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

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Contents

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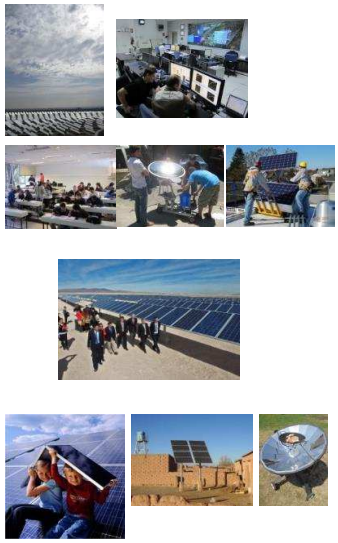
Fraunhofer Solar Hub in Chile: CSET

- 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



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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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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

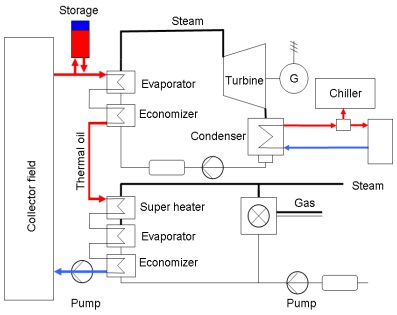
- Solar Technology for Water Treatment and Processing
- AgroPV Dual Use Technology
- Design and Optimization Methods for Thermal and Electrical Plants
- .....
- Technology Adaptation to Local Conditions

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 destillation to use waste heat
- Integration concepts for heat in industrial processes
  - Storage use
  - Heat recovery



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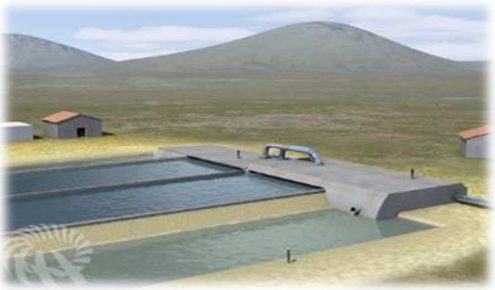
Example Technology Transfer
Solar Energy in Desalination and Water Treatment



- PV Driven Reverse Osmosis
- Membrane Distillation
- Water Desalination / Water Treatment / Solar Pumping
- Consultancy / Testing services for Mining / Energy Applications in progress

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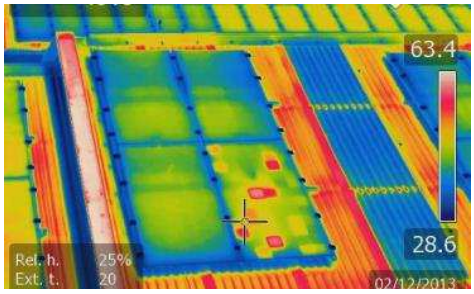
Example Quality Assessment
Monitoring from the air

Air monitoring of PV plants by drones

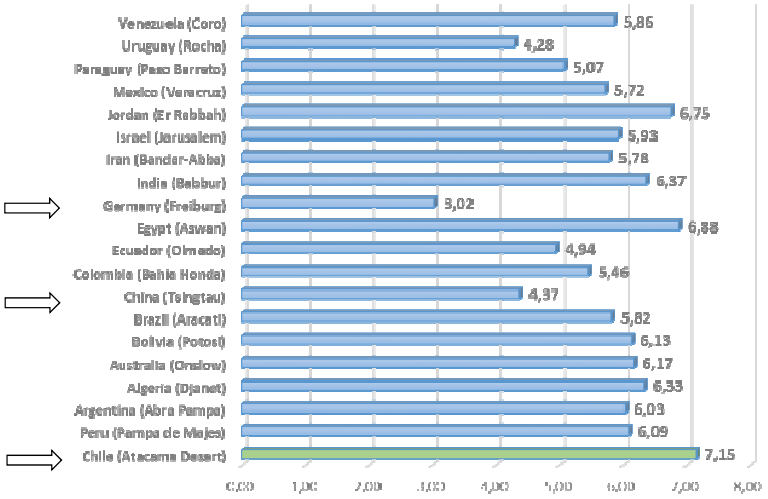
- Analysis of defects in modules using thermography from the air
- Detection of damage as hot spots
  - Reducing time
  - Reducing cost
  - Easy/fast failure detection



