, 2009)

Conclusion

Feeding solar energy into gas power plants could be a breakthrough for CSP plants. The use of solar power in gas and steam power plants easily allows a parallel use of solar power to oil, natural gas or coal[35]. As a result, a smooth and cost-effective progression from fossil fuels to sustainable power generation could be initiated. When the sun shines, solar power operates the gas and steam turbines while at night or cloudy sky, natural gas will take over. To gradually increase the solar power generation to 100%, large thermal storage systems can be utilized. The stored solar generated power is then being used when needed, thus allowing a non-stop operation of the power plant. Storage systems are key technology to increase acceptance of CSP systems and help them penetrate growing energy markets.

In comparison to other power generation methods, Solar-thermal power plants offer an efficient, cost-effective and carbon-dioxide-free power generation solution with a high considerable potential in the sun-rich belt of the world[36]. Even though this technology was developed significantly in Europe (Germany and Spain), it will be deployed in the countries of southern Europe (especially in Southern Spain, Southern Italy, Greece) and Northern Africa and the Middle East as an important export technology.

The DESERTEC scenario is a description of how the future might look but no guarantee that this will happen. Rather, it provides information on what needs to happen to achieve that goal. Politics needs to lay the foundations with long-term contracts so that energy can be generated and exported from the desert within the next decade.

[35] (Bank Sarasin & Cie AG, Solarserver.de, 2007)
[36] (Fischedick, 2007, p. 48)

Bibliography

1973 oil crisis. (n.d.). *Wikipedia*. Retrieved 09 08, 2009, from 1973 oil crisis: http://en.wikipedia.org/wiki/1973_oil_crisis

Augustin Mouchot. (n.d.). Retrieved 09 02, 2009, from Wikipedia: http://en.wikipedia.org/wiki/Augustin_Mouchot

Bank Sarasin & Cie AG, Solarserver.de. (2007). *Solarserver*. Retrieved 09 01, 2009, from news: http://www.solarserver.de/news/news-7983.html

Butscher, R. (2009). Die Sonne macht Dampf. *Bild der Wissenschaft* , 10.

Desertec Foundation. (2009). *Desertec*. Retrieved 09 01, 2009, from http://www.desertec.org/downloads/articles/DESERTEC-RedPaper_de.pdf

Deutsche Energie-Agentur GmbH. (2009). *renewables made in germany*. Retrieved 09 03, 2009, from solarthermische-kraftwerke: http://www.renewables-made-in-germany.com/en/solarthermische-kraftwerke/

Dish-Sterling. (2009). *Wikipedia*. Retrieved 08 28, 2009, from Parabolic reflector: http://en.wikipedia.org/wiki/Parabolic_dish

EU-Länder drohen Klimaziel zu verfehlen. (2009, 05 24). *FAZ Finance*. Retrieved 09 03, 2009, from fazfinance.net: http://www.fazfinance.net/Aktuell/Wirtschaft-und-Konjunktur/EU-Laender-drohen-Klimaziel-zu-verfehlen-8040.faz

Europe, B. N. (2009, 07 09). *BBC News*. Retrieved 09 03, 2009, from Climate targets around the world: http://news.bbc.co.uk/2/hi/europe/8142342.stm

Fischedick, P. H. (2007). *Erneuerbare Energien.* München: C.H.Beck.

German Aerospace Center (DLR). (2009). *DLR Energy research in images*. Retrieved 09 01, 2009, from German Aerospace Center: http://www.dlr.de/en/desktopdefault.aspx/tabid-4884/8109_read-13234/

Infranet Lab. (2009, 01 11). Retrieved 09 02, 2009, from Infrastructure networks environment: http://infranetlab.org/blog/2009/01/from-ego-to-energy-towers-of-power-revisited/

Jülich, S. I. (n.d.). Solarturm Jülich. p. http://www.solarturmkraftwerk.de/de/technik.

Kempkens, w. (2009, 07). Sonnige Zukunft. *bild der wissenschaft plus* , p. 3.

Milch, I. (2007, 08 10). *Welt der Physik*. Retrieved 09 02, 2009, from Energie-Perspektiven 1/2007 (Jan 2007): http://www.weltderphysik.de/de/3957.php

Parabolic trough. (n.d.). Retrieved 09 03, 2009, from Wikipedia: http://en.wikipedia.org/wiki/Parabolic_trough

Solar Power Tower. (n.d.). *Wikipedia*. Retrieved 09 01, 2009, from Solar Power Tower: http://en.wikipedia.org/wiki/Solar_power_tower

Solar thermal energy. (2009). *Wikipedia*. Retrieved 08 28, 2009, from Solar thermal energy: http://en.wikipedia.org/wiki/Solar_thermal_energy

Solarturm Jülich. (n.d.). Retrieved 09 03, 2009, from Solarturmkraftwerk: http://www.solarturmkraftwerk.de/de/hgf

Spiegel - Desertec II. (2009, 06 22). *Spiegel Online*. Retrieved 08 30, 2009, from Wirtschaft: http://www.spiegel.de/wirtschaft/0,1518,631699,00.html

Spiegel - Desertec. (2009, 07 01). *Spiegel Online*. Retrieved 09 06, 2009, from Spiegel Online - Wirtschaft: http://www.spiegel.de/wirtschaft/0,1518,632880,00.html

Spiegel Online - Desertec III. (2009, 07 13). *Spiegel Online*. Retrieved 08 29, 2009, from Wirtschaft: http://www.spiegel.de/wirtschaft/0,1518,635811,00.html

The other kind of solar power. (2009, 06 04). *The Economist*. Retrieved 08 30, 2009, from The Economist print edition - Technology Quarterly: http://www.economist.com/sciencetechnology/tq/displayStory.cfm?story_id=13725855

List of figures

Pictures 1, 3, 4, 5, 6, 7 and 8 taken from: (German Aerospace Center (DLR), 2009)

Picture 2 taken from: (Milch, 2007)

Pictures 9 to 11 taken from: (Infranet Lab, 2009)