SunShot Concentrating Solar Power Program
Ranga Pitchumani
Thermochemical Energy Storage Workshop • January 8, 2013
CSP Introduction

To view the video presented at the workshop, please follow the link below.

https://www.eeremultimedia.energy.gov/solar/videos/concentrating_solar_power_power_towers
CSP Systems

Power Towers

Parabolic Trough

Dish/engine Systems

Linear Fresnel
## CSP Plants Currently Operating in the U.S.

<table>
<thead>
<tr>
<th>Project (Developer)</th>
<th>Size</th>
<th>Tech</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEGS 3-9 (<em>FPL-NextEra</em>)</td>
<td>310 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>Martin (<em>FPL-NextEra</em>)</td>
<td>75 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>Nevada Solar One (<em>Acciona</em>)</td>
<td>64 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>SEGS 1-2 (<em>Cogentrix</em>)</td>
<td>44 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>Coalinga (<em>BrightSource</em>)</td>
<td>10 MW</td>
<td>Tower</td>
</tr>
<tr>
<td>Sierra (<em>eSolar</em>)</td>
<td>5 MW</td>
<td>Tower</td>
</tr>
<tr>
<td>Kimberlina (<em>AREVA</em>)</td>
<td>5 MW</td>
<td>Fresnel</td>
</tr>
<tr>
<td>Holaniku (<em>Sopogy</em>)</td>
<td>2 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>Maricopa (<em>SES</em>)</td>
<td>1 MW</td>
<td>Dish</td>
</tr>
<tr>
<td>Saguaro (<em>APS</em>)</td>
<td>1 MW</td>
<td>Trough</td>
</tr>
<tr>
<td>Cameo (<em>Abengoa</em>)</td>
<td>1 MW</td>
<td>Trough</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>518 MW</strong></td>
<td></td>
</tr>
</tbody>
</table>

![Nevada Solar One, Las Vegas, NV](image1)

![Sierra Project, Lancaster, CA](image2)
### CSP Plants Under Construction in the U.S.

<table>
<thead>
<tr>
<th>Project (Developer)</th>
<th>Size</th>
<th>Tech</th>
<th>Loan</th>
<th>Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ivanpah (BrightSource)</td>
<td>392 MW</td>
<td>Tower</td>
<td>$1.6 B</td>
<td>2013</td>
</tr>
<tr>
<td>Broke ground in 2010. After delays associated with relocation of desert tortoises, construction has resumed for a mid-2013 COD for Unit 1 and late-2013 COD for units 2 and 3. As of February 2012, largest CSP project under construction in the world.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crescent Dunes (SolarReserve)</td>
<td>110 MW</td>
<td>Tower/Storage</td>
<td>$0.7 B</td>
<td>2013</td>
</tr>
<tr>
<td>Completed financing in September 2011 by SolarReserve &amp; Santander. Completed 540 ft. power tower concrete shell in February 2012. Next phase will be to complete molten salt storage tanks.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genesis (FPL-NextEra)</td>
<td>250 MW</td>
<td>Trough</td>
<td>$0.8 B</td>
<td>2013/14</td>
</tr>
<tr>
<td>Approximately 13% of the site is undergoing further archeological surveying in accordance with approved plans. Construction continues on the remainder of site and is expected to be completed on time for the PPA start date for Unit 1 of November 2013.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solana (Abengoa)</td>
<td>280 MW</td>
<td>Trough/Storage</td>
<td>$1.4 B</td>
<td>2014</td>
</tr>
<tr>
<td>Construction began in December 2010 and solar field installation is underway.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mojave (Abengoa)</td>
<td>250 MW</td>
<td>Trough</td>
<td>$1.2 B</td>
<td>2014</td>
</tr>
<tr>
<td>CPUC approved PPA with PG&amp;E in November 2011 and construction ramped up.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1,282 MW</td>
<td></td>
<td>$5.7 B</td>
<td></td>
</tr>
</tbody>
</table>
Global CSP Development Pipeline

CSP Plants Under Construction/Development (19.8 GW Total)

The DOE SunShot Initiative is a collaborative national endeavor to make solar energy cost competitive with other forms of energy, without subsidies, by the end of the decade.
Strategy for Recent and Future CSP FOAs

