

Macro- Engineering: a Challenge for the Future
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Chapter 3

LARGE-SCALE CONCENTRATING SOLAR POWER (CSP) TECHNOLOGY

Solar Electricity for the Whole World

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Abstract:

Solar energy is the most abundant source of energy for mankind. Concentrating solar power (CSP) will become just as cheap as electricity from coal fired power stations or nuclear power plants. Operation S(un) is the macro-engineering approach for the implementation of solar energy on the globe. After an investment of 6.3×10^{12} dollar (which is 15% of the global Gross Domestic Product of one year) the solar thermal power stations produce just as much electricity as the global electricity consumption in 2003. One half of the plants is located at the coasts and their waste heat is applied for the desalination of seawater. The production of these stations satisfies the global municipal consumption of fresh water.

Key words:

Solar Energy, Solar Electricity, Solar Thermal Power, Desalination, Solar Economy.

1. THE HISTORY OF AN EXPLODING PLANET.

The planet Earth, one of the smaller planets of the ordinary star called Sun, is experiencing a remarkable history. The conditions were favorable for the appearance of life. A tiny fraction of the energy of the solar rays was used to form complicated organic compounds together with oxygen from the carbon dioxide in the atmosphere and the water at the surface. A small fraction of these

compounds did not end up as carbon dioxide, but was stored in the soil of the earth, and a small fraction of the oxygen remained in the atmosphere. Oxygen is a chemically active element, nearly all chemical elements and all compounds of carbon with hydrogen burn readily. During the billion years of photosynthesis nearly all carbon dioxide in the atmosphere was replaced by oxygen, and a large store of chemical potential energy was created at the surface of the earth in the form of the plants in the biosphere. Nearly all this potential energy was stored in the earth's crust, in layers of coal, lignite, peat, oil, and gas. They are safely prevented from burning by layers of sediments and rocks.

After millions of years of storage of peat, lignite, coal, etc. the oxygen concentration in the atmosphere became so high that the potential energy of the plants became available. The second stage of life started. Animals do not obtain their energy from the sun, but from plants burnt inside their bodies, using the oxygen that is available now. A kind of equilibrium developed at an oxygen content of 20% and a carbon dioxide content of 0.2% in the atmosphere. The oxygen can do no harm, the fossil fuels are safely protected from the oxygen by thick layers of ground and rock, mainly consisting of oxides. The plants are protected from burning by their high water content.

Then, suddenly, enter mankind. The natural environment of man is the tropical climate. But after the discovery of fire, and after the discovery of the fossil fuels, mankind created a tropical climate in his houses, offices and public buildings over the entire globe. The natural time for resting is the night. But mankind created daylight in the streets, and in the houses and buildings. The natural limit of travel is one day on foot, but mankind created railways, cars, and airplanes, and the limit of traveling nowadays is the opposite side of the globe. The natural number of persons was limited by the yield from hunting, fishing and agriculture. But mankind has increased the output of agriculture tremendously. The population is growing exponentially, and there seems to be no limit to this growth. Right now the animal called homo sapiens is the most abundant species on earth, when measured in kilograms of living flesh.

Looking on a geochronological time scale, the proliferation of this single species appears as an explosion and it was made possible by a chemical explosion. The fossil fuels are returning to their ground states at an increasing rate, delivering their chemical energy to a mankind that is addicted to energy. The safe barrier between the components of the explosion oxygen and fuel is being removed by mankind at an accelerating rate. The explosion is now propagating at a rate of oxygen consumption equivalent to 2 ppm per year. At this rate the oxygen will have been removed from the atmosphere within 100,000 years, and all animal life, including homo sapiens, will have disappeared by then.

Long before that, other major changes of the global environment will have extinguished human civilization, and the global chemical explosion will come to an end. The most apparent physical effect is becoming visible: the rising average temperature on earth. Most scientists agree that this change of climate is the result of the anthropogenic greenhouse effect. The increased amounts of carbon dioxide (35%) and other greenhouse gases absorb an increasing fraction of the long-wavelength heat radiation originating from the surface of the earth that normally disappears into outer space.

1.1 Operation S.

Let us now seek the best macro-engineering approach to stop the chemical explosion. Mankind is unable to stop the consumption of energy. We can reorganize our economies such that the efficiency of using energy is increased, but this cannot compensate the accelerating consumption of energy in fast growing countries like China, India and Brazil.

The best macro-engineering approach is to harvest the energy of the sun, solar energy, and to stop burning fossil fuels. In this chapter we will describe a project on a really global scale, that is the construction of sufficiently large numbers of solar thermal power stations in order to generate the total global electricity consumption.

