Overview of Concentrating Solar Power and Research Needs

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SAND2016-2950 PE
Outline

- Introduction to CSP
- Commercial CSP Plants
- CSP Research Needs
Problem Statement

- Current renewable energy sources are intermittent
  - Causes curtailment or negative pricing during mid-day
  - Cannot meet peak demand, even at high penetration
- Available energy storage options for solar PV & wind
  - Large-scale battery storage is expensive
    - $0.20/kWh<sub>e</sub> - $1.00/kWh<sub>e</sub>
  - Compressed air and pumped hydro – geography and/or resource limited

Source: California Independent System Operator

The “Duck Curve”
Need

- Renewable energy technology with reliable, efficient, and inexpensive energy storage

Concentrating solar power (CSP) with thermal energy storage
What is Concentrating Solar Power (CSP)?

Conventional power plants burn fossil fuels (e.g., coal, natural gas) or use radioactive decay (nuclear power) to generate heat for the power cycle.
What is Concentrating Solar Power (CSP)?

CSP uses concentrated heat from the sun as an alternative heat source for the power cycle.
CSP and Thermal Energy Storage

- Concentrating solar power uses mirrors to concentrate the sun’s energy onto a receiver to provide heat to spin a turbine/generator to produce electricity.
- Hot fluid can be stored as thermal energy efficiently and inexpensively for on-demand electricity production when the sun is not shining.
Outline

- Introduction to CSP
- Commercial CSP Plants
- CSP Research Needs
Timeline of CSP Development

1970’s
- National Solar Thermal Test Facility
  6 MW_t, Albuquerque, NM, Est. 1976

1980’s – 1990’s
- Solar One and Solar Two
  10 MW_e, Daggett, CA
  1980’s – 1990’s
- SEGS, 1980’s
  9 trough plants
  354 MW_e, CA
- Solar One and Solar Two
  10 MW_e, Daggett, CA
  1980’s – 1990’s

2000’s
- Stirling Energy Systems
  1.5 MW_e, AZ, 2010
- PS10/20, steam, Spain, 2007-2009
- Ivanpah, steam, 377 MW_e, CA, 2014

SunShot 2011 -
- Crescent Dunes, molten salt,
  110 MW_e, NV, 2015
- Gemasolar, molten salt,
  19 MW_e, Spain, 2011
- SEGS, 1980’s
  9 trough plants
  354 MW_e, CA
Direct Steam Solar Towers
PS10 and PS20 (Seville, Spain)

- First commercial power tower plants in the world (2007, 2009)
- 11 MW and 20 MW
- Saturated steam
  - 250 C, 45 bar steam, wet cooling
Ivanpah Solar Power Tower
California (near Las Vegas, NV)

http://news.nationalgeographic.com

Three towers, 392 MWe, superheated-steam at 540 C, 160 bar, air-cooled (2014)
Ashalim Solar Power Station
(Under Construction 2015 - 2017)

- 121 MWe Solar Tower
  - 2% of Israel’s electricity needs
  - 110,000 households
- Superheated steam
  - ~600°C
- Wi-Fi controlled heliostats

Photo credit: Jack Guez/AFP (May 2016)

Receiver and heliostat field under construction
Molten Salt Solar Tower
Gemasolar
(near Seville, Spain)

- 1st commercial power tower (19 MW) in the world with “24/7 dispatchable energy production” (15 hours of thermal storage using molten salt), wet cooling. Commissioned in May 2011.
Crescent Dunes
Tonopah, Nevada

110 MWe, 570 C molten-salt, 10 hours of storage, hybrid air-cooled condenser (2015)
Liquid Sodium Solar Tower
Jemalong Solar Station - Australia

- 1.1 MW\textsubscript{e}
- Liquid sodium
  - 560°C
  - 3 hour storage
  - Dry
- Expected start in 2017
  - Sodium fire in 2015 delayed start

5 modular solar fields with 30 m towers
Actual and Projected Growth of CSP
Outline

- Introduction to CSP
- Commercial CSP Plants
- CSP Research Needs
CSP Research Needs
Optical Accuracy

Mirror canting, tracking, gravity sag, and dynamic wind loads can affect optics and fatigue
Advanced Reflective Materials

Heliostat with 3M™ Solar Mirror Film 1100

3 mm silvered glass
12:56 PM, 7/6/11
Glint/Glare and Infrared Emissions

- **Glint and glare may cause unwanted visual impacts**
  - Pilots, air-traffic controllers, workers, motorists
  - Retinal burn, temporary after-image, veiling, distraction

