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SOLAR THERMAL POWER PLANTS FOR HYDROGEN PRODUCTION

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Abstract: Renewable power plants are needed, if a high amount of hydrogen shall be produced for the use in a climate-compatible energy market. Since the potentials of hydro and wind power are limited, solar electricity generation will take over an important part in the near future. Solar thermal power plants in the Mediterranean area are one promising option. After a short introduction to this technology, the potentials are pointed out. Solar powered desalination offers new opportunities for hydrogen production. The final cost estimation for hydrogen and solar electricity generation will show the potential of both technologies for a sustainable energy industry.

1. Introduction

One of the main questions to be answered when utilising hydrogen concerns the energy source for the hydrogen production. Renewable power sources with reasonable electricity costs are needed for the production of high quantities of hydrogen needed in a future climate compatible energy industry. Presently, only hydro and wind power plants at good sites can generate electricity in an acceptable cost range. The potentials of hydro and wind power, on the other hand, are limited. However, solar electricity generation is a nearly unlimited source. Photovoltaic is one promising technology. But the direct solar electricity generation will need at least two or three decades to bring the prices in a competitive range. On the other hand, prices for solar thermal power generation are only slightly above those of hydro or wind power.

2. Existing solar thermal power plants and upcoming projects

With 354 MW_e of solar electric generating systems (SEGS) parabolic trough power plants connected to the grid in Southern California since the mid-1980s, parabolic troughs represent the most mature solar thermal power technology. To date, there are more than 100 plant-years of experience from the nine operating plants, which range in size from 14 MW_e to 80 MW_e. All nine SEGS units continue generating electricity until today, demonstrating the reliability of this technology. Up to now, 9 TWh of solar electrical energy has been fed into the Californian grid, resulting in sales revenues of over 1,000 million US-dollars. Levelized electricity costs of about 12 to 14 US-cents/kWh_e have been reached with the last erected solar power plants [1]. For the background of the actual energy crises upcoming in the year 2000 in California the SEGS plants are some of the most cost-effective power stations in the state and are more competitive than ever before. Since the introduction of the power exchange market in California the electricity prices exploded dramatically; during some peak hours over 100 US-cents had to be paid for one kWh electricity.

Figure 1: Aerial view of the five 30 MW$_e$ solar parabolic trough plants at Kramer Junction, California (Courtesy of KJC)

The parabolic trough or solar farm consists of long parallel rows of identical concentrator modules, typically using trough-shaped glass mirrors. Tracking the sun from east to west by rotation on one axis, the trough collector concentrates the direct solar radiation onto an absorber pipe located along its focal line. A heat transfer medium, typically oil, at temperatures up to 400 °C, is circulated through the pipes. The hot oil then drives a conventional steam-power process

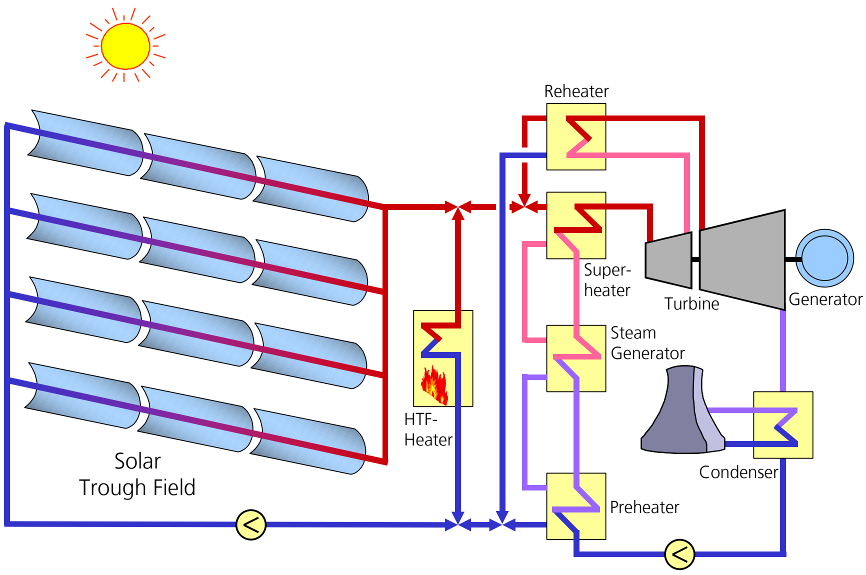

Figure 2: Schematic of a SEGS type solar trough power plant cycle

Another technology, the Solar Central Receiver or Power Tower is surrounded by a large array of two-axis tracking mirrors, termed heliostats, reflecting direct solar radiation onto a fixed receiver located on the top of the tower. Within the receiver, a fluid – water, air, liquid metal and molten salt have been

tested – transfers the absorbed solar heat to the power block where it is used to heat a steam generator. Advanced high temperature power tower concepts are now under investigation, which heat pressurized air up to over 1000 °C in order to feed it into the gas turbines of modern combined cycles.
New fed-in laws in Spain and World Bank funding promise good opportunities for the construction of new solar thermal power plants. In Spain several new projects are currently developed and the GEF (Global Environmental Facility), the environmental fond of the industry countries managed by the World Bank will support the erection of solar thermal power plants with 50 million US-dollars in Egypt, India, Mexico and Morocco.