Contents

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

Source:http://www.sealite.com.au/technical/solar_chart.php

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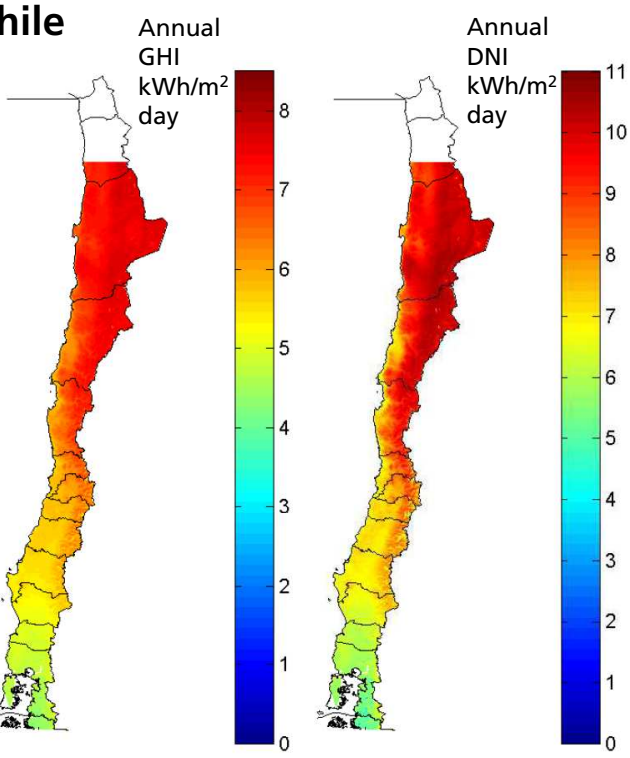
Solar energy resource in Chile

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



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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!

Contents

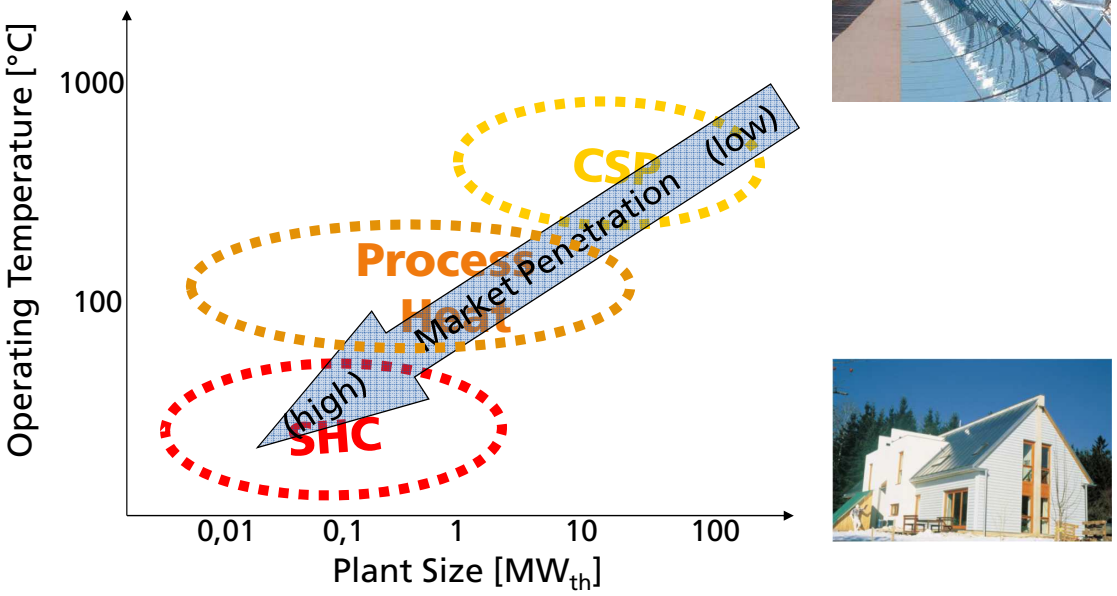
Solar Heat

Key Component: Collector for Conversion of Solar Radiation into Heat

- Solar Tower: plant capacity ~ 10 - 120 MW_{el}, operating temperature 600-1200 °C
- Dish: unit capacity ~ 10-25 kW_{el}, operating temperature 200-1800 °C
- Linear Fresnel: plant capacity ~ 30-250 MW_{el}, operating temperature < 550°C
- Parabolic trough: plant capacity ~ 30-250 MW_{el}, operating temperature < 550 °C
- Vacuum tube, stationary CPC: unit capacity ~ 1 kW_{th}, operating temperature < 150°C
- Flat plate: unit capacity ~ 1 kW_{th}, operating temperature < 100°C