We will give this macro-engineering project of global dimension a name: Operation S that is Operation Sun.

2. GENERATION OF SOLAR ELECTRICITY TO FEED THE WORLD

Most people are familiar with Photo-Voltaics (PV) as the technology for harvesting solar energy. However, Concentrating Solar Power (CSP) is a technology which produces solar electricity at much lower cost than PV (IEA, 2004; Trieb, 2005). In a solar thermal electric power station the rays from the sun are focused by mirrors onto (i) the boiler of a conventional thermal power station, (ii) a Stirling motor, (iii) (in the future) a gas turbine. There exist two different types of mirrors, those with a line focus and those with a point focus. Most experience up-till-now is achieved with parabolic trough mirrors. A variant is the linear Fresnel reflector. Both systems have a line focus in which oil is heated, or water is boiled. Systems with a point focus are the solar tower with a field of mirrors having their focal point at the top of the tower, and the solar dish mirror. The linear Fresnel reflector will probably become the most economic CSP configuration, (Morrison, 1999), see Fig.1. In this chapter we calculate the capital investments that are necessary for the implementation of Operation S. All solar thermal power stations are of the type that is shown in Fig.1.

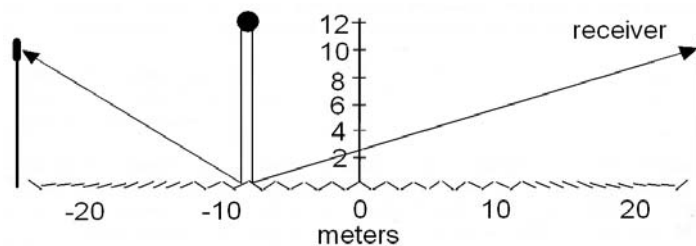


Fig.1

Schematic overview of the compact linear Fresnel mirror field of a solar thermal power station (Morrison, 1999). The long, flat, North-South oriented mirrors reflect the rays towards common receivers, which become extremely hot. Water which is pumped through the receiver is turned into high-pressure steam. During sandstorms or hailstorms the mirrors are inverted.

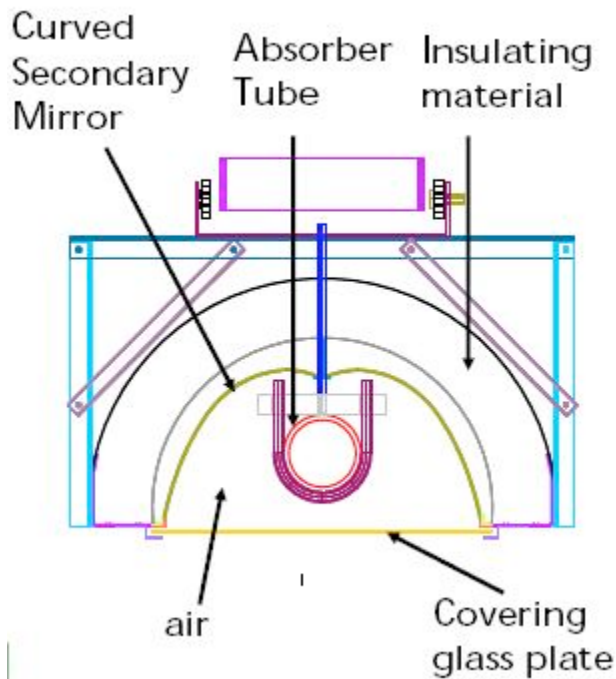


Fig. 2

The receiver. The central part is the high-pressure boiler tube. The tube is coated with a spectral-selective layer which absorbs the short-wave solar radiation and inhibits the emission of the long-wave infrared radiation due to its own high temperature, typically 400 °C. The tube is surrounded by a curved secondary mirror and a glass entrance window (Morin, 2005).

2.1 Calculation of the required area of mirrors

In the year 2003 electricity was consumed at an average rate 1686 GW (NEIC, 2005) which is 266 Watt per capita. The total amount of electric energy consumed in 2003 was 1686 GW x 365 x 24 hours = 14770000 GWh = 1.477×10^{13} kWh, (NEIC 2005).