3. Potentials for solar thermal power plants regarding hydrogen production
Resource assessment for solar power has recently become very easy, in fact much easier than for fossil or nuclear fuels: the solar radiation intensity on the ground can be measured by remote sensing technologies using weather satellites and orbiting satellites around the world. With very high spatial (up to 1 km) and temporal (up to 1h) resolution and accuracy, those technologies provide a reliable data base for the engineering and economic assessment of solar power projects, considerably lowering costs and risks in comparison to other energy prospecting activities [2].

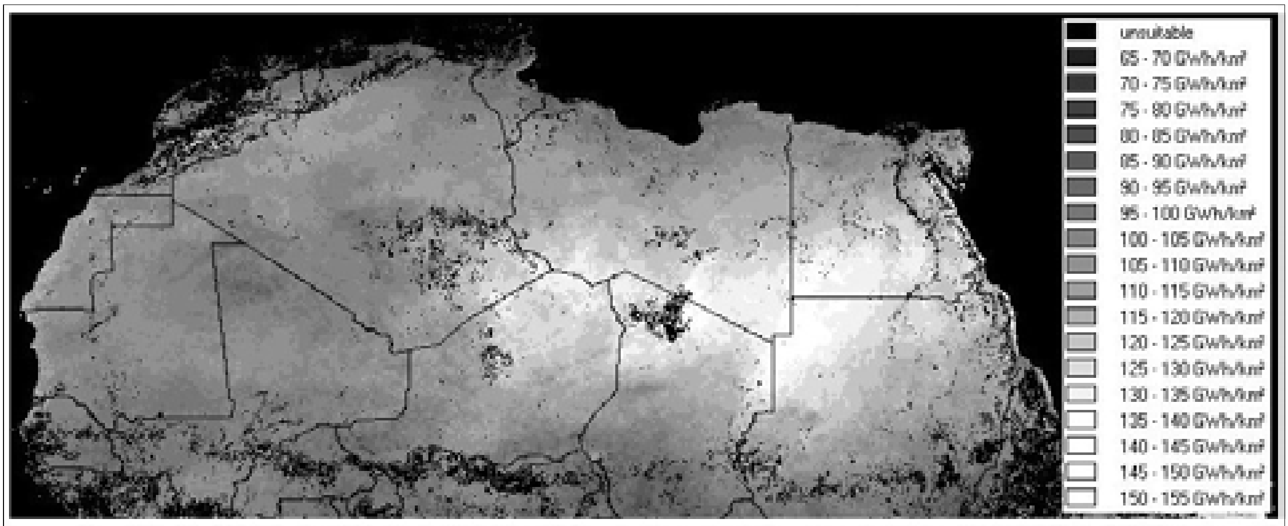

Figure 3: Annual Solar Electricity Yield of Solar Thermal Power Plants (200 MW_e SEGS) in Northern Africa. Total potential $13 \cdot 10^6$ TWh_e/year, World Electricity Demand in 1998 was $13 \cdot 10^3$ TWh_e/year [2].

The technical potential of solar power generation in Northern Africa exceeds the present world electricity demand by more than one order of magnitude. This huge potential can be activated only to a very small portion, as the regional demand for electricity is very limited, although growing steadily. In addition to that, solar electricity could be exported to the centres of demand in Europe, by high voltage direct current transmission lines (HVDC) or by means of solar hydrogen production. In this context, the generation of electricity and of desalted water for electrolysis is of particular importance.

4. Solar power and desalination plants

Solar Power and Desalination Plants (SP&D) combine commercially proven technologies to initiate a completely new era of clean electricity and water supply. The heart of the plant is a steam turbine powered by concentrating solar thermal collectors as in the Californian SEGS. A combined heat and power system (CHP) reuses the waste heat of the turbine for thermal seawater desalination, e.g. by the well known multi-stage flash (MSF) or multi-effect-desalination (MED) technology (Figure 4).

In the long term, many countries may not only cover a significant part of their electricity demand by solar energy, but may start to export solar electricity - or solar hydrogen produced by solar electricity. Using the waste heat of power generation, they also can produce large amounts of desalted water to develop agriculture and forestry in arid zones and in regions that are endangered by progressing desertification.

