REDUCTION OF THE ENERGY CONSUMPTION IN THE MINING INDUSTRY BY SOLAR ENERGY

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Contents

- Overview of FCR – CSET
- Solar resource in Chile
- Energy demand of mining
  - Heat from Solar
  - Example projects
  - Optimization and design of plants
  - Electricity from Solar
- CSP and Polygeneration
  - Why storage?
  - Polygeneration and hybrid concepts
- Conclusions
Fraunhofer Solar Hub in Chile: CSET

- FCR: Fraunhofer Chile Research
- CSET: Center for Solar Energy Technology
- International Center of Excellence supported by CORFO-INNOVA
- Bundling the joint competence:
  - School of Engineering – Pontificia Universidad Católica de Chile
  - Fraunhofer ISE - Germany
- 2014: Process of installation and start up
- 2015: Start of operations in Chile
- Fraunhofer CSET is located in the Centre of Innovation at Campus San Joaquín, PUC

Objectives
Generate innovations for the large scale implementation of solar energy in major industrial, commercial and residential sectors in Chile.

- Investigate and address the scientific, technical, economic and market challenges facing solar energy in Chile
- Development of technological systems adapted to the specific conditions of Chile “from lab to market”
- Serve as a bridge between research and industrial enterprise
- Provide unique and advanced support to customers related to solar energy and energy efficiency
- Support state policies based on scientific methods, to increase the use of solar energy in Chile, e.g. in certification and strategic studies
- Education and training
**Fraunhofer CSET**

### Structure

#### Solar Electricity
- Solar resource assessment
- Off-grid and On-grid systems
- PV, CPV and CSP
- Quality, durability and soiling
- Grid Integration

#### Solar Heat for Industry
- Solar heat for industrial processes in mining, food, others
- Solar cooling for food industry
- Energy efficiency measures
- Solar polygeneration (heat, cold, electricity, water)

#### Solar Water Treatment
- Water Desalination
- Water purification
- Industrial water treatment
- Upconcentration
- Stand-alone systems MD, PV-RO
- Upscaling
- Prototyping

### Business Development
- Generating links, contacts and coordination with the industry and public sector.
- Contact with international organizations.
- Studies and strategic consulting to government agencies and private sector.
- Strategic support to the Research Lines.

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**Fraunhofer CSET**

### Activities

#### Research and Development
- Forecasting systems
- Durability and lifetime assessment
- Soiling impact and reduction
- High-temperature Thermal Storage Systems
- Polygeneration Systems Optimization
- Energy Efficiency Methodology

#### Technology Transfer
- Solar Technology for Water Treatment and Processing
- AgroPV Dual Use Technology
- Design and Optimization Methods for Thermal and Electrical Plants
- Technology Adaptation to Local Conditions

#### Studies and Specialized Consulting
- Evaluation Technical-Economic Feasibility
- Solar Resource Assessment
- Consultancy, Studies and Specialized Engineering
- Identification of PV and Solar Thermal Plant Failures
- Financing Models
Example Research & Development
Polygeneration and Hybrid PV-CSP Power Plants

- Development of advanced simulation models
  - Control issues
  - Operational optimization
- Investigation of high-temperature storage technologies and integration schemes
- Low-temperature processes like membrane distillation to use waste heat
- Integration concepts for heat in industrial processes
  - Storage use
  - Heat recovery

Example Technology Transfer
Solar Energy in Desalination and Water Treatment

- PV Driven Reverse Osmosis
- Membrane Distillation
- Water Desalination / Water Treatment / Solar Pumping
- Consultancy / Testing services for Mining / Energy Applications in progress
Example Quality Assessment
Monitoring from the air

Air monitoring of PV plants by drones
- Analysis of defects in modules using thermography from the air
- Detection of damage as hot spots
  - Reducing time
  - Reducing cost
  - Easy/fast failure detection

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**Solar Energy in Chile:**
* A valuable natural resource

Global Solar Horizontal Radiation GHI [kWh/m²-day]


No clouds -> Direct normal radiation
DNI: Up to 10 kWh/m²-day

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**Solar energy resource in Chile**

Source: Escobar et al. “Solar Energy Resource Assessment In Chile: Satellite Estimation And Ground Station Measurements”

Solar resource suitable for many applications:

- **Solar electricity**
  - PV, CPV
  - CSP + thermal storage
- **Solar heat**
  - Steam
  - Hot water
- **Clean water**
  - Desalination
  - Upconcentration waste
Arguments for Use of Solar Energy
... and against?

- High upfront investment and nearly negligible O&M cost (no fuel cost!) make SOLAR a business with long-term horizon
  - Energy costs are constant for 25 years to come!
  - Large demand for many years is positive for the business case
  - Financing options are needed for the investment
- Increasing number of installations will drive investment cost down
  - Know-How, trust and experience reduce the risk
  - Market increase will result in strong competition of providers

- Low fuel prices may suggest to wait for the moment
  - However the next energy crisis will strike – and then everybody wants it => resulting high prices, low quality and waiting times!