The intensity of the solar radiation before entering the atmosphere is 1367 W/m². So an area of 1233 km², just 35 x 35 km, receives just as much solar energy as the global consumption of electricity. Unfortunately a cluster of solar power stations with a total surface of 1233 km² will never produce 1686 GW. Many physical effects are spoiling the game:

- a. Absorption and scattering of sunlight in the atmosphere, leading to a reduction with an absorption factor τ . The Direct Normal Irradiation, DNI, is equal to 1367τ W/m².
- b. The horizontal Fresnel mirror field is generally illuminated by oblique solar rays, leading to a reduced perpendicular irradiation $I_{hor} = \text{DNI} \cos \theta_z$; the zenith angle θ_z is the angle between the solar rays and the perpendicular.

- c. Water droplet clouds and dust clouds. The thousands of solar power stations are expected to be located in climates where clouds are virtually absent.
- d. Optical loss in concentrating the solar heat to high-temperature heat, we estimate this loss factor to be 50%.
- e. Loss in generating electricity from high-temperature heat, including the parasitic losses of the pumps; we estimate the net electric production to be 30% of the high-temperature heat.

The efficiency of the solar thermal power plant is the product of the effects d and e: 15%. Photovoltaic cells have the same efficiency, which is a remarkable coincidence.

The reduction effects a and b depend on the geographical location of the plant. We choose a representative latitude $\varphi = 28^{\circ}$, which corresponds to optimum locations for CSP plants such as Northern Mexico, Southern Morocco, Central Egypt, Kuwait, New Delhi (India), South-West China, Northern Chili, Central South Africa, and Brisbane (Australia). The absorption factor τ depends on the path length of the sunlight through the atmosphere, which in turn depends on the zenith angle θ_z . As θ_z depends on the time of day and the time of year, the irradiation on the horizontal mirrors I_{hor} must be integrated over the day in order to obtain the average irradiation on the mirror field as a function of date. Such calculations were performed by Du Marchie (2005). Table 1 gives the results for the daily DNI and the daily I_{hor} for 4 different days of the year for a location at latitude $\varphi = 28^{\circ}$ North.

Table 1. Daily irradiation data for latitude = 28° North.

	December 21	March 21 and September 21	June 21
zenith angle θ_z at noon	51.5°	28.0°	4.5°
Daily DNI (kWh/m ² day)	5.67	7.53	9.09
Daily I_{hor} (kWh/m ² day)	2.59	5.02	6.70

The average daily Direct Normal Irradiation DNI is $7.46 \text{ kWh/m}^2\text{day} = 2723 \text{ kWh/m}^2\text{year}$. The average daily irradiation on the mirrors of the solar power stations is $4.83 \text{ kWh/m}^2\text{day}$ or $201 \text{ W}_{th}/\text{m}^2$ continuously. The efficiency of the solar thermal power plant is 15%, so $30.2 \text{ W}_e/\text{m}^2$ is available in the form of electricity.

The average citizen in the world consumes 266 Watt/person of electricity, which could be harvested from an area of 9 m² of mirrors. However, (i) these mirrors cannot be situated on the roofs of private houses like solar panels, but in large solar thermal power plants only, and (ii) a large part of the population is not living in the sunny climate which is needed for an economical operation of CSP plants. Their solar electricity has to be transported by means of long-distance transmission lines.

The total area of mirrors that is needed for producing the solar 1686 GW of Operation S is $1686 \times 10^9 / 30.2 = 55900 \text{ km}^2$ or an area of 236 x 236 km. The total space to be reserved in the deserts of the world for the solar power stations of Operation S is less than Holland and Belgium added together.

The electricity production per km² of mirror surface is 30.2 MW/km². An agglomeration of solar thermal power stations with the capacity of an average nuclear or coal-fired power station, 1 GigaWatt, occupies an area of 33 km².

During the day the mirrors receive much more solar heat than the steam turbines can handle. This extra heat is stored in insulated tanks containing molten salts. When the sun is low, hidden by clouds or absent at night, this heat is used for the uninterrupted production of 1686 GW of electricity. The storage losses are negligible.

2.2 Cooling and sea water desalination

Any thermal electric power station needs cooling. In the arid climate where the solar thermal power stations will be exploited cooling water is scarce, except in coastal regions, where sea water is available. The waste heat of these coastal CSP stations is extremely useful for the desalination of sea water. The product is distilled water, which can be used for producing drinking water, for irrigation and for industry. Fig.3 gives the simplified block diagram of a complete solar thermal power station with sea water desalination. The plant is equipped with an auxiliary gas or oil fired boiler that provides heat when the heat storage tanks are empty. Gradually, during the transition of the fossil-fuel based economy towards the solar economy, natural gas and oil will be replaced by solar-generated hydrogen. The Multiple Effect Desalination (MED) factory consists of some 15 distillation vessels in series, operating at decreasing temperatures and pressures. The production capacity per MW of electric capacity is about 1000 m³/day of distilled water. If one half of the solar thermal power stations needed for producing all the electricity in the world (Operation S) were equipped with sea water desalination, the water production would be 843 million m³ per day or 308 km³ per year. This is equal to the total municipal consumption of water in the world or 12 to 15% of the world consumption of water for irrigation.

