Solar Thermal Power Plants

408. Heraeus-Seminar „Energy Supply and Climate Change“
Dr. Henner Gladen, Lars Schnatbaum-Laumann, May 2008
Content

- Portrait of the Solar Millennium AG
- Potential of solar energy
- Parabolic-trough power plants
- Firm capacity and power generation on demand
- Solar chimney power plants
- Market development
- Import of solar power from north africa
- Cost of concentrating solar power – an example
Portrait of the Solar Millennium AG

→ Founded: 1998

→ Headquarter: Erlangen, Germany

→ Offices: Erlangen, Köln, Essen, Madrid (Spa.), Almeria (Spa.), Aldeire (Spa.), Berkeley (USA) …

→ Sector: Renewable energies (large scale solar power plants, 50-250MW)

→ Number of employees:
  Approx. 120 equivalent full-time

→ Board members:
  Christian Beltle (Chairman)
  Dr. Henner Gladen
  Thomas Mayer

→ Supervisory board:
  Helmut Pflaumer (Chairman)
  Hannes Kuhn
  Prof. Dr. Michael Fischer
## Business Model

<table>
<thead>
<tr>
<th>Solar Millennium AG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project-development</strong></td>
</tr>
<tr>
<td>Site selection and qualification</td>
</tr>
<tr>
<td>Permission process</td>
</tr>
<tr>
<td>Real estate procurement</td>
</tr>
</tbody>
</table>
Specialist for Solar Thermal Power Plants

We’re developing the future!

Solar Millennium AG

... is a successful pioneer thanks to the early entry into the market (1998)

... developed the first parabolic trough power plants in Europe

... is a technological leader in parabolic trough power plants

... enabled the first project-specific financing of solar-thermal power plants

... has strong growth due to flexible cooperation in the corresponding business sectors

... is supplying the technology for Egypt’s first parabolic trough solar field

... is developing a multitude of new projects worldwide
Fossil fuel based economy comes to its limits as environmental damages increase and prices are out of control

2008-05-21, US Energy Secretary Sam Bodman said that there was nothing the government could do to ease the pain of soaring fuel prices for consumers and added that a rise in speculative investment in commodities was not behind the rally.

"We have flat (oil) production ... and increasing demand. I don't think anything can be done near term," he said.

(source: Thomson Reuters 2008)

Crude oil prices have risen sixfold since 2002, coal prices quadrupled, gas prices more than tripled
Most oil producing countries outside OPEC are past peak production

Oil producing countries past peak

U. S. oil magnate T. Boone Pickens, who chairs the hedge fund BP Capital Management, projected that light crude will reach US$150 a barrel this year as demand outstrips supply. (source: www.financialpost.com, 2008-05-21)

More information @ http://www.energywatchgroup.org
Solar Energy is inexhaustible . . .

The yearly irradiation on earth amounts to 1.080.000.000 terawatthours – 60,000-times the global power demand.
... yields the highest energy density of renewables ...

Source: DLR

Every 10 km² in MENA yield 15 million barrels of fuel oil per year in form of solar energy
... potential sites are abundant

1 km² of desert land yields up to 200 - 300 GWh\textsubscript{el}/year
... equals 50 MW coal or gas power plant
... saves 500,000 bbl of oil / year
... avoids 200,000 tons CO2 / year
... can produce 165,000 m³ freshwater/day by desalination

Source: DLR
Solar Thermal Power Plants …

- utilize simple physical principles
- convert solar irradiation into heat and generate power with a conventional water/steam cycle
- allow large scale, climate friendly power generation: Power plants with 50 to 250 MW
- are located in the „sunbelt of the earth“
- is a collective term for different technologies; Solar Millennium AG focuses on parabolic trough power plants and solar chimney power plants
History of the parabolic-trough power plants

Egypt 1912: 55 kW power plant built by Shuman
California in the 1980’s

High oil prices triggered a boom for renewable energies.
Solar thermal power plants provide firm capacity during times of peak demand

Construction of SEGS* I - IX

- 9 power plants with 354 MWe
- 1.2 Bill. US$ investment
- 13 TWh power generation
- Revenues to date: 2.3 Bill. US$

* SEGS = Solar Electricity Generation System
Parabolic-trough power plants are a mature technology

→ Solar irradiation is concentrated 70-80 times on a receiver tube, which is situated in the focal line of a parabolic-trough mirror; the heat is picked up by a thermo oil, flowing inside the tubes, and transferred to a conventional water/steam cycle with a steam turbine and generator set.

