U.S. Department of Energy
HelioCon
Heliostat Consortium for
Concentrating Solar-Thermal Power

Outlook on Heliostat Technology

Guangdong Zhu, Ph.D.
Margaret Gordon, Ph.D.

October 10th, 2023 • SolarPACES 2023 • Sydney, AU

conceptual design • components • integration • mass production • heliostat field

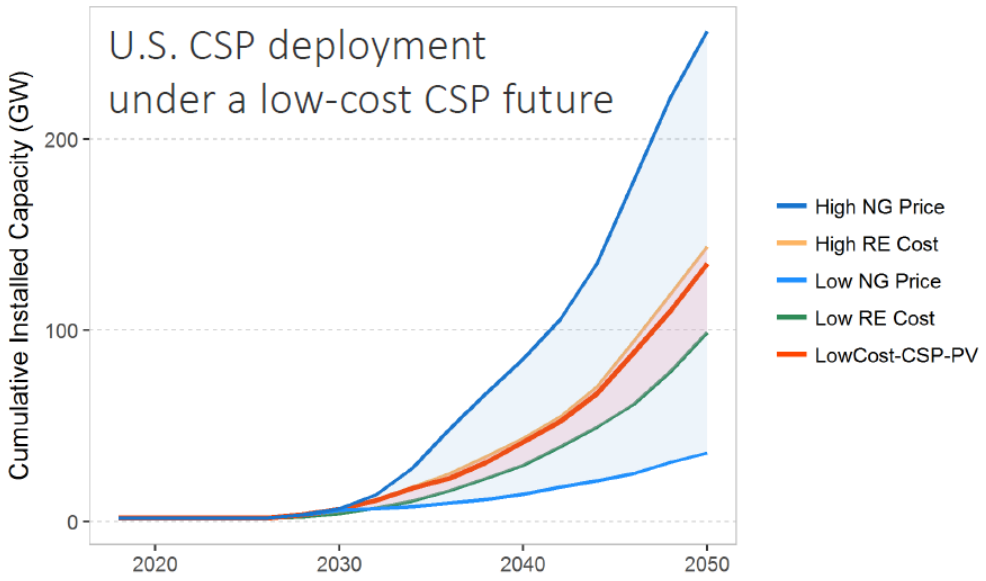
Outline

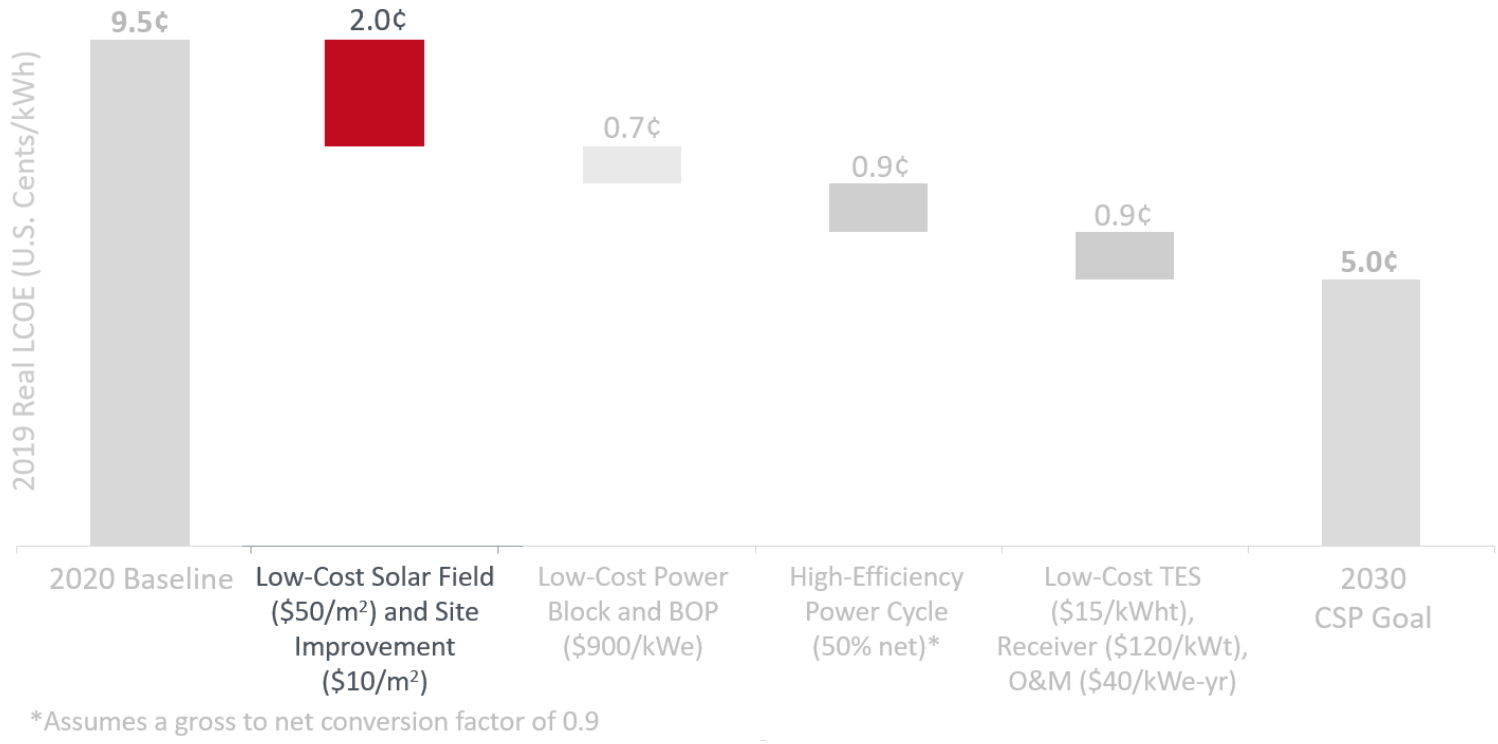
- A vision of Heliostat technology
  - Guangdong Zhu, Ph.D., National Renewable Energy Laboratory
- An Overview of HelioCon
  - Margaret Gordon, Ph.D., Sandia National Laboratories