2.3 Economic integration of solar thermal power stations in developing countries.

Many deserts are situated in poor developing countries with growing populations and weak economies. The construction of solar thermal power plants requires much local labor and is of great importance for combating unemployment. The water from the solar desalination power stations is urgently needed by the municipal water utilities and by farmers. A good option is to operate the mirror fields at some elevation, 4 or 5 meters, and to utilize the underlying soil for advanced horticulture using drip irrigation (Nokrachy, 2004). Many vegetables need much less irrigation water when they grow in the semi-shade of the Fresnel mirrors (Bassam, 2004). A part of the irrigation water can be used beforehand for cleaning the mirrors.

The electricity is initially fed into the local grid, replacing oil, coal, or gas, and thereby relieving the national financial burden. Following the increase of the oil prices in 2004/5 the vulnerable economies of the developing countries are heavily burdened by the necessary imports of oil. Desert countries such as those in North-Africa that have rich energy importing countries in their neighborhood have the opportunity to export solar electricity. They can earn a significant part of their national income by exporting solar electricity and solar hydrogen. The Trans-Mediterranean Renewable Energy Cooperation is an international network of scientists that promotes a scenario for producing solar electricity in North-Africa and the Middle-East and for exporting a part of this electricity to Europe (Knies and Kabariti, 2004). The transportation of electricity over large (>1000 km) distances can be achieved by means of high voltage transmission lines transporting direct current, see Section 2.5.

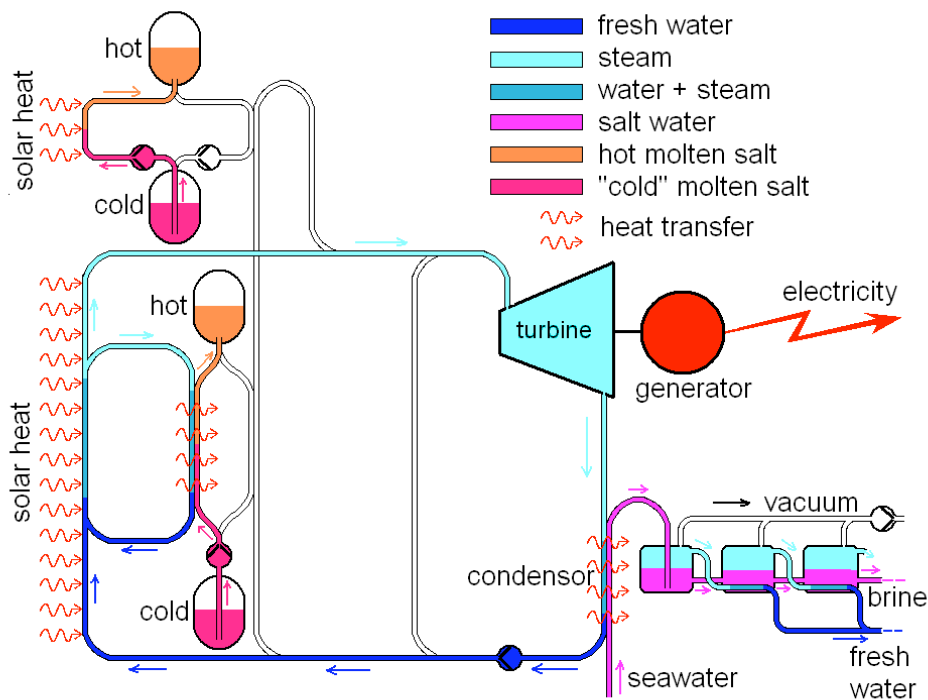
It is a common misunderstanding that solar energy is of no use to oil-exporting countries. When these countries are located in the sun belt they can choose between either continuing to produce all their electricity and desalinated water from oil and gas, or investing in solar desalination power stations for their local needs and selling the unused oil and gas otherwise needed for good prices on the world market. A sensible society chooses the latter option.