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Solar Heat

- **Key Component: Collector for Conversion of Solar Radiation into Heat**

  - **Solar Tower**: plant capacity ~ 10 - 120 MW<sub>el</sub>, operating temperature 600-1200 °C
  - **Dish**: unit capacity ~ 10-25 kW<sub>el</sub>, operating temperature 200-1800 °C
  - **Linear Fresnel**: plant capacity ~ 10-250 MW<sub>el</sub>, operating temperature < 550 °C
  - **Parabolic trough**: unit capacity ~ 30-250 MW<sub>el</sub>, operating temperature < 400 °C
  - **Vacuum tube, stationary CPC**: unit capacity ~ 1 kW<sub>th</sub>, operating temperature < 150°C
  - **Flat plate**: unit capacity ~ 1 kW<sub>th</sub>, operating temperature < 100°C

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**Solar Thermal Technologies**

![Diagram showing the relationship between operating temperature, plant size, and market penetration for different solar thermal technologies.](image)

- **CSP**: high market penetration, high operating temperature
- **Process Heat**: medium market penetration, medium operating temperature
- **SHC**: low market penetration, low operating temperature

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**Market available technology**
Mining Industry

Mining location in Chile

Annual average, total daily DNI

(www.consejominero.cl, 2007)

(Atlas Solar de Chile, 2013)

Copper extraction process

CODELCO, Copper Production Process
Copper mining

- Large demands around the clock
  - Electricity
  - Heat
  - Clean Water
  - Treatment of Waste

- Solar can provide a large part of the required energy
  - Space requirements
  - Financing of plants

Existing solar thermal plants in Chilean mining

<table>
<thead>
<tr>
<th></th>
<th>Gabriela Mistral (El Tesoro)</th>
<th>Minera Centinela</th>
<th>Minera Constanza</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Production or Power rating</td>
<td>51,800 MWhth</td>
<td>24,800 MWhth</td>
<td>540 MWhth</td>
</tr>
<tr>
<td>Type of collector</td>
<td>Flat plate collectors</td>
<td>Parabolic Trough</td>
<td>Flat plate collectors</td>
</tr>
<tr>
<td>Area</td>
<td>39,300 m²</td>
<td>16,700 m²</td>
<td>404 m²</td>
</tr>
<tr>
<td>Temperature supplied</td>
<td>45-51°C</td>
<td>80-85°C</td>
<td>47°C</td>
</tr>
<tr>
<td>Storage system</td>
<td>4,700 m³</td>
<td>Yes</td>
<td>25 m³</td>
</tr>
<tr>
<td>Portion of heat supplied</td>
<td>85%</td>
<td>55%</td>
<td>80%</td>
</tr>
</tbody>
</table>
Solar thermal energy integration

- Great potential for integrating solar thermal energy in electro-winning process
- Temperatures needed depend on the exact process
- Two solar plants already operating
  - 2010, Minera El Tesoro. Parabolic trough collector system. 16700 m² aperture area. 7.0 MWth. Turnkey project, executed by Abengoa, operated by Minera El Tesoro

Two solar plants already operating

- 2013, Gabriela Mistral - Flat plate collector system. 39000 m² aperture area. 32 MWth, 4700 m³ storage
- Consortium between Sunmark (Denmark) and Energía Llaima (Chile). Minera Gaby buys energy. Thermal Power Purchase Agreement contract for 10 years
Solar thermal at Gabriela Mistral

- 10 year contract
- Stable energy tariff US$/MWh + Fixed charge heaters O&M

- KPI: Electrolyte Temperature
- Has provided 10% more energy than contracted
- Diesel savings: 6,500 ton/year

Electro-winning process. Case study

- Expected copper production: 100000 tonnes/year (~12 tonnes/hour)
- We study two possible configurations to warm up the electrolyte.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>a)</th>
<th>b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corresponding notation</td>
<td>TProc70</td>
<td>TProc90</td>
</tr>
<tr>
<td>Heater inlet temperature (°C)</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Heater outlet temperature (°C)</td>
<td>70</td>
<td>90</td>
</tr>
<tr>
<td>Flow rate (m³/hour)</td>
<td>1200</td>
<td>600</td>
</tr>
<tr>
<td>Water specific heat (kJ/kg °C)</td>
<td>4.19</td>
<td></td>
</tr>
<tr>
<td>Heater efficiency (%)</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Energy supplied (MJ/hour)</td>
<td>59150</td>
<td></td>
</tr>
<tr>
<td>Diesel calorific power (MJ/kg)</td>
<td>44.8</td>
<td></td>
</tr>
<tr>
<td>Diesel consumption (m³/year)</td>
<td>13900</td>
<td></td>
</tr>
</tbody>
</table>
Results

Variable energy demand. Case 2

- Annual energy consumption decreases considerably (from ~14000 m³/year to ~8000 m³/year)
- As the storage size increases, the solar fraction increases. Solar system covers a significant part of the demand during the night
- Under no demand conditions
  - Worst case: after two days solar tank reaches 120 °C. Increasing solar storage capacity extend the period of time

<table>
<thead>
<tr>
<th>Solar field (m²)</th>
<th>30000 / 35000 / 40000 / 45000 / 50000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corresponding notation</td>
<td>AF_1 / AF_2 / AF_3 / AF_4 / AF_5</td>
</tr>
<tr>
<td>Storage capacity (m³)</td>
<td>4000 / 5000 / 6000</td>
</tr>
<tr>
<td>Corresponding notation</td>
<td>VT_1 / VT_2 / VT_3</td>
</tr>
</tbody>
</table>

Photovoltaic power plants

PV power production profile vs. load

- PV production follows irradiation with peak at noon
- CPV has slightly lower output because it only uses direct irradiance

Exemplary day (June 28th)  
Annual average
Why CSP?