→ Operation is possible in solar-only or hybrid mode (w/ natural gas co-firing)

→ Power generation is possible on demand; thermal storage and natural gas co-firing allow power generation independent from actual solar irradiation
Process diagram of a parabolic-trough power plant with molten salt storage and natural gas co-firing
Low CO$_2$-emissions and short energy payback periods

Greenhouse gas emissions (BMU 2002)

Energy Payback Period
- Solartherm. power plants: app. 5 month
- Windmills: 4 - 7 month
- PV in middle europe: 2 - 5 years
- Uranium, natural gas, coal, oil: never

CO$_2$-Reduction of an Andasol-type power plant compared to a modern hard coal power plant: 149.000 t$_{CO2}$/y
New developments – improved receivers by Schott Solar

Receiver is the Key Component in Parabolic Trough Collectors

The receiver achieves high efficiency with:
- low thermal losses
  (→ vacuum, absorber with low thermal emittance)
- high solar absorptance
  (→ efficient absorber, highly transmittent cover)
- minimum of shading
  (→ short bellows)
Enhanced mirrors by Rioglass Solar

Enhanced mirrors by Rioglass Solar

Development targets for mirrors

- Improve back side reflectivity, reduce front side reflectivity
- Reduce absorption
- Decrease energy consumption and cost of bending process
- Increase mechanical strength
- Implement cost effective mass production

Advantages of tempered glass:
Higher strength and smaller splitters
Current and advanced thermal storage technologies

**Andasol 1-3, molten salt storage**
- Storage capacity 1010 MWh (7.7h)
- Nitrate salts (60% NaNO3 + 40% KNO3)
- Salt inventory 28,500 t
- Tank volume 14,000 m³
- 6 HTF/salt heat exchangers

**Selection of R&D projects (DLR)**
- Demonstrate pilot scale concrete storage
- Further development of phase change material storage
- Solid media storage for Solar Tower with Air Receiver
Plant concepts currently in development

- Solar tower with direct steam generation (PS10/20, DPT550)
- Solar tower with molten salt (Solar tres)
- Solar tower with hot air and conventional boiler (STJ)
- Solar tower with gas turbine
- Parabolic trough with direct steam generation
- Parabolic trough with molten salt
- Parabolic trough with air
- Direct steam generation with Fresnel concentrator
Research and Development

→ Parabolic Trough Power Plant
  → Higher efficiency (e.g. direct steam generation)
  → More potential sites (e.g. dry cooling)
  → Expansion of the field of applications (e.g. desalination)

→ Biogas
  e.g. as a technology for hybrid power plants in combination with parabolic trough plants

→ Solar Chimney Power Plant
  as an alternative solar thermal power plant technology
Andasol 1-3: Largest site for solar power generation in the world

- 3x 50 MW
- app. 471,000 MWh/y
- app. 447,000 t/a CO₂-reduction
- 7.5 h thermal storage

Owing to the Andasol projects, Solar Millennium AG won the Energy Globe World Award 2008 in the category „fire“.
Parabolic-trough solar power plant Andasol 1
Andasol movie
Characteristic data of Andasol 1-3

per power plant:

→ 512,000 m² collector area (= 70 soccer fields)

→ Thermal storage for 7.5 baseload hours almost doubles power generation of each plant – about 180 GWh (gross) per year