The optimum capacity of a solar thermal power plant is smaller than those of fossil-fuel fired or nuclear thermal power stations, which are typically 1 GW_e. The area of the collector field of a 1 GW_e solar power station would be 33 km², leading to an average transport distance for the steam from the receiver to the turbine of more than 2 km. The inevitable losses of this transport make a solar thermal power plant of this size unattractive. The optimum size is the result of a trade-off between these losses and the optimum size of the power block (turbine + generator). It will probably be around 100 MW_e. Many of these units will probably be combined and will together form one large solar thermal power station.

The transition of the world economy towards a solar society in a short time, say 25 years, requires an enormous stream of investments in solar thermal power stations in the sunny countries all over the world. The world market for solar electricity to be delivered to the (inter)continental grid will be highly competitive, and only large internationally operating solar exploitation companies will be able to negotiate the most attractive power purchase agreements with the buyers of electricity and to obtain the best concessions in the

desert countries. The management of the CSP stations has to be perfect and the working mentality has to be according to international standards. In many developing countries the culture of such efficient organizations will be regarded as rather alien and many large-scale projects fail. In many developing countries the culture and the existing economy favors artisans, small shops and farms, and disfavors paid employment.

Solar thermal power is able to meet this preference of the local people for economic independence, at least for a fraction of the working people. Fig. 4 gives a schematic bird's-eye view of a coastal CSP-desalination plant of 100 MW. The produced electricity is delivered to the grid and most of the produced water is pumped to the city nearby. By day the steam for the power block is produced in the 1.1 km² central mirror field that surrounds the central building. At the same time some hundred independent "solar farmers" operate their own mirror fields and gather solar heat at high temperature in specially designed, well insulated heat containers. At the end of the day the hot containers at the farms are replaced by cold ones, and the hot containers are transported to the central building over a narrow-track railway. At night the turbine consumes steam generated with heat from the containers. The solar farmers sell solar heat to the solar exploitation company and are paid pro rata in cash and in fresh water. The water is sufficient to produce food for their own families.