- CSP SunShot (2011)
  - SOLAR FIELD
    - Cost ≤ $7.5/kW
    - Optical Error ≤ 3 mrad
    - Wind Speed ≥ 365 mph
    - Lifetime ≥ 30 yrs
  - RECEPTOR
    - HTF Exit Temp. ≥ 650°C
    - Thermal Eff. ≥ 90%
    - Lifetime ≥ 10,000 cyc
    - Cost ≤ $150/kW
  - POWER BLOCK
    - Net Cycle Eff. ≥ 50%
    - Dry Cycle Eff. ≥ 50%
    - Cost ≤ $1,200/kW
  - THERMAL STORAGE
    - Cost ≤ $15/kW
    - Exergy Loss ≤ 66.5%
    - Power Cycle Initial Temperature ≥ 600°C
  - FLUIDS
    - Melting Point ≥ 250°C
    - CP ≥ 3.0 KJ/kg°C
    - Thermal Stability ≥ 80°C

6¢/kWh

HEATS & SunShot Awards (2011)

MURI HOT Fluids (2012)
FY12 CSP Funding Distribution

- Laboratory: 33%
- Industry: 45%
- University: 20%
- Other: 2%

- Dish: 11%
- Tower: 35%
- Storage: 26%
- Trough: 28%

- Dish: 10%
- Tower: 40%
- Storage: 30%
- Trough: 20%
- University: 20%
- Laboratory: 33%
- Industry: 45%
- Other: 2%

- Tower: 42%
- Dish: 29%
- Trough: 29%
DOE CSP Portfolio

**CSP SYSTEMS**
- Penn State U.
- Jet Propulsion Laboratory
- U. of Arizona
- Thermata
- BrightSource Energy
- Boston U.
- 3M
- HiTek
- Skyfuel
- SunTrough
- Alcoa
- Skyfuel
- Solar Millennium
- eSolar
- Abengoa

**CSP COMPONENTS**
- Norwich Technologies
- U. of Cal. San Diego
- NREL
- Oregon State Un.
- San Diego State U.
- ANL
- SNL
- Brayton Energy
- Wilson
- PWR
- MIT
- SLAC National Accelerator Lab
- Southwest Research Institute
- Abengoa
- PPG
- Infinia
- Abengoa
- 3M

**THERMAL ENERGY STORAGE**
- LANL
- ORNL
- ANL
- SNL
- Acciona
- CCNY
- Texas A&M U.
- Halotechnics
- U. of Alabama
- U. of South Florida
- Infinia
- NREL
- Lehigh U.
- U. of Connecticut
- Terrafore
- Infinia
- Abengoa
- Acciona
- SENER
- U. of Arkansas
- US Solar
- General Atomics
- PNNL
- General Atomics

**Total DOE Funding ($ Millions)**
- PWR: $35M
- Abengoa: $30M
- Skyfuel: $25M
- 3M: $27M
- HiTek: $29M
- Solar Millennium: $27M
- U. of Arizona: $25M
- BrightSource Energy: $29M
- Boston U.: $27M
- Penn State U.: $27M

**Funding Projects**
- CSP SunShot (2011): $55M
- Baseload FOA (2010): $53M
- CSP Lab Call (2009): $29M
- Storage FOA (2009): $27M
- CSP R&D (2007): $35M

Thermal energy storage is a distinguishing feature of Concentrating Solar Power

Storage Options

• Sensible Energy \( \sim 150 \text{ kJ/kg} \)
• Latent Energy \( \sim 230 \text{ kJ/kg} \)
• **Chemical Energy** > 12,000 kJ/kg

1. Can we engineer CSP integrated energy storage based on chemical reactions to capture and release energy on demand?

2. Can we do so in a cost-effective manner with high efficiency to meet the SunShot goals?
Workshop Objectives

• To convene experts from industry, academia, national labs to have an open discussion on the viability of TCES for CSP as a solution to achieving the SunShot Initiative goals.

• To identify the significant technical challenges to be addressed based on CSP-integrated system considerations (system-driving-science and science-enabling-systems)

• Workshop Format:
  • Two keynote presentations on the international efforts related to thermochemical energy storage for CSP
  • A perspective on lessons learned in developing thermochemical cycles for solar energy storage
  • Breakout sessions for guided in-depth discussions
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