# COMPETITIVE SOLAR THERMAL POWER STATIONS UNTIL 2010 - THE CHALLENGE OF MARKET INTRODUCTION

Franz Trieb
German Aerospace Center (DLR) - Institute of Technical Thermodynamics,
Pfaffenwaldring 38-40, D-70569 Stuttgart, Germany
Tel./Fax: ++49-711-6862-423/783, e-mail: Franz.Trieb@DLR.de

## ABSTRACT

Solar thermal power stations based on parabolic trough concentrating collectors can soon become a competitive option on the world's electricity market, if the market extension of this mature technology is supported by a concerted, medium-term programme capable of bundling the forces of industry, finance, insurance and politics. Technical improvement based on the experience of over ten years of successful operation, series production and economies of scale will lead to a further cost reduction of 50 % and to electricity costs of less than 0.06 US$/kWh for hybrid steam cycles and less than 0.038 US$/kWh for hybrid combined cycles, respectively. Until 2010, a capacity of 7 GW shall be installed, avoiding 16 million tons of carbon dioxide per year at an avoidance cost of 2.5 US$/ton. The SYNTHESIS programme comprises a total investment of 16 billion US$ and requires additional start-up funding of 6 %. The bulk investment volume and at least two third of the start-up funding is covered by private finance.

## REQUISITES OF MARKET INTRODUCTION

Introducing solar power into the electricity market requires certain requisites in order to become attractive to investors. The projects must offer:

- an acceptable technology,
- an acceptable profit, and
- an acceptable financial risk.

Solar thermal power plants using parabolic trough concentrating collectors can offer those items, if the projects are embedded in a programme as described here.

The electricity cost of solar thermal power stations has come down to 12 - 14 cents/kWh following an impressive learning curve since 1983 (Fig. 1). In terms of profit, electricity from solar thermal power stations is not yet competitive to fossil fired plants, but closer to competitiveness than any other solar technology.

Solar thermal power stations achieve the same availability and power flexibility as conventional power plants, because the solar collector performance can be extended by a thermal energy storage or complemented by a fossil backup burner. Parabolic troughs can be integrated to steam cycle- and to combined cycle power plants.

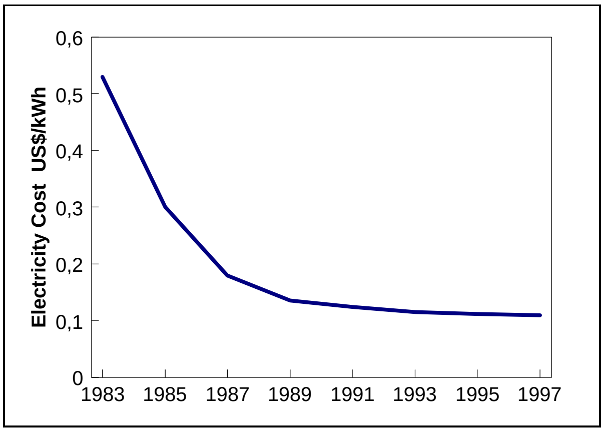


**Fig. 1: Learning curve of solar thermal power plants (Source: US-DOE)**

Nine Solar Electricity Generating Systems (SEGS) using parabolic trough concentrating collectors with a total capacity of 354 MW are presently installed in the United States, delivering about 800 GWh every year to the Californian grid (Kearney and Cohen 1997, Pilkington 1996). Today, the plants have generated revenues of more than one billion US$ (Fig. 2). With that maturity and experience, parabolic trough power plants bear no excessive technical risk for investors.

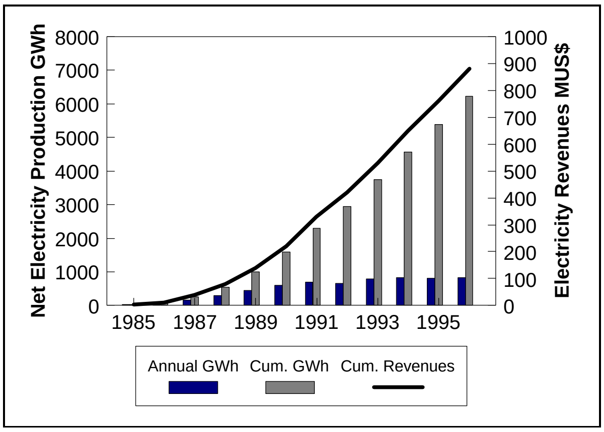


**Fig. 2: Performance of SEGS I-IX (Source: KJC Operating Co.)**

Export- and country-related risks are qualitatively the same as in conventional power projects. Though, the high investment elevates quantitatively the financial risk.