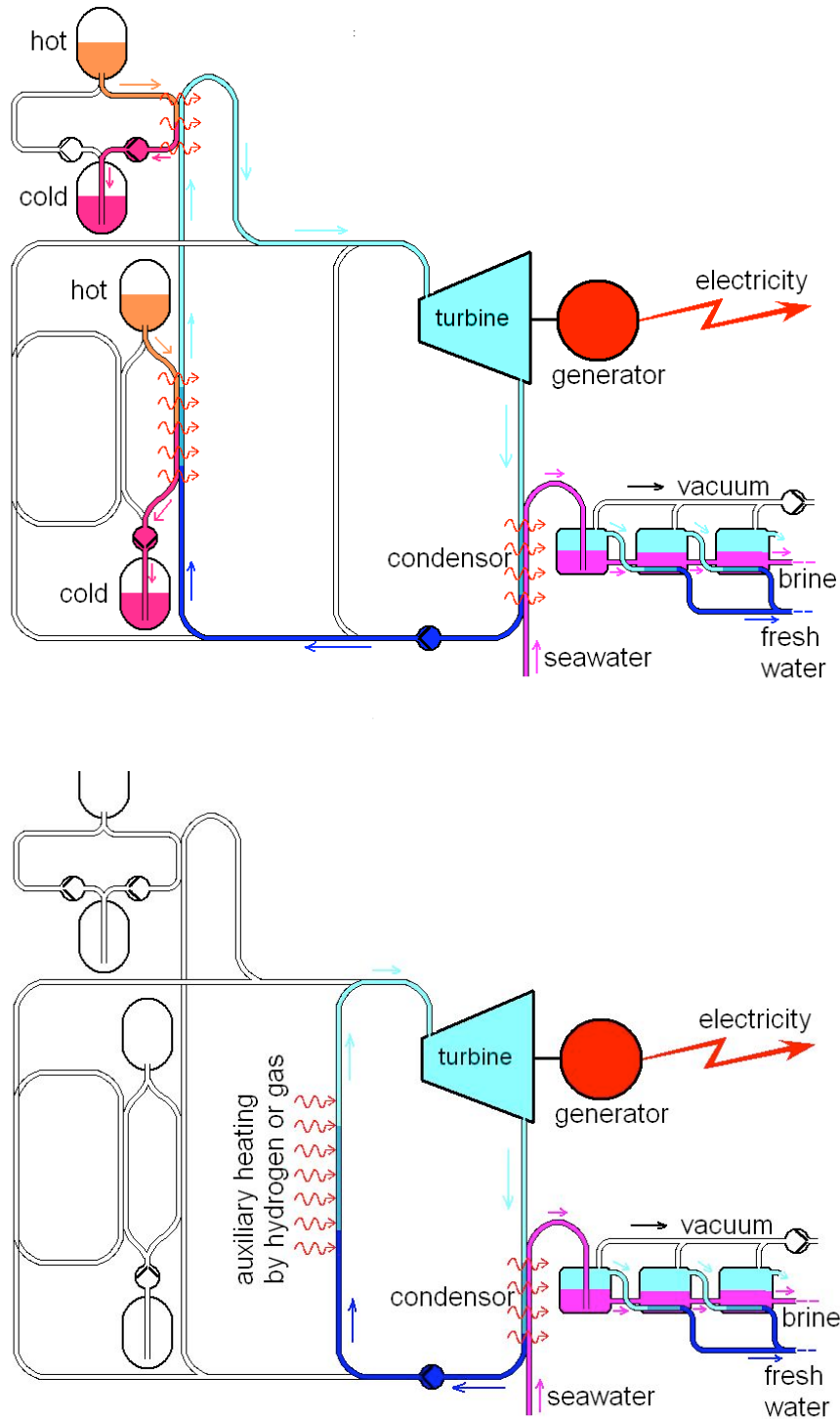


Fig. 3.

Block diagram of a solar thermal power station equipped with heat storage, auxiliary gas heating and sea water desalination in the three modes of operation. Top: solar operation at daytime, two thirds of the solar heat is stored in tanks containing molten salts. The upper tanks are destined for superheating the steam. Middle: operation at night, steam is produced out of the heat in the storage tanks. Bottom: operation on fossil fuel or hydrogen during cloudy days, when the heat storage tanks are empty.

2.4 Total cost of the solar thermal power stations needed for Operation S.

There are three ways to quantify the costs of an energy source: (i) the inventory of materials that are needed, (ii) the energy payback time, and (iii) the financial cost: dollars and euros, specified for a certain reference year because of the inevitable inflation.

At the solar energy department of the German institute for Aviation and Space, DLR, a thorough inventory has been made of the consumption of materials and energy during the construction and the exploitation of various types of solar thermal power stations (Viebahn, 2004). For CSP stations equipped with Fresnel mirrors, having a total capacity of 1686 GWe (continuous), the amounts of needed material are given in Table 2, together with the world production of these materials, and the production time needed when the total global production capacity is assigned to the construction of the power stations.

Table 2. Need of materials for producing all electricity with CSP.

material	CSP plants 1686 GW (Mton)	World production (Mton/year)	Production time for CSP plants (years)
steel	3370	1050	3.2
bauxite	3.05	144	0.02
copper	2.17	15	0.14

It is clear that steel production will become a bottle-neck in the transition toward the solar economy. The project is feasible, but improved engineering resulting in a smaller need for steel in the solar mirror field is an essential step to be made.

The energy payback time of a CSP station with Fresnel mirrors is 6.7 months. It was calculated in the following way. Keep account of all primary sources of energy (oil, coal, uranium, hydropower, etc.) needed for the construction of the equipment of the plants, transporting it to the site and for building at the site, including final decommissioning. Calculate the amount of electricity that could be generated from these amounts of primary energy. The solar power plant needs to operate a certain time to produce the same amount of electricity. This time is the energy payback time.

In the following paragraph, dealing with financial costs, euros and dollars are quoted directly from the literature, without any attempt to correct for inflation and without calculating any change of currency.

No new solar thermal power plants have been constructed during the last fifteen years. Therefore it is not easy to calculate the financial cost. Fortunately

contracts for two major projects have been signed recently, the 100 MW Andasol Project in Spain and the 500 MW Solar Dish Project in California.

The Andasol Project comprises two 50 MW CSP stations with 6 hours of thermal storage. The solar field consists of parabolic trough mirrors produced by the German firm Schott. The investment is 520 M€ all told (Flagsol GmbH, 2005) for a solar power station that produces electricity 14 hours a day. If these stations were to be upgraded to 24 hours production, the mirror field would have to be expanded by a factor $24/14 = 1.7$ and the heat storage capacity by a factor $16/6 = 2.7$. The cost of the mirror field dominates the total cost, so we estimate a factor 2 increase of investment costs, making 1040 M€ for a 100 MWe plant of base-load solar electricity, or €10.40 per watt of installed base-load generation capacity.