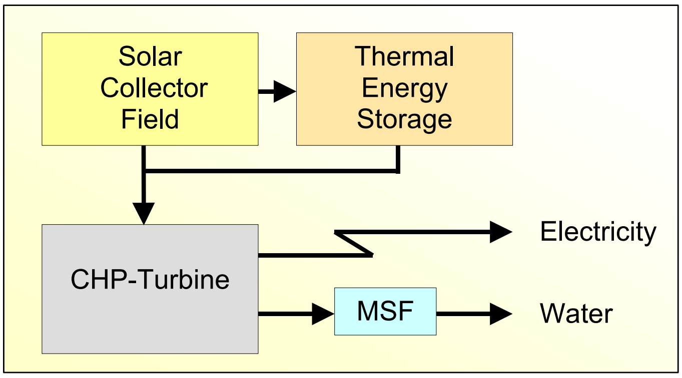

Figure 4: Sketch of a Solar Power and Desalination Plant with Combined Heat and Power System (CHP) and Multi-Stage Flash Desalination (MSF)

A Solar Power and Desalination Plant with 200 MW_e capacity operating e.g. 5000 full load hours will deliver approximately 1000 million kWh_e of electricity at 5 US-cents/kWh_e plus 40 million cubic meters of freshwater at 1.5 US\$/m^3 per year (interest rate 10 %/year, economic lifetime 25 years, investment 3500 US\$/kW_e) [3]. Such plants would start today with a 40 % solar share and reach 100 % solar share in about 10 years, making use of solar thermal storage technology. An equivalent base load plant with e.g. 8000 operating hours per year would deliver approximately 1.5 billion kWh_e/year of electricity at 3.5 US-cents/kWh_e and 60 million m^3/year of freshwater at 1 US\$/m^3, respectively. The present layout of such a base load plant would have 25 %, a future layout in about 10 years 60 % solar share or more.

Hydrogen generation with high-pressure electrolysis will cost additionally about 2 to 5 cents/kWh_{H2} and transportation below 1 cent/kWh depending on the number of full load hours [4,5]. Using these assumptions the total costs of hydrogen in Middle-Europe will reach about 7 cents/kWh_{H2} for solar and fossil hybrid co-generation and up to 16 cents/kWh_{H2} for solar only power generation.

4. Perspectives for future cost reductions and hydrogen utilisation

In the above mentioned cost estimations decreasing electricity generation costs are assumed due to an increasing number of installed solar thermal power capacity. Prices in the range of 5 to 8 cents/kWh_e of generated electricity can be expected in the medium term for solar only operated thermal power plants (Figure 5).

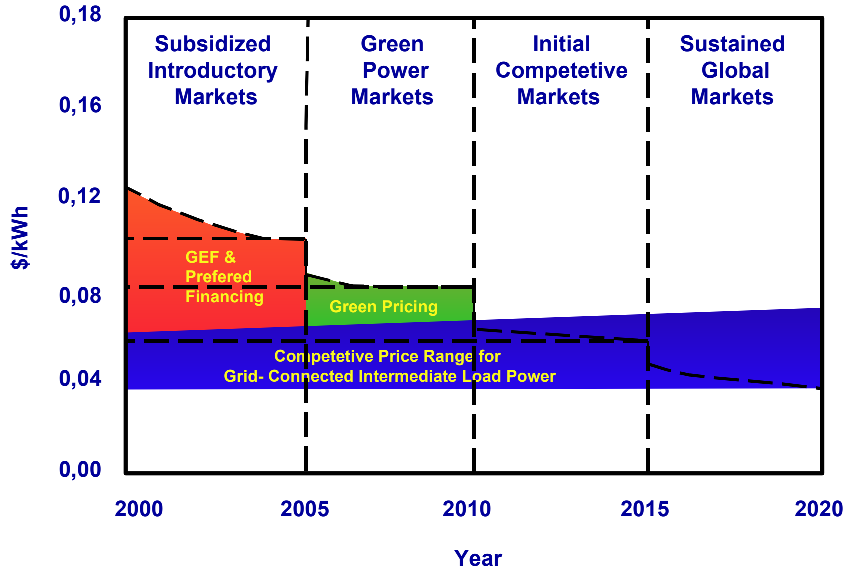

Figure 5: Market introduction of solar thermal power technologies with initial subsidies and green power tariffs (SunLAB, USA)

With electricity transportation costs below 2 cents/kWh_e using high-voltage DC transmission solar generated electricity from solar thermal power plants in Northern Africa may be available for 5 to 9 cents/kWh_e in Europe. In other words, direct electricity generation and transportation will be less expensive than hydrogen production, transportation and regeneration to electricity. However, hydrogen produced with electricity from solar thermal plants will be one major option for clean fuel alternatives and electricity supply when storage possibilities are needed. Together they are key technologies for a sustainable energy industry with a main focus on climate protection.

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