Thus, while the technical risk is already acceptable in case of the parabolic trough technology, the reduced profit and the financial risk require further measures to increase the acceptability of solar thermal power stations.

## A PLAN OF MARKET EXTENSION

In order to provide an acceptable internal rate of return to investors, there is a need for initial external funding and for a stable, medium term policy of support that allows solar industry to enter series production, to continue the learning curve and to reduce costs to a competitive level (Trieb et al. 1998). The combination of technical improvement and series production still holds a cost reduction potential of over 50 %.

Figure 3 shows how this potential can be exploited in a period of ten years, increasing the production capacity of today 1.2 million square meters of parabolic trough collectors per year to 10 million m²/a and reducing the electricity cost to less than 0.060 US$/kWh for hybrid steam cycles and less than 0.038 US$/kWh for hybrid combined cycles, respectively (Fig. 4).

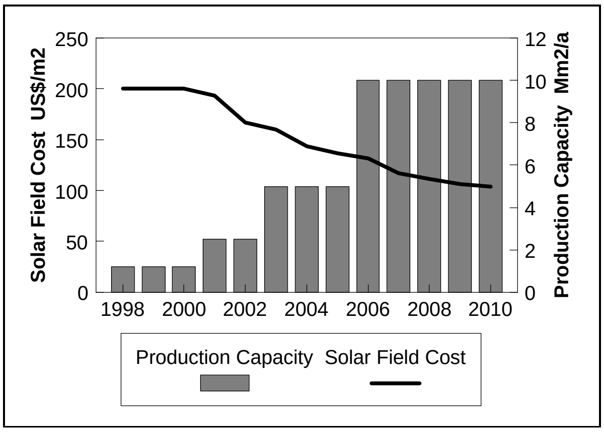


**Fig. 3: Cost reduction of the solar collector field by technical improvement and by increasing the solar field production capacity.**

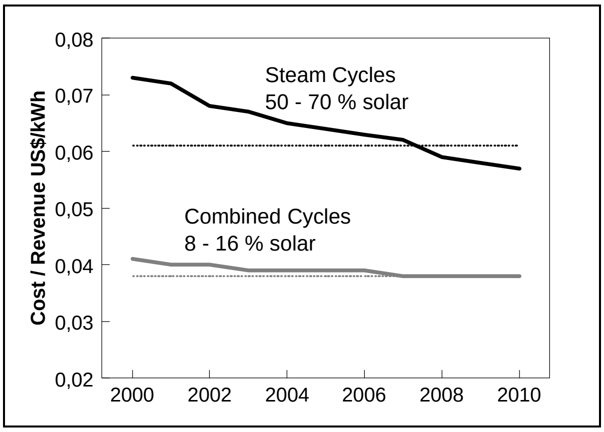


**Fig. 4: Electricity cost (solid lines) and expected revenues (broken lines) of hybrid steam cycles in medium load and hybrid combined cycles in base load. Parameters: average interest rate 8 %/a, economic life 25 a, insurance rate 1 % of investment per year, surcharge for contingencies 10 %, fuel price 4 US$/GJ, direct normal irradiation 2350 kWh/m²a, plant size 100 - 200 MW, after 2007 plants are installed with an integrated 6 hour solar thermal storage capacity.**

By 2010, approximately 50 power stations with a total capacity of 7 GW and with a total collector area of 63 million m² shall be installed, generating 25 TWh of solar electricity per year. At a rate of 0.7 kg/kWh, those plants will avoid 400 million tons of $CO_2$-emissions in 25 years of operation (Weinrebe et al. 1998).

Table 1 illustrates the corresponding plan of market extension within the SYNTHESIS programme.