A Californian grid operating company has recently signed the power purchase contract with the Stirling Energy Systems company (PESNetwork, 2005) for 20,000 solar dishes of 25 kW each. The total investment will be 600 M\$ for a 500 MWe plant running at daytime only. If this project were to be upgraded to a 500 MWe base-load station, the number of parabolic dish mirrors would have to be tripled and some kind of heat storage would have to be added. We estimate the total investment of a dish-based 500 MWe base-load solar plant to be 2100 M\$, or \$4.20 per watt.

A very competitive solar power station using Fresnel mirrors has been proposed by the Australian company Solar Heat&Power (SHP, 2005) using a low-temperature 240 MW steam turbine and heat storage by means of underground pressurized hot water. A 240 MWe solar power station with a capacity factor of 68% would cost 496 M\$. According to their numbers upgrading to a base-load plant would increase the total investment to 708 M\$, or \$2.95 per watt.

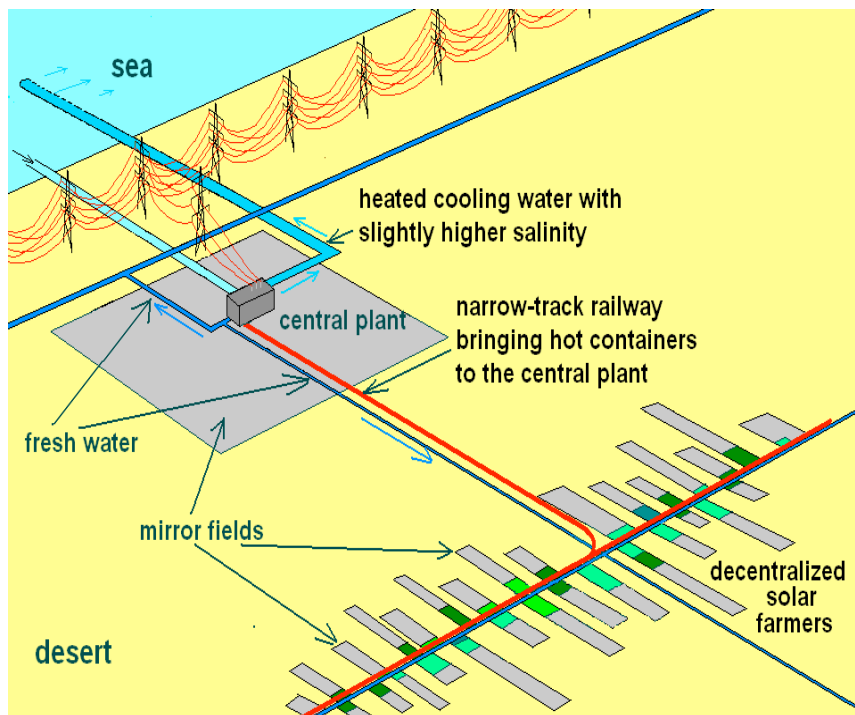


Fig.4

Birds-eye view of a coastal CSP-desalination plant of 100 MW surrounded by solar farmers. At daytime the independent solar farmer pump heat into containers. Hot containers are transported to the central plant and used for electricity

generation at night. The solar farmers are partially paid by means of fresh water.

The mirror field needs more than half of the investment costs for a base-load solar thermal power plant. The main emphasis for reducing the costs should therefore be given to the mirror field. At the moment these costs are 206 €/m² for parabolic trough mirrors (Pitz-Paal et al., 2005). Fresnel mirrors are cheaper, 120 – 150 €/m² (Bockamp et al., 2003) and 103 \$/m² (SHP, 2005) due to their more simple and more robust design. Therefore we have chosen to equip the thousands of solar thermal power stations that are needed for Operation S with linear Fresnel mirrors, see Fig.1.

As with any emerging technology the costs of CSP technology components will decline, following a so-called learning curve. In the scenario of TREC-DLR (Trieb and Knies, 2004; Du Marchie, 2004) the costs of parabolic trough mirrors drop from 320 \$/m² in 2006 to 124 \$/m² in 2020 and ultimately to 106 \$/m² in 2040. In the report by Sargent & Lundy, 2003, these costs decline from 234 \$/m² in 2004 to 181 \$/m² in 2020. There are no learning curve estimates available for Fresnel mirror fields, but starting from the current situation, 103 \$/m² to 150 €/m² it is not unreasonable to expect a reduction to 50 \$/m² in the future for the total cost of a linear Fresnel field.