- **Infrared emissions**
  - Heated objects can emit infrared radiation that may interfere with infrared sensors
Examples of Glare from Solar Technologies

**Photovoltaics**

**Concentrating Solar Power**

- Heliostats and Central Receiver at Sandia Labs, Albuquerque, NM
- Dish Collectors at Sandia
- Parabolic Trough Collectors at Kramer Junction, CA
Solar Glare Hazard Analysis Tool

- Free web-based software that predicts impacts of glare and annual energy production from photovoltaic arrays

- Uses interactive Google Maps
- Very fast annual simulations
Anti-Soiling Coatings

- Need anti-soiling coatings for mirrors to reduce need for washing and maintain high reflectivity
High-Temperature Receivers

- Maximize solar absorptance and minimize heat loss (selective absorber coatings, geometry, concentration ratio)
- Need materials that operate at high temperature (>650 °C) and are durable in air

National Solar Thermal Test Facility, Sandia National Laboratories, Albuquerque, NM

Cavity receiver

External tubular receiver
Fractal-Like Receiver Designs

- Develop fractal-like designs and structures across multiple scales to increase solar absorptance while minimizing heat loss.

Conventional cylindrical solar receiver

New fractal-like designs with light-trapping and low-emittance properties at multiple scales

Patents Pending
High Temperature Falling Particle Receiver (DOE SunShot Award FY13 – FY16)

Participants: Sandia, Georgia Tech, Bucknell U., King Saud Univ., DLR
Advantages of particlePower™

- Higher temperatures (>1000 °C) than molten salts
  - Enables more efficient power cycles
- Direct heating of particles vs. indirect heating of tubes
  - Higher solar fluxes for increased receiver efficiency
- No freezing or decomposition
  - Avoids costly heat tracing
- Direct storage of hot particles
  - Reduced costs without extra heat exchangers and separate storage media

CARBO ceramic particles ("proppants")
Particle Receiver Designs – Free Falling
Prototype System Design

- Olds Elevator
- Top hopper (two release slots)
- Receiver
- Bottom hopper (~45 ft)
- Caged ladders
- Work platforms
- Water-cooled flux target
- Open space for 1 MW particle heat exchanger
- Top of tower module

Prototype System Design

[Image of prototype system design with labeled parts]
On-Sun Tower Testing

Over 600 suns peak flux on receiver
(July 20, 2015)
On-Sun Tower Testing

Particle Flow Through Mesh Structures
(June 25, 2015)
Thermal Storage
Corrosion studies in molten salt up to 700 C in “salt pots”

Ceramic particle storage and heating with falling particle receiver

Component testing with molten-salt test loop

Thermochemical particle storage with reduction/oxidation of perovskites

Latent phase-change material storage in dish engines
Solar Fuels

- Creating hydrogen and liquid fuels with concentrated sunlight

Sunlight in Your Tank

Conventional solar technologies produce electricity, but most transportation fuel comes from oil. A new class of solar chemical reactors aims to make liquid fuels from air, water, and sunshine.

Ermanoski et al.
Science (2009)
Systems Analysis and Modeling

- Reflectivity
- Tracking
- Alignment
- Reliability

- Transient flux
- Solar absorptivity
- Mass flow rate
- Reliability

- Heat loss
- Materials compatibility/erosion
- Reliability

- Thermal-to-electric efficiency
- Part-load operation
- Reliability
Summary

- Renewables require energy storage for increased penetration
- Concentrating solar power provides utility-scale electricity AND energy storage for dispatchability when it is most needed
  - Cost of CSP with storage is currently cheaper than photovoltaics with large-scale battery storage
- Research on collectors, receivers, storage
  - Electricity production
  - Energy Storage
  - Process Heat
  - Thermochemistry/solar fuels
  - Systems Analysis
- National Solar Thermal Test Facility open for collaborations
The National Solar Thermal Test Facility

NSTTF is a DOE Designated User Facility

- Strategic Partnerships Projects (SPP)
- Cooperative Research And Development Agreement (CRADA)
Solar Furnace

- 16 kW Solar Furnace
- Peak flux $\sim 600 \text{ W/cm}^2$ (6000 suns)
- 5 cm spot size
Solar Simulator

- High-Flux Solar Simulator with Automated Sample Handling and Exposure System (ASHES)
  - Four 1.8 kW lamps
    - 7.2 $kW_{\text{electric}}$, 6.2 $kW_{\text{radiative}}$
  - 1100 kW/m$^2$ peak flux over 1 inch spot size
Questions?