Already 60 % of the recommended extension would suffice to achieve the required cost reduction. Integration of solar thermal storage will increase the annual solar share per plant and will open an additional potential of cost reduction after 2007.

**Table 1: SYNTHESIS - Programme**

- **Duration : 1998 - 2010**
- **Technology: SEGS & ISCCS**
- **Installed Capacity : 7 GW in approx. 50 plants**
- **Solar Electricity : 25 TWh per year**
- **Avoided $CO_2$ : 16 million tons per year**
- **Employment : 12,500 Persons**
- **Total Investment : 16 billion US$**
- **Required start-up funding : 1 billion US$**
- **LEC steam cycles < 0.060 US$/kWh**
- **LEC combined cycles < 0.038 US$/kWh**

FINANCING MARKET EXTENSION

In order to achieve an effective market extension, electricity prices have to be competitive starting with the first plants. The additional start-up funding necessary to bring down the electricity cost during the programme is of the order of one billion US$, distributed over a period of eight years, starting with 30 % of the investment for the first plants and coming down to zero in 2008 (Fig. 5). The necessary additional funding corresponds to 6 % of the total investment of 16 billion US$.

Grants from public funds are justified by a number of socio-economic benefits like e.g.: a reduction of the energy-related risk of adverse effects on health and environment, a diversification of primary energy sources, a potential exportation of solar electricity to neighbour- or industrial countries compromised in greenhouse gas reduction, positive effects on employment, a high national scope of supply during plant construction, the reduction of international conflict potential, saving valuable resources like oils and natural gas for other than burning purposes and finally the step into a sustainable electricity economy.

Funding is not necessarily restricted to grants. A number of possible measures of support avoid any cash flow from part of the donor. E.g., support can be provided by tax-incentives. Even an equalisation of the tax burden of fossil-fired and solar power plants helps to achieve competitiveness, because capital-intensive solar systems are strongly underprivileged in many of today's taxation schemes (Nathan and Chapman 1995). Similar measures are possible for an equalisation of custom duties.

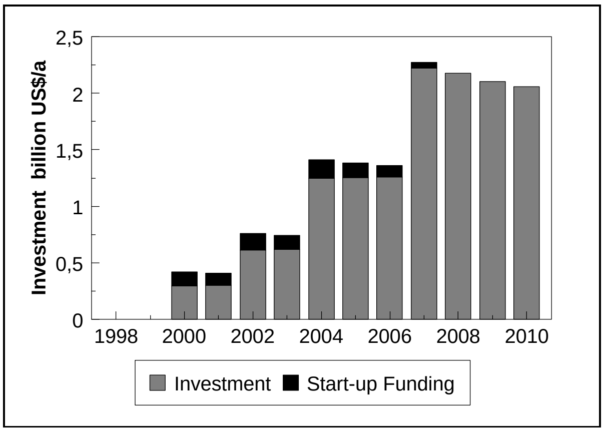


**Fig. 5: Investment and start-up funding necessary to realise the market development and the cost reduction shown in Fig. 3.**

Another possibility of support from the governmental side are guaranties and funds covering the financial risks of international projects. It must be underlined that the 6 % external funds necessary to finance the programme are in the same order of magnitude as surcharges for risk-control usually added to the costs by producers, investors and project developers. Avoiding those surcharges will reduce the capital cost and will effectively trigger market introduction.

Insurance and re-insurance companies world wide are realising that climate change caused by greenhouse gas emissions will directly affect their line of business. Low insurance fees for emission-free power stations can effectively reduce costs and accelerate market penetration as a preventive measure from part of the insurance business.

Substituting fuels by collectors leads to a large investment and to a high capital cost that is moreover inflated by taxes and interest rates. Thus, loans at low interest rates are particularly important for the market introduction of solar power.

Tradable certificates of avoided emissions in the frame of Activities Implemented Jointly (AIJ) can generate an additional income for solar thermal power stations. Such schemes are presently discussed by the United Nations Framework Convention on Climate Change (UNFCCC). Assuming that 400 million tons of $CO_2$ are avoided while an additional 1 billion US$ is required, a $CO_2$-credit of 2.5 US$/ton would suffice to finance the programme as a whole. Until 2010, the $CO_2$-reduction cost is reduced to zero.