→ Water/steam cycle with 50 MW steam turbine and wet cooling towers

→ 149,000 to/y CO₂-reduction compared to a modern hard coal power plant

→ about 300 Mio. Euro investment
W/o large storage facilities for electricity, power generation needs to match power demand

Spain: Demand and power generation by windmills on a summer day

High peak load during daytime ($\Delta \sim 16.000$ MW)

Feed-in by windmills mainly during night times
Andasol, operation w/ 7.5h thermal storage
Windpower is a fuel-safer but not firmly available during times of system peak

NREL: Wind output on 9/8/04 at the time of the system peak was 60 MW out of 2100 MW of installed capacity (<3%).
Solar Chimey Power Plant
Principle function of a Solar Chimney Power Plant
Principle of energy storage

Day:
- Sunlight enters through a glass roof.
- Heat is transferred into the soil and water tubes.

Night:
- Heat is transferred from the soil and water tubes into the air.
The capacity of the thermal storage is adapted to the load profile of the grid
Typical dimensions of a 100MW Solar Chimney Power Plant

**Chimney**
- Height: 1000m
- Diameter: 130m
- Wall thickn. bottom: 1m
- Wall thickness top: 0.25m

**Collector**
- Radius: 3500m
- Height outer radius: 3.5m
- Height inner radius: 35m

Yearly power generation: app. 700 GWh$_{el}$/y
The Highest Buildings in the World

- **Burj Dubai**
  - **Status**: 07-04-2008
  - **Height**: 629 m
  - **Planned**: 818 m

- **Taipei 101**
  - **Height**: 508 m

- **Petronas Towers**
  - **Height**: 452 m

- **Sears Tower**
  - **Height**: 442 m

- **Jin Mao Tower**
  - **Height**: 420.5 m

[http://www.burjdubai.com](http://www.burjdubai.com)
Prototype plant at Manzanares, Spain

- Chimney height: 200 m
- Collector-ø: 240 m
- 7-year testphase successfully completed
Advantages of Solar Chimney Power Plants

- No cooling water needed
- Base load plant
- Low generation costs for clean power
- Reduction of CO2 and other emissions
- Creation of many local jobs
Large Potential for Market Growth

MW solar-thermal power plants

900 Parabolic trough power plants (e.g. Andasol)

400 power plants

100 power plants

Studies

- Greenpeace/ESTIA 2005
- Sarasin 2007
- Greenpeace/EREC 2007
- DoE
- IEA min.
- IEA max.

Market potential and market development
Today 450 MW of CSP power plants are under construction

Spain: 370 MW CSP
Algeria: 135MW ISCCS with 30MW CSP
Morocco: 450 MW ISCCS with 30MW CSP
Egypt: 135 MW ISCCS with 20MW CSP
In Spain, the feed-in tariffs initiated planning and construction of more than 2150 MW of new CSP power.
Today, about 11GW of new CSP plants are planned worldwide, most of them waiting for political support.
How to implement renewable power generation?

The most effective and efficient means to enhance the utilization of renewable energies are feed-in tariffs, e.g. like in Germany, Denmark or Spain. In contradiction, quota and trade systems in other countries showed little or no benefit.
High-voltage-direct-currency (HVDC) transmission lines are necessary for the secure energy supply of Europe.

- Sites of solar thermal power plants
- Sites of other renewable energy power plants
Space required for 10 GW power transmission

AC     Alternate Current
HVDC   High Voltage Direct Current
UHVDC  Ultra High Voltage Direct Current

800 kV AC
425 m

600 kV HVDC
150 m

800 kV UHVDC
100 m

Source: DLR; trans-csp; June 2006
World largest HVDC line under construction in China: Remote hydropower Xiangjiaba - Shanghai

Main data
Commissioning year:
Pole 1: 2010
Bipole: 2011
Power rating: 6 400 MW
No. of poles: 2
DC voltage: ±800 kV
Length of overhead DC line: 2 071 km
Losses: < 7%
Main reason for choosing HVDC: Long distance