For the investment costs of the power block and the desalination equipment we conform to the TREC-DLR scenario. We apply heat storage in molten salts for the future costs as quoted in the TREC-DLR scenario (Trieb and Knies, 2004). We assume that half of the solar power stations will be built at coastal sites, and that these stations will be equipped with Multiple Effect Desalination (MED) facilities. For the total investment see Table 3.

Table 3. Overview of the investments for the solar thermal power stations.

	Unit costs	Needed for 1686 GW	Investment (G\$)
Solar field	50 \$/m ²	55.9 x 10 ⁹ m ²	2793
Power block etc.	800 \$/kW		1350
Storage cost	9 \$/kWh _{th}	77560 GWh _{th} (15.3 hours)	698
Subtotal			4841
Desalination	800 \$/m ³ /day	½ : 0.843 x 10 ⁹ m ³ /day a)	675
Total			5516

a) A solar thermal power station with desalination produces 1000 m³/day per MW_e of installed continuous power.

In the start-up phase of Operation S the investment per GW_e solar capacity will be higher. These costs will decrease towards their saturation value because of learning effects well before 10% of all investments are made. Therefore we

hardly make an error in assigning this saturation value to all investments. So the total investment that is needed for the solar thermal power stations is about 5500 G\$, or 5500 billion dollar.

2.5 Total cost of the power lines from the solar power stations to the consumers

Large sections of the population live in regions where solar thermal power stations cannot be exploited because of excessive cloud coverage or geographical latitude. This is the case for most of the Europeans, the Russians, the Canadians, the Japanese, many Chinese, many Americans, and most people living in a tropical monsoon climate. The solar electricity has to be brought to them by means of High Voltage Direct Current (HVDC) transmission lines and sea cables. Europe for instance has to be supplied from North Africa by means of 3500 km long power lines and 50 km of submarine cables.

We make the rough estimate that one half of the population of the world can obtain electricity from CSP stations that are located within 500 km, and for the other half the solar electricity has to be transported over 3500 km. In the latter case the resistive loss of electricity together with the loss at the AC-DC conversion stations is 14.5% (Trieb 2004). This loss has to be compensated for by adding 7.25% to the world capacity of solar power stations. The additional investment is $7.25\% \times 4841 = 351$ G\$. The investment for 3500 km of power line, 50 km of submarine cable, and the conversion stations is 430 M\$/GW (Trieb 2004). The total investment for transporting the electricity is $\frac{1}{2} \times 1686 \times 1.0725 \times 0.430 = 390$ G\$. Together with the extra stations that are needed for compensating the resistive loss we arrive at 741 G\$.

2.6 Conclusion

The total investment that is needed for Operation S is $5516 + 741 = 6257$ G\$. This is the investment for producing 1.477×10^{13} kWh per year of electricity and 3.08×10^{11} m³/year of fresh water. This electricity and water is for free, because solar energy is free. The only costs are capital costs and operational costs. The capital costs depend on the interest rate and the period of repayment. When the power stations and the power lines are financed at a rate of 6% with a repayment period of 30 years, the capital costs are $0.07265 \times 6257 = 454.6$ G\$/year. The operational, maintenance, and insurance costs are estimated to be 3% of the investment, leading to 187.7 G\$/year. So the total cost is 642.3 G\$/year.

The annual production of solar electricity is 1.477×10^{13} kWh so the cost per kWh becomes \$0.0435, which will certainly be cheaper than all other methods for producing electricity.

Besides electricity the power stations also produce 308×10^9 m³ of fresh water annually. If this water is sold for \$0.50 per m³, the price of the electricity is reduced by one cent per kWh.

The total investment is just 15% of the Gross Domestic Product (GDP) of the whole world. If all countries invest 1% of their GDP in the solar infrastructure for the next 15 years, Operation S would become reality. The benefits are obvious. The consumption of coal would be drastically reduced and the consumption of oil would go down too, but at a lower rate. The production of radioactive waste would stop. The emission of carbon dioxide would decrease by about 30%. The most important benefit will be the proliferation of solar energy to other branches of energy. Solar hydrogen will be produced that will replace the oil in the transport sector. Additional solar power stations will produce extra electricity for heating houses and buildings by means of heat pumps. The global economy will be powered by renewable energy sources, and solar energy will provide the largest contribution.

The transition of electricity production from fossil fuel and uranium towards solar energy is a major operation, to be compared with the American space program in the sixties. When President Kennedy proclaimed: "Before the end of the decennium an American will walk on the Moon" a wave of enthusiasm swept through the nation and the objective was achieved. The world is now waiting new leaders who proclaim: "All electricity will become solar within a quarter of a century."

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