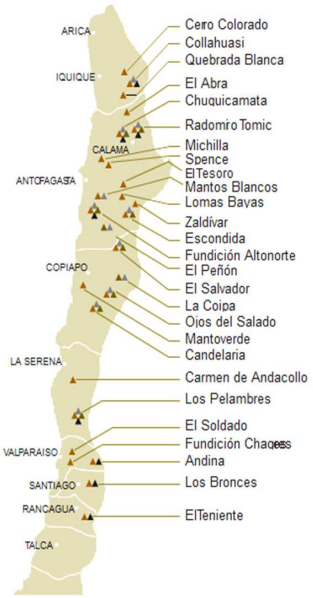
Market available technology

Solar Thermal Technologies



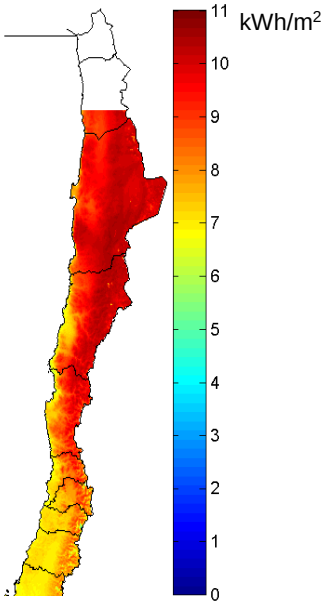
Mining Industry

Mining location in Chile



(www.consejominero.cl, 2007)

Annual average, total daily DNI



(Atlas Solar de Chile, 2013)

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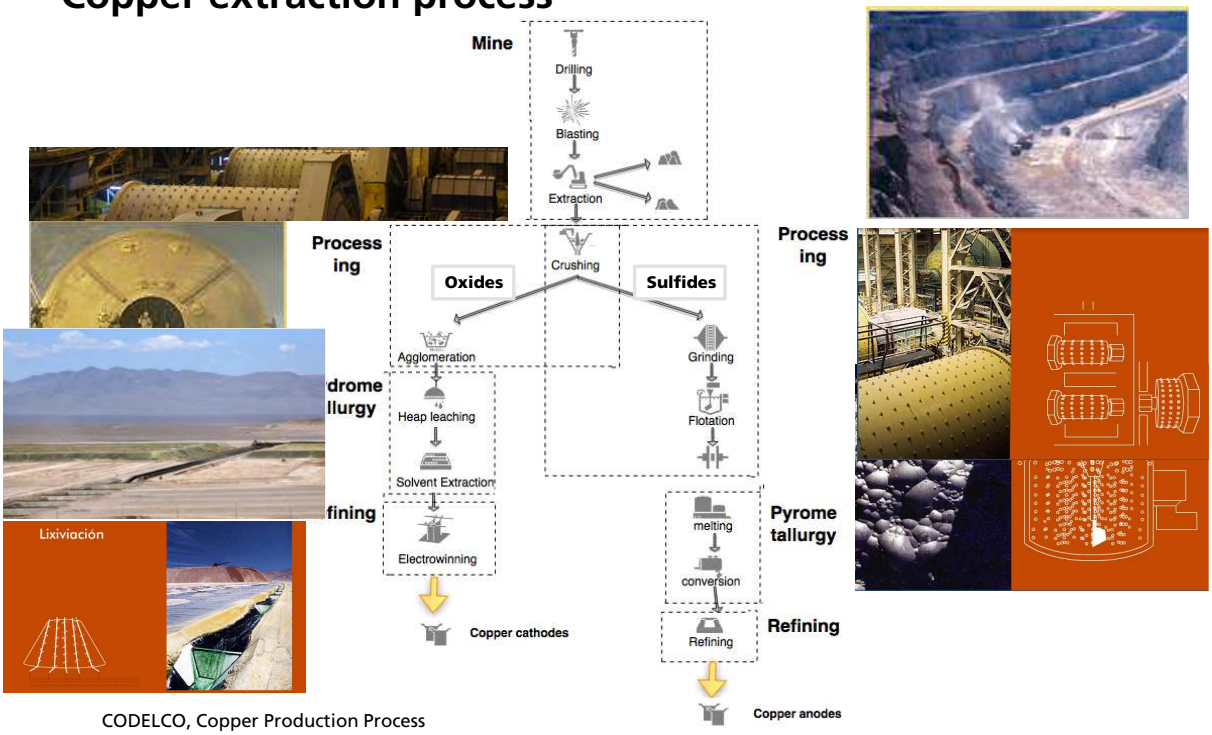
Copper extraction process



