Concentrated Solar Power

In partnership with the Clean Energy Solutions Center (CESC)

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01.05.2019
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ISA
INTERNATIONAL SOLAR ALLIANCE

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
Overview of the expert

Factor is an international group, specialized in providing global, innovative and sustainable solutions in areas such as climate change, energy, sustainability, trading and innovation.

Our key value is our people. We have offices in six countries, where our interdisciplinary team works for public and private stakeholders, international organizations and non-profit entities.

Our own history and experiences are based on constant innovation. This helps us target our services, by combining academic knowledge, technology and practical experience.
This Training is part of Module 2, and focuses on the Concentrated Solar Power
Overview of the Training

1. Introduction: Learning Objective
2. Understanding Concentrated Solar Power
3. Main body of presentation
4. Concluding Remarks
5. Further Reading
6. Knowledge Check: Multiple-Choice Questions
1. Introduction: Learning Objective
Learning Objective

This lecture provides:

1 An overview of CSP technologies

2 Status and trends of CSP markets over the world

3 Discussion on the costs of CSP

4 Research and Development programs for CSP
2. Understanding Concentrated Solar Power
Understanding Concentrated Solar Power

Concentrated Solar Power (CSP), also called Solar Thermal Power Generation, plants produce electric power by using mirror to concentrate a large area of sunlight onto a small area, the boiler.

Electricity is generated when the concentrated light is converted to heat, which drives a heat engine (usually a steam turbine) connected to an electrical power generator.

Source: La Dehesa plant
Concentrated solar power (CSP) plants can integrate thermal energy storage systems to generate electricity during cloudy periods or even several hours after the sunset. CSP systems can be also combined with combined cycle power plants resulting in hybrid power plants which provide high-value, dispatchable power.

Concentrated Solar Power systems can be sized for village power (10 kilowatts) or grid-connected applications (more than 100 megawatts).
Understanding Concentrated Solar Power

Worldwide historical evolution:

• At the beginning of the 70s, with the rapid increase in oil prices, is when the great impulse to solar concentration technologies takes place.

• High intensity of research activity in Solar Concentration Systems was developed between the mid 70's and the end of the 80's.

• During the 1980s and 1990s, the first commercial initiatives were built in the USA. (SEGS plants, in the Mojave desert of California).

• The thermoelectric solar sector is currently in the commercial takeoff phase throughout the world, and especially in Spain.
Understanding Concentrated Solar Power

Research and development centers

• The Solar Platform of Almería (PSA), Spain belongs to the Center for Energy, Environmental and Technological Research (CIEMAT). It is the largest public research and testing center dedicated to solar concentration technologies.

• The Solar Platform Sanlúcar la Mayor (SOLUCAR): It belongs to the Abengoa group and it is the largest private centre of solar energy, with technologies of all the solar areas, mainly solar thermoelectric.

• Sandia National Laboratories, in EE.UU.: carries out the NSTTF (National Solar Thermal Test Facility), near Alburquerque in New Mexico with a tower plant of 5 MW for component tests.

• Other centers with tower plants of 1-2 MW such as: Weizmann Institute, in Israel, in Rehovot, Colonia (Germany) and soon in the French Pyrenees (former THEMIS plant).
3. Main Body of Presentation
Main Body of Presentation

1. An overview of CSP technologies

2. Status and trends of CSP markets

3. Costs of CSP

4. Research and Development programs for CSP
An overview of CSP technologies

Thermoelectric solar energy groups four technological areas with different commercial maturity and different potential:

