Outlook on Heliostat Technology

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Margaret Gordon, Ph.D.

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Outline

• A vision of Heliostat technology
  o Guangdong Zhu, Ph.D., National Renewable Energy Laboratory

• An Overview of HelioCon
  o Margaret Gordon, Ph.D., Sandia National Laboratories
Projected market penetration of CSP electricity in future US grid in 2050:
• 35 – 200 GWe (3.5% - 20% of the total national electricity generation)
Baseline Power Tower System For Electricity

- Base case: molten salt power tower default
  - Net Power Output: 100 MWₑ/727 MWₑ
  - External Receiver
    - Solar Salt (60% NaNO₃/40% KNO₃)
      - Max heat flux – 1 MW/m²
    - Hot Side Temp: 575°C
    - Cold Side Temp: 290°C

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Base Case Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Heliostat Cost</td>
<td>140</td>
<td>$/m²</td>
</tr>
<tr>
<td>Optical Error</td>
<td>1.5</td>
<td>mrad</td>
</tr>
<tr>
<td>Reflectance</td>
<td>90</td>
<td>%</td>
</tr>
<tr>
<td>Field O&amp;M Costs</td>
<td>66</td>
<td>$/m²/year</td>
</tr>
<tr>
<td>Construction Time</td>
<td>24</td>
<td>months</td>
</tr>
</tbody>
</table>

*Large Electric Field*
More Than Just Installation Cost

- **Solar field performance** is important
  - Maximize solar field efficiency
  - Minimize solar field and receiver failure

- Additional 2 mrad would result into 20% energy loss

![Graph showing the relationship between RMS of Heliostat Canting Error (mrad) and Annual Optical Efficiency.]
More Than Just Installation Cost

- Solar field performance is important
  - LCOE can be sensitive to increasing solar optical error

![Graph showing LCOE sensitivity to optical error](image_url)
More Than Just Installation Cost

- **Solar field performance** is important
- But, challenges are:
  - Missing metrology and/or standards on solar field performance
    - Sun shape
    - Incidence angle (sun position relative to individual heliostat)
    - Heliostat shape
    - Attenuation
    - Solar-weighted specular reflectance
  - Opto-mechanical errors
    - Mirror surface slope error
    - Mirror facet canting error
    - Heliostat pointing error
    - Heliostat tracking error
  - Soiling (a separate subtopic discussed later in this section)
  - Structural/wind load (a separate subtopic discussed later in this section)
  - Receiver coating properties
  - Receiver geometry.
More Than Just Installation Cost

• **Operation and maintenance (O&M)**
  • Impact the cost of a CSP plant
  • Impact solar field performance

• **Challenges**
  • No measurement standards on mirror soiling
  • Missing site characterization standard on soiling
  • Under-explored design and automation of new cleaning systems
  • Poor understanding on the trade-offs between soiling losses, cleaning regime, design choice and heliostat reliability
More Than Just Installation Cost

- **Commercial risks** through deployment
  - Missing third party evaluation
  - Missing third party evaluation standards
  - Missing solar field acceptance test standards
  - Missing proper wind characterization
  - and, more

- Is the construction time on Schedule?
More Than Electricity Generation

- CSP for industrial process heat and solar fuel
- Three example solar field configurations

<table>
<thead>
<tr>
<th>Electricity Generation – Large Solar Field</th>
<th>Electricity Generation – Small/Modular Field</th>
<th>Industrial Process Heat – Small Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>~100 MW_e/727 MW_th</td>
<td>~20 MW_e/100 MW_th</td>
<td>~10 MW_th</td>
</tr>
<tr>
<td>Surround Field</td>
<td>Polar Field</td>
<td>Polar Field</td>
</tr>
<tr>
<td>External Receiver</td>
<td>Cavity Receiver</td>
<td>Cavity Receiver</td>
</tr>
<tr>
<td>575°C (Gen 2)</td>
<td>575°C (Gen 2)</td>
<td>1,000°C (High-Temp)</td>
</tr>
<tr>
<td>1 MW_th/m²</td>
<td>1 MW_th/m²</td>
<td>~2 MW_th/m²</td>
</tr>
</tbody>
</table>
More Than Electricity Generation

- CSP for Solar Industrial Process Heat (SIPH)
  - Assume 10 MWth
  - Solar field needs to be optimized for various operation temperature
More Than Electricity Generation

- CSP for Solar Industrial Process Heat (SIPH)
  - Assume 10 MWth
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More Questions Than Answers

• How to
  o Reduce the installation cost
  o Improve solar field performance
  o Optimize solar field operation & maintenance
  o Minimize commercial deployment risks

