SOLAR STEAM GENERATION WITH LINEAR FRESNEL CONCENTRATED SOLAR POWER TECHNOLOGY

1st Concentrating Solar Heat (CSH) Workshop
Amman Crowne Plaza, September 18-19
MAIN APPLICATIONS

- **Thermal Enhanced Oil Recovery**
  - Steam injection to increase amount of oil extracted from an oil field

- **Industrial steam or hot water**
  - Process steam for industrial consumers: food, mine, textile, chemical

- **Desalination**
  - Steam to produce soft water through multiple effect distillation (MED)
TECHNOLOGY CHOICE

INDUSTRY
LOW
Below 150 °C
150 °C
100 °C
Flat plate
Vacuum tube
Vacuum tube CPC
MEDIUM
150 to 400 °C
150 °C
Small parabolic trough / linear Fresnel without evacuated receiver
Concentrating dish
HIGH
> 400 °C
350 °C
Large parabolic trough / linear Fresnel with evacuated receiver
GENERAL PRINCIPLES
OPERATING PRINCIPLE

The mirrors follow the sun’s path throughout the day, concentrating the sunrays onto a receiver. Water circulating in the receiver is then heated to generate steam.
MODULAR CONCEPT

DIMENSIONS

- Length 67m
- Width 18m
- Height 10m
- Mirrors area 900m² (560 units)

OPERATING PARAMETERS

- Peak power 500kWth
- Saturated steam up to 100 bars or superheated water up to 300°C
DEMO PLANT LA SEYNE SUR MER, FRANCE
BENEFITS OF THE TECHNOLOGY

SIMPLE, ROBUST & MODULAR
- Direct steam generation
- Fix receiver, flat glass mirrors
- Modular & scalable
- Automatic cleaning system
- Designed for harsh environment

COST EFFECTIVE
- Standard materials
- Optimized design
- Low-cost components
- Light foundations
- Low OPEX with automatic cleaning
- Low land usage

STRONG LOCAL CONTENT
- Mobile workshop with local manpower
- Standard equipment purchased locally
- Local manpower for erection & operation

SIMPLE & RAPID INSTALLATION
- Simple design for simple erection
- Workshops on site
- Lightweight components for the solar field
- On-site installation from 3 to 16 months depending on size
FOUNDATIONS / PILING

REVERSIBLE FOUNDATIONS
- Pile can be removed
- No heavy concrete foundation on solar field
- Site can be returned to its initial state

RAPID INSTALLATION
- High precision installation
- High installation rate
- In parallel with solar field erection

IMMEDIATE LOADING
- No concrete drying time needed
- Metallic structure directly installed for optimized time schedule

ADAPTABILITY
- Different type of piles available (rammed, screw)
- Design optimized according to soil characteristics
- Adapted to non flat sites
METALLIC STRUCTURE

1/ Standard galvanized steel profiles
2/ Easy & fast erection
3/ Light erection means
4/ Design adapted to any kind of non flat site
REFLECTORS

1/ Profiled coated steel sheets with proprietary tools

2/ Stamped coated steel sheets with proprietary tools, assembly by clinching tools

3/ Patented design with low weight/high wind resistance/corrosion resistance

4/ Low iron solar glass mirrors with high reflectivity, each row bended at optimal curvature
Reflectors are produced on-site in dedicated workshops

- Easier & faster shipping, only flat glass and thin metal sheets shipped on-site
- Safer method
- Automated tools for optimized quality
- Quality control of produced reflectors
- Use of local manpower
- One workshop produces one module quantity in 3 shifts
TRACKING SYSTEM

1/ System ensures automatic focusing of mirrors rows onto the receiver

2/ Electric actuator, one per module, low electric consumption

3/ High precision inclination control for optimized focusing
- Non-evacuated tube with selective coating
- 3" (88.9mm) diameter tube, thickness & material according to specific design (stainless or carbon steel)
- Secondary reflector to enhance efficiency
- Protective glass panes made of heat and thermal stress resisting glass
MIRRORS CLEANING SYSTEM