US Projection on CSP Deployment

Projected market penetration of CSP electricity in future US grid in 2050:

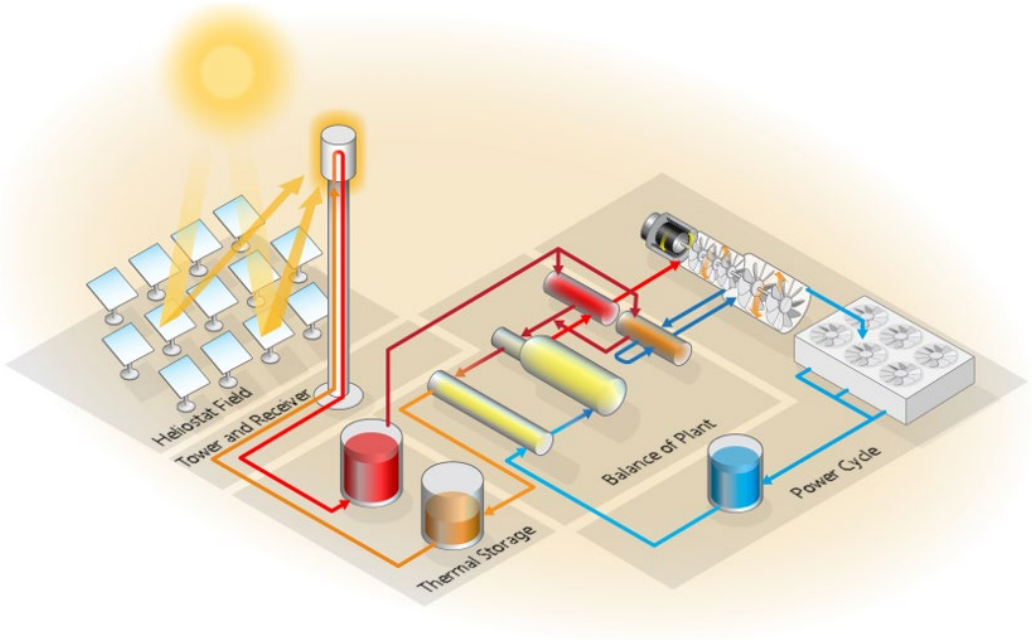
- 35 – 200 GWe (3.5% - 20% of the total national electricity generation)





Baseline Power Tower System For Electricity

- Base case: molten salt power tower default
  - Net Power Output: 100 MW_e/727 MW_{th}
  - External Receiver
    - Solar Salt (60% $NaNO_3$/40% KNO_3)
      - Max heat flux – 1 MW/m^2
    - Hot Side Temp: 575°C
    - Cold Side Temp: 290°C



Parameter	Base Case Value	Units
Installed Heliostat Cost	140	$/m²
Optical Error *(Single-Axis Equivalent)*	1.5	mrad
Reflectance *(Base + Soiling Avg.)*	90	%
Field O&M Costs	66	$/m²/year
Construction Time *Large Electric Field*	24	months