As an example of a possible AIJ, an average car produces about 30 tons of carbon dioxide in an operational lifetime equivalent to 150,000 driven kilometers. That means that 75 US$ per car would suffice to compensate its total $CO_2$-emissions by solar thermal power stations installed within the SYNTHESIS programme. Adding this cost to 1.7 million new cars per year for eight years would suffice to finance the market introduction programme as proposed here (for comparison: in Germany approximately 3.6 million new cars are registered per year).

A combination of measures, bundling the forces of industry, finance, insurance and politics in a medium-term programme, creates a particularly attractive environment for private investors and reduces the need for direct subsidies. The projected scheme of finance is based on the following contributions (Fig. 8):

- Grants on the investment of a total of 175 million US$ as shown in Fig. 6 (the need for grants becomes higher by a factor of 2-3 if the total installed capacity is split into small units of well less than 100 MW each and if higher solar shares are required).
- Insurance and re-insurance covering losses of equipment and lost revenues with premium rates reduced to 0.8 % of the investment per year.
- Loans at an interest rate of 2 % per year for the first projects that gradually climbs to 8 % at the end of the programme (Fig. 6).
- Guaranties that reduce risk-surcharges by a rate of 20 to 1; that means, a guaranty covering 100 % of the investment will reduce the capital cost by 5 %, (Fig. 7).

As a matter of principle, support is initially strong and is then gradually reduced to commercial standards to the same extend as production costs decrease. The measures suffice to achieve an internal rate of return on equity of 15 % per year for all projects within the programme.

Tradable emission credits are assumed not to be available, but if so, they will increase the internal rate of return to over 15 %.

In spite of a much higher taxation load and a higher capital cost compared to conventional plants, after 2010 solar thermal power plants will be cost competitive without any further support.

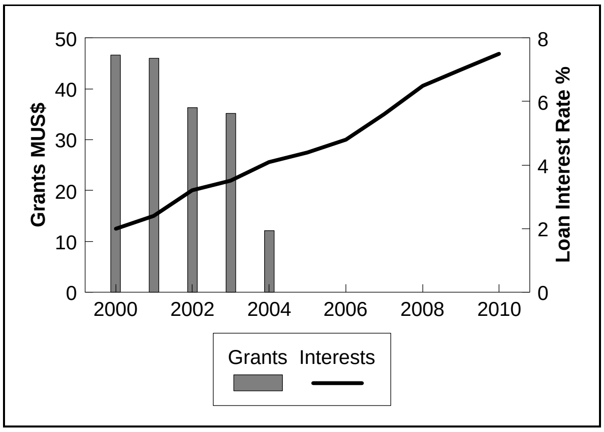


**Fig. 6: Grants and interest rates on loans projected to be available during the programme**

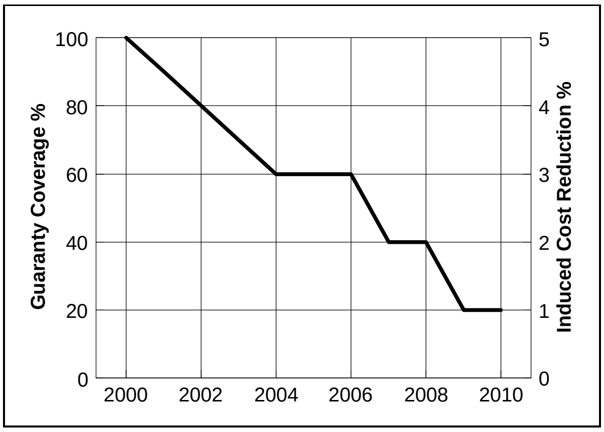


**Fig. 7: Guaranty coverage and corresponding reduction of capital costs**

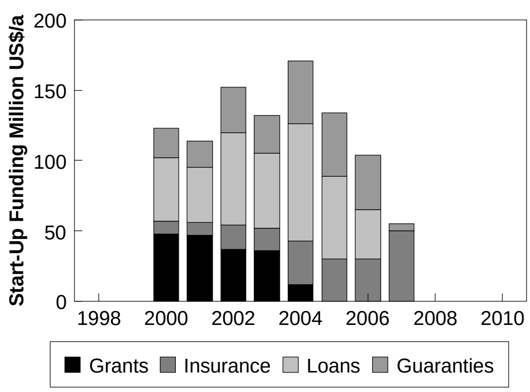


**Fig. 8: Projected contributions to the SYNTHESIS start-up funding by grants, reduced insurance premia, loans at low interest rates and guaranties**