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Backup Slides
# U.S. CSP Plants in Operation

<table>
<thead>
<tr>
<th>Project</th>
<th>Developer</th>
<th>Technology</th>
<th>Heat Transfer Fluid</th>
<th>Capacity (MWe)</th>
<th>Storage Capacity (hours)</th>
<th>Completion Date</th>
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<td>Power Tower</td>
<td>Molten salt</td>
<td>110</td>
<td>10</td>
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†ISCCS - Integrated solar combined-cycle system
Dish Stirling Thermal Storage

**Goal:**
- Thermal storage for dish Stirling systems (6 hours)

**Innovation:**
- Heat pipe transport to storage and engine
- Condensate return via pump
- Latent storage and transport matches Stirling cycle isothermal input
Particles Provide Reaction Enthalpy + Sensible Heat Storage for Increased Capacity, Higher Temperature Delivery

High Performance Reduction/Oxidation Metal Oxides for Thermochemical Energy Storage (PROMOTES)
Molten-Salt Test Loop

- 3 parallel test loops
- Salt Temperature: 300 – 585 °C (572 - 1085 °F)
- Maximum pressure: 40 bar (580 psi)
- Maximum flow: 44-70 kg/s (600 gpm)
AREVA Molten-Salt Linear Fresnel System
<table>
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<th>Storage Medium</th>
<th>Specific Heat (J/kg K)</th>
<th>Latent Heat of Fusion (kJ/kg)</th>
<th>Density (g/cm³)</th>
<th>Temperature Range (°C)</th>
<th>Gavrittic Storage Density (kJ/kg)</th>
<th>Volumetric Storage Density (MJ/m³)</th>
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<td>CH3(g) + H2O(g) -- 3H2(g) + CO(g)</td>
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<td>NH3(g) -- 1/2N2(g) + 3/2H2(g)</td>
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<td>3900</td>
<td>195</td>
<td>3900</td>
<td>--</td>
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Siegel (2012)
MEMORANDUM FOR ASSISTANT SECRETARY OF THE ARMY (INSTALLATIONS, ENVIRONMENT, AND ENERGY)
ASSISTANT SECRETARY OF THE NAVY (ENERGY, INSTALLATIONS, AND ENVIRONMENT)
ACTING ASSISTANT SECRETARY OF THE AIR FORCE (INSTALLATIONS, ENVIRONMENT AND LOGISTICS)

SUBJECT: Glint/Glare Issues on or near Department of Defense (DoD) Aviation Operations

In conjunction with the Department of Energy (DOE), the Federal Aviation Administration (FAA) has determined that glint/glare from some types of solar renewable energy systems could result in ocular impact to pilots and/or air traffic controllers, and thus potentially compromise the safety of the air transportation system. Glint is defined as the momentary flash of bright light, while glare is a continuous source of bright light. The FAA interim procedures require commercial airport operators who receive airport operations funding from FAA to conduct glint/glare studies for solar renewable energy systems on or near their airports. While commercial aviation has generally more rigid landing procedures, DoD flight procedures are more varied due to multiple military aircraft types and training requirements. Thus, FAA’s interim guidance should only be used as a guide for consideration.

As part of the Office of the Secretary of Defense (OSD) review of solar renewable energy projects, the Directorate of Facilities Energy & Privatization (FE&P) will review your mission compatibility assessments, including the potential for glint/glare. Solar renewable energy projects using the authority found in 10 U.S.C., § 2922a or in 10 U.S.C., § 2667 (Enhanced Use Lease) will require the SGHAT analysis for OSD review/approval/certification. For renewable energy projects that do not require OSD approval (e.g. renewable energy included in Military Construction (MILCON); Facilities Sustainment, Restoration, and Modernization (FSRM); Energy Savings Performance Contract (ESPC); Utility Energy Services Contract (UESC); or Energy Conservation Investment Program (ECIP) projects), OSD encourages a mission compatibility assessment include glint/glare as applicable. The use of the SGHAT is optional, and other glint/glare tools may be used.

Should your staff have questions, please contact Ms. Sara Streff, FE&P at 571-372-6843 or Mr. Steve Sample, SCH at 703-571-0067.

[Signature]
Acting Deputy Under Secretary of Defense (Installations & Environment)