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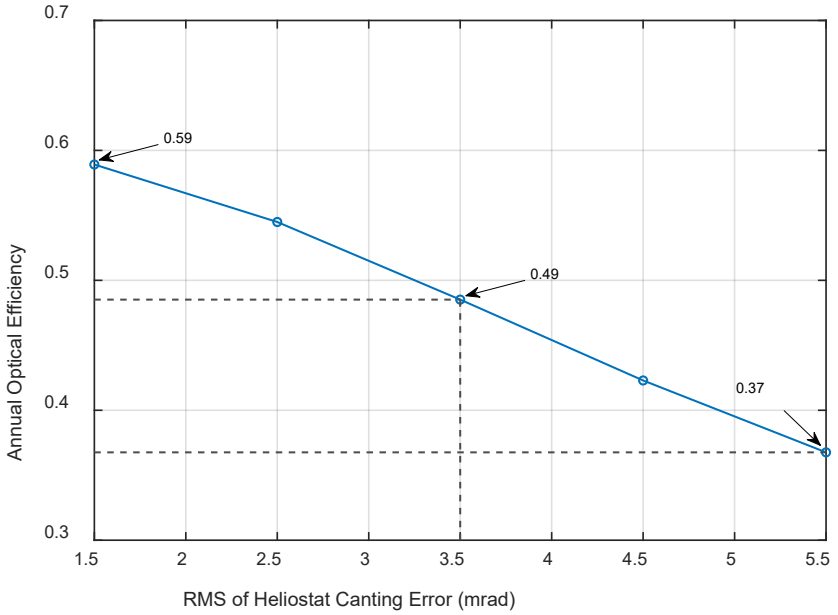
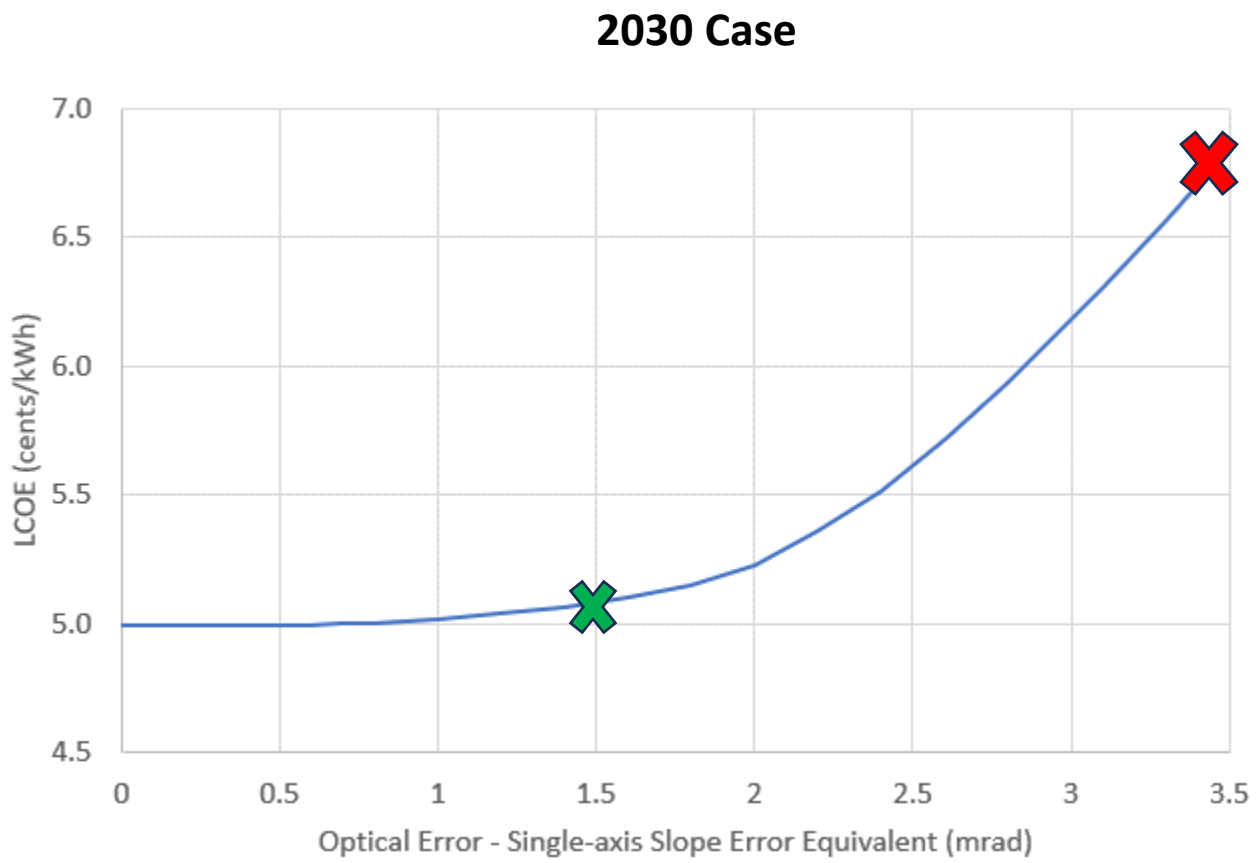
More Than Just Installation Cost