- TOWER
- PARABOLIC TROUGH
- PARABOLIC DISH
- LINEAR FRESNEL COLLECTOR
## An overview of CSP technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>PT</th>
<th>LF</th>
<th>DS</th>
<th>CT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical size (MW)</td>
<td>10 – 280</td>
<td>1 – 125</td>
<td>1</td>
<td>10 – 135</td>
</tr>
<tr>
<td>Concentration Factor</td>
<td>70 – 80</td>
<td>25 – 100</td>
<td>600 – 4000</td>
<td>600 – 1200</td>
</tr>
<tr>
<td>Capacity Factor (%)</td>
<td>30 – 50</td>
<td>20 – 30</td>
<td>20 – 30</td>
<td>40 – 70</td>
</tr>
<tr>
<td>Operation Temperature (°C)</td>
<td>293 – 393</td>
<td>140 – 275</td>
<td>250 – 700</td>
<td>290 – 565</td>
</tr>
<tr>
<td>Installed worldwide (MW)</td>
<td>4,336</td>
<td>319</td>
<td>3</td>
<td>689</td>
</tr>
<tr>
<td>Use of land (MWh/(ha-year))</td>
<td>600 – 1,000</td>
<td>600 – 1,000</td>
<td>400 – 800</td>
<td>400 – 800</td>
</tr>
<tr>
<td>Maturity</td>
<td>Commercial</td>
<td>Commercial</td>
<td>Demo</td>
<td>Commercial</td>
</tr>
<tr>
<td>Reflector</td>
<td>Parabolic mirror</td>
<td>Flat/curved mirror</td>
<td>Paraboloid mirror</td>
<td>Curved mirror</td>
</tr>
<tr>
<td>Receiver</td>
<td>Absorber tube w/ vacuum cover</td>
<td>Absorber tube w/ concentrator</td>
<td>Stirling engine / gas turbine</td>
<td>External / Cavity</td>
</tr>
<tr>
<td>HTF</td>
<td>Thermal oil</td>
<td>Saturated steam</td>
<td>Air</td>
<td>Molten salt / Water-steam</td>
</tr>
<tr>
<td>TES</td>
<td>Molten salts, indirect</td>
<td>Steam accumulator</td>
<td>N/A</td>
<td>Molten salts, direct / steam accumulator</td>
</tr>
<tr>
<td>TES capacity</td>
<td>4 – 12 hours</td>
<td>&lt; 1 hour</td>
<td>N/A</td>
<td>6 – 14 / &lt; 1 hours</td>
</tr>
<tr>
<td>Hybridization capable</td>
<td>Yes, existing</td>
<td>Yes</td>
<td>Unlikely</td>
<td>Yes</td>
</tr>
</tbody>
</table>
An overview of CSP technologies

Parabolic trough
An overview of CSP technologies

Linear Fresnel Collectors
An overview of CSP technologies

Power tower
Central receiver
An overview of CSP technologies

Parabolic dish
An overview of CSP technologies

Hybridizing CSP – 100% renewable

[Diagram showing CSP technologies hybridized with PV, WIND, BIOMASS, and GEOTHERMAL]
An overview of CSP technologies

Hybridizing CSP-fossil fuels
An overview of CSP technologies

CSP, PV or Hybrid

• On production cost alone, PV is, today, significantly cheaper than CSP. It is also more modular and easier to design, construct, maintain and operate.

• When dispatchability is required, CSP+TES is cheaper to install and to run than PV with batteries, which gives CSP a competitive advantage. Nevertheless this is changing fast.

• Hybridizing CSP with fuels can ease the path, reducing emissions while providing track record to CSP, and time to amortize plants in operation.
Main Body of Presentation

1 An overview of CSP technologies

2 Status and trends of CSP markets

3 Costs of CSP

4 Research and Development programs for CSP
Status and trends of CSP markets

Global Capacity by Country and Region, 2007-2017

Source: REN21 Renewables 2018 – Global Status Report
# Status and trends of CSP markets over the world

## Global Capacity and Additions, 2017

<table>
<thead>
<tr>
<th>Country</th>
<th>Total End-2016</th>
<th>Added 2017</th>
<th>Total End-2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>2,304</td>
<td>0</td>
<td>2,304</td>
</tr>
<tr>
<td>United States</td>
<td>1,738</td>
<td>0</td>
<td>1,738</td>
</tr>
<tr>
<td>South Africa</td>
<td>200</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>India</td>
<td>225</td>
<td>0</td>
<td>225</td>
</tr>
<tr>
<td>Morocco</td>
<td>166</td>
<td>0</td>
<td>166</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Algeria</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Egypt</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Iran</td>
<td>17</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>China</td>
<td>20</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

**World Total**

<table>
<thead>
<tr>
<th></th>
<th>Total End-2016</th>
<th>Added 2017</th>
<th>Total End-2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>4,810</strong></td>
<td><strong>100</strong></td>
<td><strong>4,910</strong></td>
</tr>
</tbody>
</table>

Source: REN21 Renewables 2018 – Global Status Report
Status and trends of CSP markets


Source: REN21 Renewables 2018 – Global Status Report
Status and trends of CSP markets