• How to address the technical and non-technical gaps through the whole heliostat development cycle
  • For electricity, process heat and solar fuel
Heliostat Consortium (HelioCon)

• HelioCon is set up to integrate/support the community to address all challenges for heliostat technologies

*Assumes a gross to net conversion factor of 0.9
HelioCon funded by US DOE-SETO

5 year, $25M + cost share begun in FY22
- To advance U.S. heliostat technologies, capabilities and national workforce
- 30% of funds allocated to annual Requests For Proposals (RFPs) for engagement of U.S. industries and other stake holders

Leadership team:
• Guangdong Zhu, Ph. D. (NREL), Mark Mehos, PhD. (NREL), Margaret Gordon, PhD. (Sandia), + NREL admin support, Cindy Gerk
• Non-voting members: ASTRI Australian Solar Thermal Research Institute

Topic Area Leads: NREL- Chad Augustine, Tucker Farrell, Parthiv Kurup, Rebecca Mitchell, Matt Muller, GD Zhu, Alex Zolan; Sandia- Ken Armijo, Randy Brost, Jeremy Sment

Board of Advisors: Utility, developers, plant owners, component suppliers, EPCs, Academia, standards and international advisors

Members: Consortium funded project performers and cost-share providers.

Non-consortium stake-holders: Subject-matter experts; U.S. and international institutions.
HelioCon Mission Goals

• A fully validated third-party performance assessment platform for an integrated heliostat and its components
• A series of publically available modeling and testing guidelines and standards
• A publicly available, easily accessible suite of tools, models, and resources for the public
• An engaged, active heliostat community to further advance heliostat technologies.

Reduce commercial risks

support the CSP industry

more competitive heliostat technologies
Plan → Support → Innovate → Validate

Support existing plants and stakeholders
- Outdoor field assessments – UFACET & NIO tests at Crescent Dunes, scheduling NIO test at Cerro Dominador)
- Round-Robin tests of metrology systems
- International collaborations

7 New 2023 projects Industry & Academia Awardees

Improved tools and access to National Laboratory resources
- SAMS
- C&C Testbed at NSTTF
- OpenCSP
- Flatirons Campus
- NSTTF Heliostat Field + tower

RoadMap report at HelioCon.org
Round 1 RFP Awardees Announced in June 2023: Total $3.5M, 7 Awardees

- Solar Dynamics - SunRing: Advanced Manufacturing and Field Deployment
- UNM HELIOCOMM: A Resilient Wireless Heliostats Communication System
- Northeastern U. - An Educational Program on Concentrating Solar Power and Heliostats for Power Generation and Industrial Processes
- Solar Dynamics - Demonstration of a Heliostat Solar Field Wireless Control System
- U. of AZ - Actively Focused Lightweight Heliostats
- Tietronix - Digital Twin and Industry 4.0 in Support of Heliostat Technology Advancement
- Sarcos - Robotic-Assisted Facet Installation (RA-FI)
Resources, Training & Education

Lead: Rebecca Mitchell

Major Gaps:

- Lack of publicly available resources, awareness, and education/training opportunities

Progress to date:

- Hosting, recording and sharing monthly seminars with the public - 16 expert seminars, 2 training seminars
- Gathered available resources and knowledge into web database: reference library; Education and training resources; Lists of heliostat component suppliers and developers, metrology tools, and software tools; Existing power tower plant database
Women+ in Concentrating Solar

• Formed at SolarPACES 2022 to promote education, professional development, and advancement of underrepresented genders in the Concentrated Solar Power community

• Use our expert database to recruit speakers from diverse backgrounds: https://women.solarpaces.org/members/

• Mentorship program coming soon!

Become a member today, all gender identities welcome!

https://women.solarpaces.org/register/
Soiling
Lead: Michael Cholette (QUT)

Major gaps
• Soiling measurement and characterization at heliostat field sites
• Trade-offs between soiling losses, cleaning regime, design choices

Progress to date:
• Soiling data collection, analysis, and soiling model development; contributed to an international effort (including DLR, Fraunhofer, CIEMAT, NREL, among others) to characterize and compare image processing techniques to assess the soiling status of reflective surfaces through a Round Robin test.
**Objectives**

- Develop detailed measurement procedure to reconcile single heliostat load field measurements with wind tunnel experiments.
- Investigate loads in low- and high-density arrays of heliostats for wind load prediction in a heliostat field at different elevation angles.

**Approach**

- Field measurements at UoA Atmospheric Boundary Layer Facility (ABLRF) Roseworthy campus to verify single heliostat loads with wind tunnel data.
- Heliostat field array load and flow measurements in different rows of linear staggered field array.