UNIQUE PATENTED SYSTEM
- Patent on cleaning robot
- Patent on complete system with automated support
- Patent on optimized cleaning methods adapted to the environment

FULLY AUTOMATIC SYSTEM
- Cleaning sequence performed off-line before sunrise
- Automated water filling
- Automatic battery charging
- No operation team needed

LOWEST WATER CONSUMPTION
- Very efficient washing method with extremely low water spray
- Typically 1 cleaning every 2/3 days
- Can run on morning dew deposit w/o additional water spray

ADAPTIVE SYSTEM
- Operator can select the cleaning frequency & adapt according to the season
- Several cleaning methods adapted to different environmental conditions (i.e. desert)
MIRRORS CLEANING SYSTEM
PROJECT

1st commercial Fresnel to produce 20 GWh of electricity per year

85MWt CSP plant with 4 hours storage, Llo, France, under construction
Concentrated Solar Power thermal energy plants competitiveness are mainly influenced by Location (DNI) + Plant size + Financing cost

LCoS below 20€/MWh is achievable but still over marginal natural gas costs in many countries, hence the need for other drivers to trigger an investment decision (subsidies, carbon tax, Co2 certificates...)

### BUSINESS CASES

**Solar Steam Generator for a mine**

<table>
<thead>
<tr>
<th>Site conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual DNI</td>
<td>3,186 KWh/m²</td>
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<tr>
<td>Location</td>
<td>Chile</td>
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<tr>
<td>Solar field design data</td>
<td></td>
</tr>
<tr>
<td>Total number of modules</td>
<td>45</td>
</tr>
<tr>
<td>Mirrors area</td>
<td>40,446 m²</td>
</tr>
<tr>
<td>Land area</td>
<td>7 Ha</td>
</tr>
<tr>
<td>Maximum thermal power output</td>
<td>26,000 kW</td>
</tr>
<tr>
<td>Yearly thermal energy supplied</td>
<td>46,300 MWh (157,860 MMBtu)</td>
</tr>
</tbody>
</table>

### Cost of energy

<table>
<thead>
<tr>
<th></th>
<th>CAPEX</th>
<th>Average Cost of Steam (ACoS)</th>
<th>Levelized Cost of Steam (LCoS)²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.7M€</td>
<td>12.6 €/MWht</td>
<td>17.3 €/MWh</td>
</tr>
<tr>
<td></td>
<td>(240€/m²)</td>
<td>(3.2 €/MMBTu)</td>
<td>(4.4 €/MMBTu)</td>
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### Solar Steam Generator for EOR

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<tr>
<th>Site conditions</th>
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<tbody>
<tr>
<td>Annual DNI</td>
<td>2,144 KWh/m²</td>
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<tr>
<td>Location</td>
<td>Oman</td>
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<tr>
<td>Solar field design data</td>
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<tr>
<td>Total number of modules</td>
<td>960</td>
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<tr>
<td>Mirrors area</td>
<td>864,000 m²</td>
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<tr>
<td>Land area</td>
<td>150 Ha</td>
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<tr>
<td>Maximum thermal power output</td>
<td>550,000 kW</td>
</tr>
<tr>
<td>Yearly thermal energy supplied</td>
<td>772,878 MWh (2,637,808 MMBtu)</td>
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</thead>
<tbody>
<tr>
<td></td>
<td>174M€</td>
<td>12.3 €/MWh</td>
<td>17.1 €/MWh</td>
</tr>
<tr>
<td></td>
<td>(201€/m²)</td>
<td>(3.1 €/MMBTu)</td>
<td>(4.2 €/MMBTu)</td>
</tr>
</tbody>
</table>

¹ ACoS Considering CAPEX and OPEX only — 25 years lifetime
² LCoS Considering: Indexation of 3%pa and discount rate of 7% — 25 years lifetime
THANK YOU FOR YOUR ATTENTION!

Merci pour votre attention!

Данку для вашей Aufmerksamkeit!

Спасибо за внимание!

Gracias por su atención!