Evolution of the thermosolar capacity installed
Status and trends of CSP

Trends in technology choice

- PT: 79%
- HY: 3%
- CT: 12%
- DS: 0%
- LF: 6%
Status and trends of CSP

Net CSP capacity additions
Main and accelerated case, 2012-2023

Source: International Energy Agency
Status and trends of CSP markets

Uncertainty in projections

![Graph showing installed capacity growth from 2015 to 2030 with various scenarios and projections.](image)

Scenarios:
- **BAU**: business as usual
- **ID**: increased deployment
- **RD**: reduced deployment
- **STE-GO**: Solar Thermal
- **GP-IEA**: Electricity Global Outlook 2016
- **GP-IEA**: Greenpeace-IEA
Status and trends of CSP markets

Power generation capacity (GW installed by 2030)
Main Body of Presentation

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3 Costs of CSP

4 Research and Development programmes for CSP
Costs of CSP

Figure 4.3 Installed costs and capacity factors of CSP projects by their quantity of storage, 1984-2016.

Source: IRENA Renewable Cost Database.
Costs of CSP

Figure 4.7 Capacity factor trends for CSP plants, 2009-2016

Source: IRENA Renewable Cost Database.
Costs of CSP

**Figure 4.9** The levelised cost of electricity for CSP projects, 2009-2016

*Source: IRENA Renewable Cost Database.*
Costs of CSP

Figure 4.10 Levelised cost of electricity and auction price trends for CSP, 2010-2022
Costs of CSP

Cost reduction potential

PTC and ST total installed cost reduction potential by source, 2015-2025

Source: IRENA and DLR, 2016.
Costs of CSP

Indirect EPC & owners costs

cost reductions for CSP plants to 2025

Source: IRENA and DLR, 2016.
Costs of CSP

Solar field components

Cost reduction potentials of the solar field component of PTC and ST CSP plants by source, 2015-2025

Source: IRENA and DLR, 2016.
Costs of CSP

Thermal energy storage

Source: IRENA and DLR, 2015.
Costs of CSP

LCOE reduction potential

Source: IRENA and DLR, 2016.
Costs of CSP

LCOE sensitivity to WACC

Sensitivity of the levelised cost of electricity of PTC and ST plants to variations in the WACC, 2015 and 2025

Source: IRENA and DLR, 2016.
Main Body of Presentation

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R&D Programmes for CSP

**Equipment**
- New heat transfer fluids
- Structures and trackers
- Reflectors
- Receiver
- Thermal Energy Storage

**System**
- Dispatchability
- Scales limits
- Use of water
- Hybridization

Some key aspects are not included in typical R&D

- Soft costs in development and EPC
- Risk reductions/ cost of capital
- New business models
R&D Programs for CSP

Evolution of R&D private investment and aggregated
R&D Programs for CSP

Evolution of R&D public investment

![Graph showing the evolution of R&D public investment from 2000 to 2014 for different countries and regions.](image-url)
4. Concluding Remarks
Concluding Remarks

- Half a decade ago, expectations for CSP deployment were higher than the current situation: most long-term forecasts and country plans have not been fulfilled.

- There is not only one reason for this:
  - the quick cost reduction of PV made it a more attractive alternative (so some efforts were moved from CSP to PV);
  - several other initiatives were halted, hoping that a PV-like cost reduction would bring CSP’s LCOE closer to grid parity;
  - when the cost reduction was not as quick as expected, the sector risked entering a vicious circle as a slower deployment further slowed cost reduction.
Concluding Remarks

• The future development of CSP is linked to its ability to provide value to the electric system in comparison with other alternatives.

• CSP’s strengths, beyond possible cost break through, are:
  - cheap storage;
  - demand management capabilities;
  - ancillary services, etc.

• There is potential for cost reduction in both hard and soft costs, but some chapters (civil works, power block, BoP, EPC cost and Owner’s cost) have barely improved despite its significant impact.

• Soft costs are not a typical target in R&D programs.
Concluding Remarks

Hybridization can be a key to the future of CSP:

• Hybridizing CSP with fuels can ease the path, reducing emissions while providing track record to CSP, and time to amortize plants in operation;

• CSP integration costs are as low as conventional, especially if hybridized;

• Risk is concentrated on investment in CSP, and on operation in conventional; hybrids can have a better balance between both, diluting them.
5. Further Reading


https://www.nrel.gov/docs/fy15osti/64256.pdf

6. Knowledge Checkpoint: Multiple Choice Questions