CODELCO, Copper Production Process

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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

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

Solar thermal energy integration

- Great potential for integrating solar thermal energy in electro-winning process
- Temperatures needed in 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

21 Abengoa. Installed plants

Solar thermal energy integration

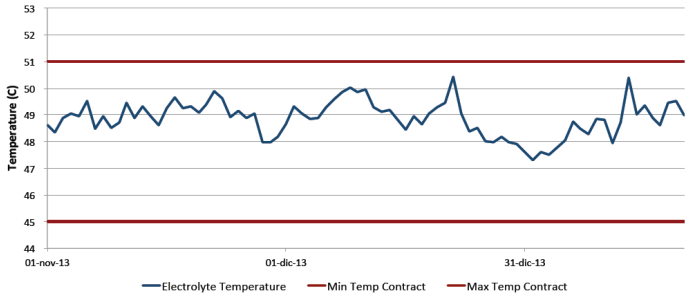
- Two solar plants already operating
  - 2013, Gabriela Mistral - Flat plate collector system. 39000 m² aperture area. 32 MWth, 4700 m3 storage
  - Consortium between Sunmark (Denmark) and Energia Llaima (Chile). Minera Gaby buys energy. Thermal Power Purchase Agreement contract for 10 years

22 Ian Nelson. ISES Webinar, 31.01.2014. Sun is shining on mining thermal processes. Replacing fosil fuels with solar supply

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



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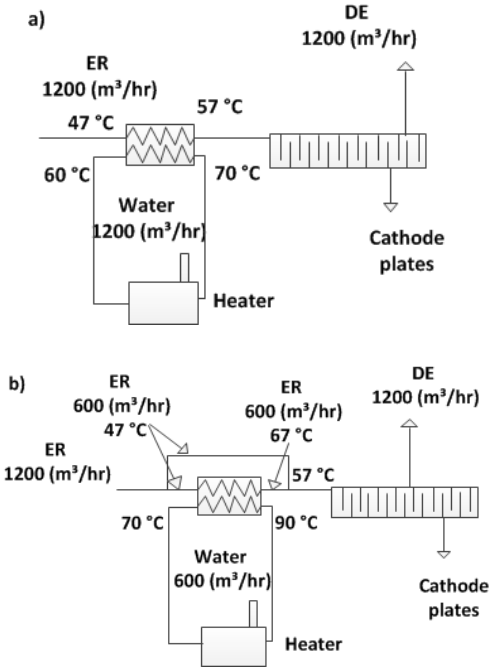
Electro-winning process. Case study



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

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

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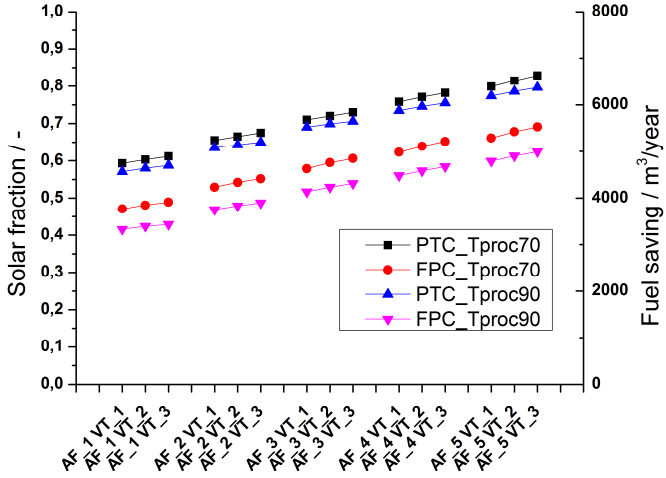
Results