Source: ABB
Import of solar electricity is worthwhile & possible

In 2050 Concentrating Solar Power Plants in the Mediterranean Region will deliver twice as much electricity per year as wind, PV, biomass and geothermal plants together. (Med-CSP-Study by German Aerospace Center, DLR)

In 2050, about 15 % of the European electricity demand can be met by solar imports from the Middle East and North Africa. (Trans-CSP-Study by German Aerospace Center, DLR)

“We must use the chances provided by intelligent solar-politics across the globe, in order to promote economic development in a sustainable manner. This also prevents conflicts over raw materials or water getting out of control in the medium term...” (German Federal Foreign Minister Steinmeier)
Cost of CSP compared to our economic capacity … an example

In 2002 ExxonMobil and Shell were on rank 4 and 5 of the 10 most profitable companies in the world and accounted for 6.5% of world oil production.

What would have happened, if their additional profit since 2002 would have been spent into renewable energy, e.g. CSP plants?

Between 2002 and 2007, additional profit due to rising oil prices accumulated to **170 Billion US$** for both companies.
For 170 Billion US$ we can …

- Install 56.7 GW of parabolic trough plants …
  = 42.9% of installed power plant capacity in Germany

- Generate 141.7 TWh/y renewable power (RE)
  = 164% of actually generated RE in Germany

- Reduce CO₂ emission by 131 Million to/y
  = 15.3% of CO₂ emissions in Germany

With a GDP of 3,322 Billion US$ in 2007, Germany is the third largest economy in the world. All comparison data for Germany from 2007.
We don’t need rocket-science with the promise of a bright but distant future

- Right now, we need the large scale deployment of available technology to bring down production cost
- We need increased R&D efforts to further enhance efficiency of solar energy conversion and decrease installation cost
- We have to start planning high capacity transmission lines to allow for on-demand production and distribution of renewable power.
Welcome to the Solar Millennium!
Any questions?

<table>
<thead>
<tr>
<th>Contact:</th>
<th>Lars Schnatbaum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adress:</td>
<td>Solar Millennium AG</td>
</tr>
<tr>
<td></td>
<td>Naegelsbachstr. 40</td>
</tr>
<tr>
<td></td>
<td>91052 Erlangen, Germany</td>
</tr>
<tr>
<td></td>
<td>Tel.: +49 (9131) 9409-0</td>
</tr>
<tr>
<td></td>
<td>Fax: +49 (9131) 9409-111</td>
</tr>
<tr>
<td></td>
<td>E-Mail: <a href="mailto:info@SolarMillennium.de">info@SolarMillennium.de</a></td>
</tr>
<tr>
<td></td>
<td><a href="http://www.SolarMillennium.de">www.SolarMillennium.de</a></td>
</tr>
</tbody>
</table>
Contact

Contact Person: Dipl.-Ing. Sven Moormann
(Head of Corporate Communications)

Address: Solar Millennium AG
Nägelsbachstr. 40
91052 Erlangen
Germany
Tel.: +49 9131/9409-0
Fax.: +49 9131/9409-111
E-Mail: presse@SolarMillennium.de/
investor@SolarMillennium.de
www.SolarMillennium.de

Disclaimer:
The present presentation does not constitute a legally binding offer of participation or for the purchase of shares in the company. It is not to be viewed by the recipient as constituting the subject matter of a contract or as a contractual basis for investment. Only inquiries and assessments carried out by the recipient on his/her own account can form a basis for investment in the company.
The presentation has been compiled solely on the basis of the company’s business model and range of services, as well as on market and competitive environment research based on sources available publicly. No guarantee or warranty is provided for the accuracy, precision and completeness or for the interpretation of the data and the commentary, nor is any other form of liability for the content of this presentation acknowledged.
Budgeting is based on management assumptions and projections and reflects the market development and market opportunity perspectives at the time of compilation. The nature of the dynamic market environment is such that it is subject to constant changes and can therefore influence this budgeting content. No guarantee is provided for the budgeting feasibility.