**Status**

- Single heliostat load field measurements consistent with wind tunnel data for prevailing wind direction, other wind directions to be analyzed.
- Increasing load reduction in downstream rows of heliostat array for increasing elevation angle and increasing field density.

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**Wind Loading**

**Lead: Matt Emes (ASTRI)**

- **M. Arjomandi**
  - Impact of Atmospheric Wind turbulence
  - Session: Solar Collection Systems 1

- **Matt Emes**
  - Field Measurement & Analysis of Wind Loads on a Single Heliostat
  - at ABLRF
  - Session: Solar Collection Systems 1
Metrology & Standards

Major gaps
• Lack of > two validated metrology techniques for a given measurement parameter (such as heliostat tracking error, laboratory vs. outdoor, as manufactured vs. in situ) available for the global CSP industry
• Standards: Heliostat terminology, design guidelines, solar field design/simulation guidelines, heliostat test guidelines, solar field acceptance test guidelines, site characterization guidelines (e.g., wind, topography, soiling characteristics).

Progress to date:
• SOFAST near open source release, ReTNA in development at labs, including ground truth validation for SOFAST
• Drone-based NIO, UFACET and advanced outdoor deflectometry are being developed at labs
• Round robin for activities in-situ tools being coordinated with international society
• BCS systems are being improved and standardized
• Outdoor ground truth methods

- Devon Kesseli – Improvement in ReTNA Optical Measurement System
  Msrmt Sys. Devices, & Proc. 1  Wed. 11th 9:10
- Tucker Farrell – NIO Method to measure optical errors in situ
  Solar Collector 3  Wed. 11th 5:15
- Randy Brost – Poster: Interactive CAD Layout Tool
  Wednesday
- Braden Smith – Robust Deflectometry
  Msrmt Sys. Devices, & Proc. 2  Thurs. 11:10
- Braden Smith – Variation in reflected beam shape and pointing accuracy over time and heliostat field position
  Thurs. 3:25
Metrology in action:

On-Going Work

Addressing unsolved problems:
- Temperature optical effect?
- Tilt angle optical effect?
- Mobile SOFAST.

Increasing benefit:
- Ease of use.
- Industrial support.
- Educational version.
- Easy access – OpenCSP, Open SOFAST.

Our goal is to maximize benefit to CSP industry, research, education.

Related work:
Field Deployment
Lead: Jeremy Sment/Alex Zolan

Major gaps
• Heliostat fields have higher risk than other power investments
• Heliostat field integration with industrial thermal processes lacks precedent
• The site-specificity of O&M and field preparation/installation procedures limits the opportunity for incremental improvements that span multiple sites

Progress to date:
• We are developing a High Fidelity Performance forecasting methodology that characterizes key points of uncertainty to obtain confidence intervals on out-year performance (after learning has taken place).
• Stakeholder interviews are ongoing to obtain field deployment cost estimates.
Components & Controls
Lead: Ken Armijo, Matt Muller

Major gaps:
• Lack of lower-cost design for heliostats
• Lack of closed-loop controls to achieve higher flux
• Missing wireless systems approaches, including standardized requirements and testing capabilities

HelioCon Progress to date:
• Closed loop controls test bed is in development at the Sandia NSTTF
• Support for two RFP projects demonstrating wireless controls, and hardware/software upgrades to NSTTF to support testing.
• Software architectures utilized to determine optimal pointing of each heliostat, accounting for unique metrology considerations
Advanced Manufacturing
Lead: Randy Brost, Parthiv Kurup

Major gaps:

- Heliostats not designed for high-productivity manufacturing
- Innovative heliostat mirror facet/array designs needed, materials (composites) needed
- Insufficient facet/array fabrication process knowledge

HelioCon Progress to date:

- RFP work by two awardees advances concepts in this area. (U of Az – variable shaped heliostat, and SD Sunring. Tietronix to interface with SolarDynamics as well.)
HelioCon 2024 RFP

- Please watch for the Round 2 HelioCon RFP
  - Expect to award $3M total external to US Nat’l Labs
  - To fund 3-7 projects
  - Cost Share requirement minimum 20%
  - Open topic area (international proposals welcome) with cost share

- Some NREL and Sandia Lab support possible
  - Access to facilities
  - Access to tools
  - Access to expertise
HelioCon Workshop 2024

• Co-located with ASME-ES 2024 in Anaheim, CA; July 15-17th, 2024
• Review advances in Heliostats
• Special Heliostat Track
Thank you!

• Visit our Booth
  • Details on research, workshops

• Thank you to our Researchers and Industry collaborators!