Variable energy demand. Case 2



Solar field (m²)	30000 / 35000 / 40000/ 45000 / 50000
Corresponding notation	AF_1 / AF_2 / AF_3 / AF_4 / AF_5
Storage capacity (m³)	4000 / 5000/ 6000
Corresponding notation	VT_1 / VT_2 / VT_3

- Annual energy consumption decreases considerable (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

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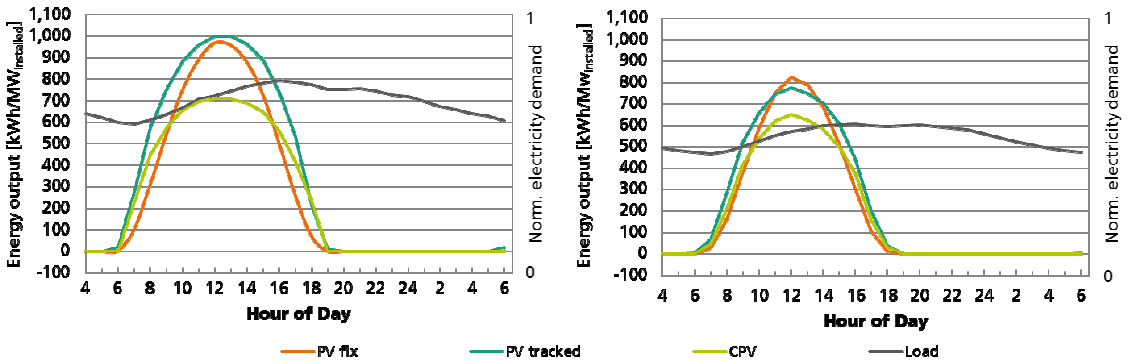
Photovoltaic power plants

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



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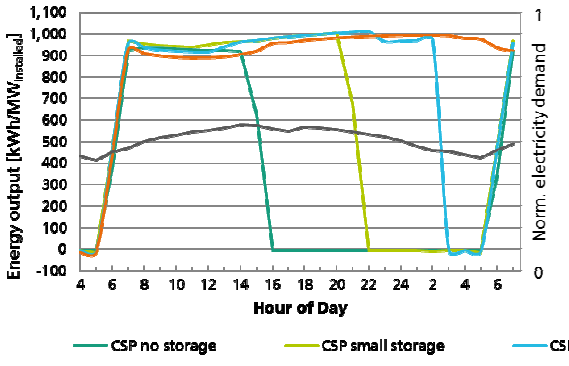
Contents

- 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

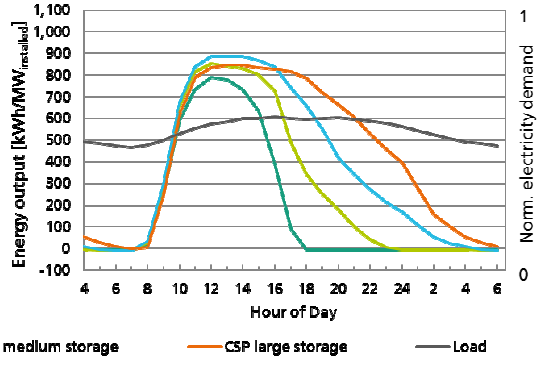
Why CSP?
CSP production profile vs. load

- 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

Exemplary day (May 5th)