## STARTING THE PROGRAMME

Presently, projects in Egypt, Greece, India, Iran, Jordan, Morocco and Namibia with a total power of 1.5 GW and an investment volume of approximately 2 billion US$ are in the pipeline, and consortia for project development and finance are built. The German Development Bank (KfW), the European Union and the World Bank (GEF) support some of those projects with grants and soft loans (Aringhoff et al. 1997). The private support within SYNTHESIS can effectively help to trigger and accelerate projects. A first project is already developed under this new frame of finance.

SYNTHESIS is supported by strong firms from the finance and insurance business that provide special conditions for solar thermal power projects (Fig. 9). As described above, this support reduces considerably the financial risk and offers acceptable profits to private investors.

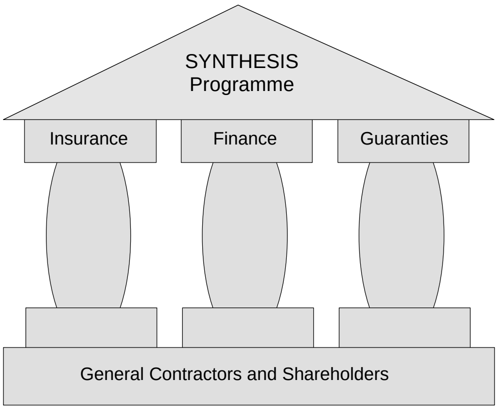


**Fig. 9: Insurance, finance and guaranties as a service pack for solar thermal power projects**

Potential project consortia, general contractors and host countries are now invited to make use of this opportunity in order to initiate the market introduction of solar thermal power plants.

## CONCLUSIONS

Solar thermal power stations are on the verge of competitiveness. Their market introduction requires a reliable, medium term programme until 2010 with strong initial support.

This support must cover finance and risk management at attractive conditions. It must generate acceptable profits for private investors, thus activating private funds for solar thermal power projects. DLR has succeeded in designing such a frame that is supported by the finance and insurance industry.

We expect that the conditions offered will raise a strong interest of private investors and entrepreneurs to initiate and realise a continuous line of projects that will complete the learning curve of solar thermal power.

We also expect a decisive support from the German government, the European Commission and from International Development Organisations in order to make this programme a success and to move ahead with determination towards a sustainable energy future.

## REFERENCES

Pilkington Solar International (1996). Status Report on Solar Thermal Power Plants, Köln

Nathan, W.H., Chapman, R.A., (1995). Tax Equity of Solar Electric and Fossil Power Plants, ASME Solar Energy Conf., Mauii, Hawaii

Aringhoff, R., Benemann, J., Nava, P. (1997). Emerging Solar Thermal Trough Projects - the proof for appropriate financing, in Becker, M., Böhmer, M. (Hrsg.): Proceedings of the 8th International Symposium on Solar Thermal Concentrating Technologies, C.F. Müller Verlag, Heidelberg

Kearney, D.W., Cohen, G.E. (1997). Current Experiences with the SEGS Parabolic Trough Plants, in Becker, M., Böhmer, M. (Hrsg.): Proceedings of the 8th International Symposium on Solar Thermal Concentrating Technologies, C.F. Müller Verlag, Heidelberg

Trieb, F., Milow, B., Nitsch, J., Knies, G. (1998). Introducing Solar Thermal Power Stations to the World Energy Market - A Chance for German Labour and Climate Protection Policy; Energiewirtschaftliche Tagesfragen

Weinrebe, G., Böhnke, M., Trieb, F. (1998). Life Cycle Assessment of an 80 MW SEGS and a 30 MW PHOEBUS Power Tower, ASME International Solar Energy Conference, Albuquerque

## ACKNOWLEDGEMENTS

Dear thanks to Dr. Gerhard Knies, Manfred Randecker and to the contributing firms for their invaluable support.