CSP production profile vs. load

- On a good solar day, CSP storages are filled and the complete period of high load can be covered
- With large thermal storage, even 24/7 operation is possible
- Also the annual average shows the positive influence of storage
Capacity factors of CSP
CSP provides wide range of plant types with different CF

<table>
<thead>
<tr>
<th>Plant</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivanpah</td>
<td>33%</td>
</tr>
<tr>
<td>Andasol</td>
<td>40%</td>
</tr>
<tr>
<td>Shams</td>
<td>24%</td>
</tr>
<tr>
<td>Solana</td>
<td>43%</td>
</tr>
<tr>
<td>Gamasolar</td>
<td>75%</td>
</tr>
<tr>
<td>Kuraymat ISCC</td>
<td>77%</td>
</tr>
<tr>
<td>(solar 20%)</td>
<td></td>
</tr>
<tr>
<td>Hydro world avrg</td>
<td>44%</td>
</tr>
<tr>
<td>Coal avrg</td>
<td>63%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>up to 90%</td>
</tr>
<tr>
<td>PV max ~20%</td>
<td></td>
</tr>
<tr>
<td>Coal avrg</td>
<td>63%</td>
</tr>
</tbody>
</table>

Hybrid CSP / PV plants may lower cost for 24h supply

- **CSP**: Dispatchability using Thermal Energy Storage (TES) allows a generation of electricity in high-load situations, even at night time
- **PV**: Decreased investment cost due to the large market growth lead to much lower LCOE compared to CSP
- Combination of CSP + PV leads to low cost dispatchable solar power
- Copiapó 130 MW CSP-150 MW PV Chile (Solar Reserve)
- Redstone 100 MW CSP-75/97 MW PV South Africa (ACWA, Solar Reserve)
- Complejo Atacama 1+2, 110 MW CSP-100 MW PV Chile (Abengoa)

LCOE for HYBRID is lowered to about 60% when compared to pure CSP power plant with storage

Solar Polygeneration - Combined Heat & Power
Use reject heat additionally for other services!

- solar electricity
- integrated fossil fuel backup capacity, power on demand
- increased solar operating hours, reduced fuel input
- Many options exist for producing low temperature heat without cost for: process heat, cooling, waste water treatment, drying, desalination, etc.

Potential of CSP in Northern Chile
Case Study

- Technologies considered:
  - parabolic trough collector (PTC) & linear Fresnel collector (LFC)

- On 1 km² a PTC plant could have:
  - 52 MW nominal capacity
  - 120 GWh/year annual production

- On 1 km² a LFC plant could have:
  - 67 MW nominal capacity
  - 130 GWh/year annual production

CSP Potential for Northern Chile:

<table>
<thead>
<tr>
<th>Slope</th>
<th>Proximity to transmission</th>
<th>&lt; 1%</th>
<th>&lt; 20 km</th>
<th>&lt; 50 km</th>
<th>&lt; 20 km</th>
<th>&lt; 50 km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area [km²]</td>
<td>1235</td>
<td>1508</td>
<td>15894</td>
<td>23749</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equivalent installed power [GW]</td>
<td>PTC</td>
<td>64.7</td>
<td>79.0</td>
<td>832.1</td>
<td>1034.8</td>
</tr>
<tr>
<td></td>
<td>Generation [TWh]</td>
<td>PTC</td>
<td>147.4</td>
<td>180.0</td>
<td>1897.3</td>
<td>2834.8</td>
</tr>
<tr>
<td></td>
<td>Equivalent installed power [GW]</td>
<td>LFC</td>
<td>82.8</td>
<td>101.1</td>
<td>1009.3</td>
<td>1591.7</td>
</tr>
<tr>
<td></td>
<td>Generation [TWh]</td>
<td>LFC</td>
<td>160.6</td>
<td>196.1</td>
<td>2066.6</td>
<td>3087.9</td>
</tr>
</tbody>
</table>

28 times current ann. electricity production
Conclusion

- Solar energy can provide not only electricity, but also heat for mining processes like electro-plating (copper) -> reduction of electricity or fuel bill!
- Solar thermal energy plants can provide heat for drying or water treatment as a side product to electricity generation -> liquid waste treatment (zero liquid discharge) -> non-metallic mining industry!
- Hybridization of PV and CSP with storage allows a combination of both -> competitive cost -> dispatchable firm capacity
- Individual case studies and advanced planning of concepts may lead to cost-optimized solutions – the potential is there!