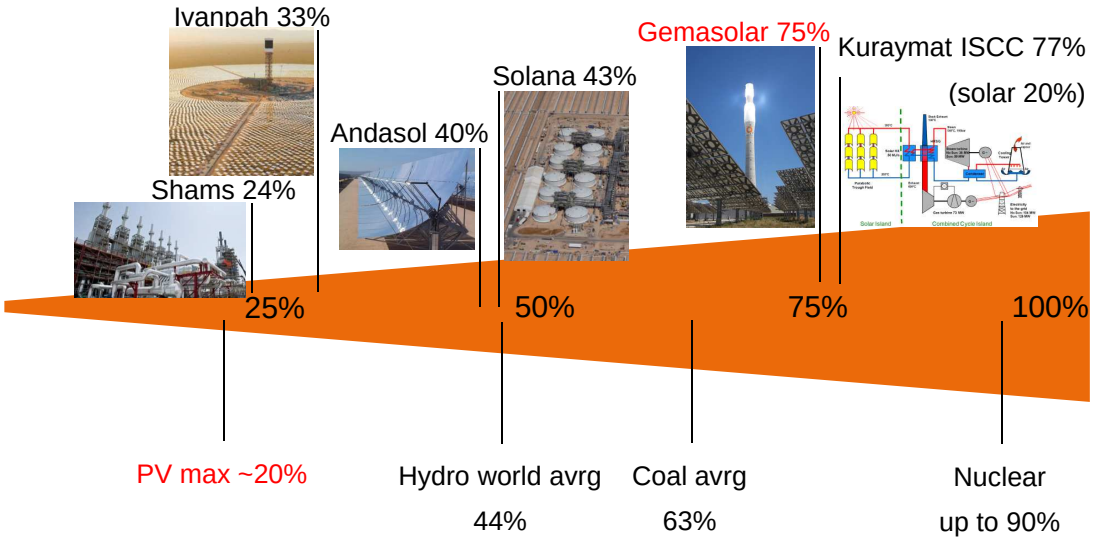


Annual average



Capacity factors of CSP

CSP provides wide range of plant types with different CF



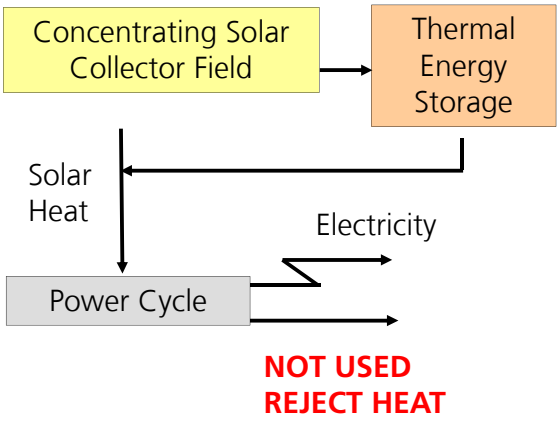
Hybrid CSP / PV plants may lower cost for 24h supply

- 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

Source: W.J.Platzer, Combined Solar Thermal and PV Power Plants – an Approach to 24h Solar Electricity? SolarPaces Conference 2015,Cape Town

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:

Slope		< 1%		< 3%	
Proximity to transmission		< 20 km	< 50 km	< 20 km	< 50 km
Area [km²]		1235	1508	15894	23749
Equivalent installed power [GW]	PTC	64.7	79.0	832.1	[illegible]
Generation [TWh]	PTC	147.4	180.0	1897.3	2834.8
Equivalent installed power [GW]	LFC	82.8	101.1	1065.3	1591.7
Generation [TWh]	LFC	160.6	196.1	2066.6	3087.9

28 times current ann. electricity production

Fluri, T. P.; Cuevas, F.; Pidaparthi, P. & Platzer, W. J.: "Assessment Of The Potential For Concentrating Solar Power In Northern Chile"
Proceedings of the 17th SolarPACES Conference, 20. - 23. September 2011, Granada, Spain, **2011**

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!

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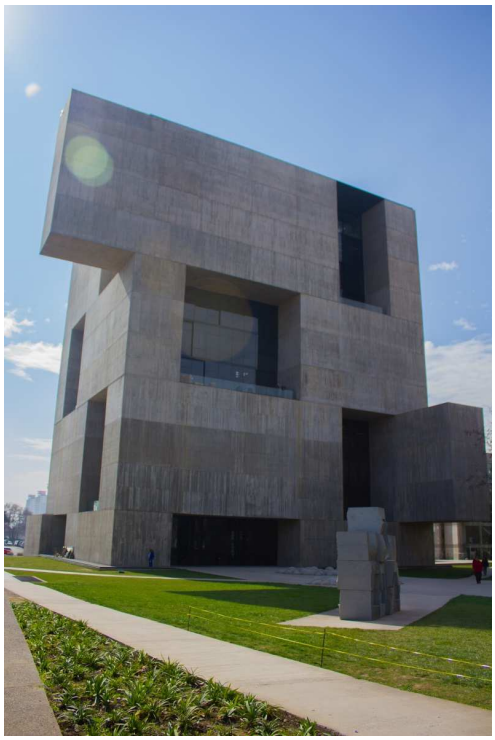
Reduction of the Energy Consumption in the Mining Industry by Solar Energy



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