- **Solar field performance** is important
  - Maximize solar field efficiency
  - Minimize solar field and receiver failure
- Additional 2 mrad would result into 20% energy loss



More Than Just Installation Cost

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

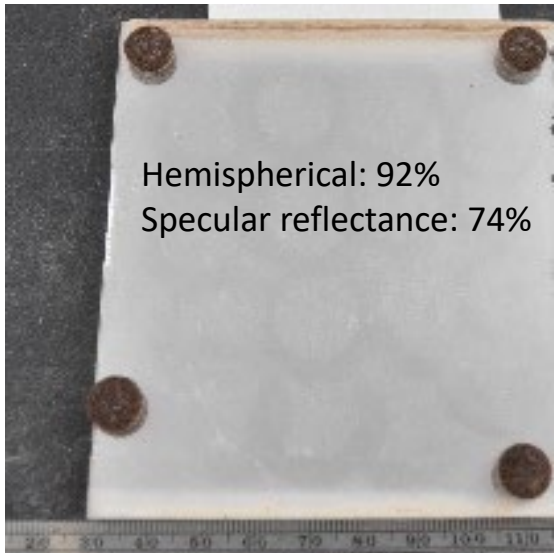


More Than Just Installation Cost

- **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.

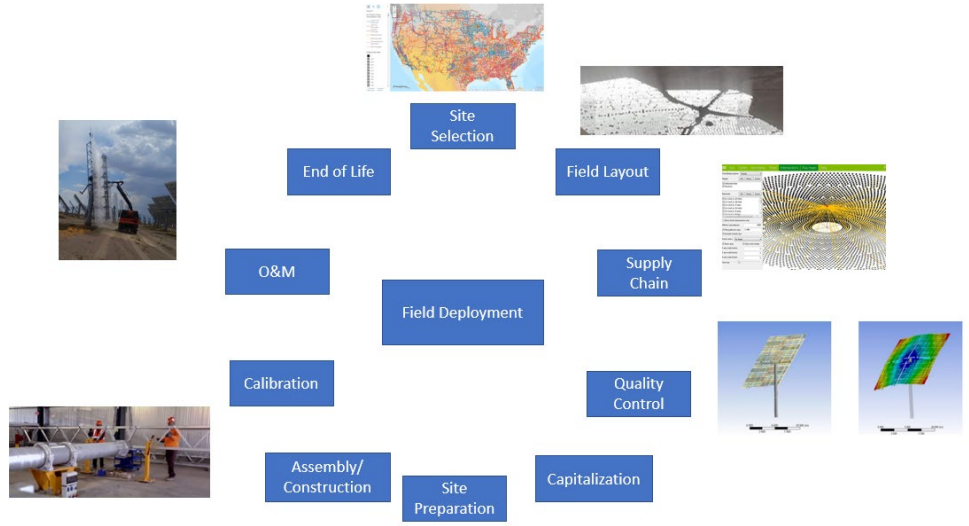
More Than Just Installation Cost

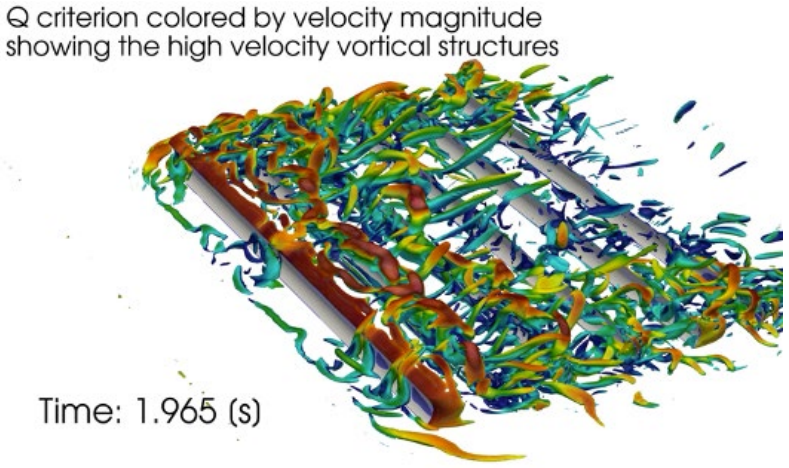
- **Operation and maintenance (O&M)**
  - Impact the cost of a CSP plant
  - Impact solar field performance
- Challenges
  - No measurement standards on mirror soiling
  - Missing site characterization standard on soiling
  - Under-explored design and automation of new cleaning systems
  - Poor understanding on the trade-offs between soiling losses, cleaning regime, design choice and heliostat reliability

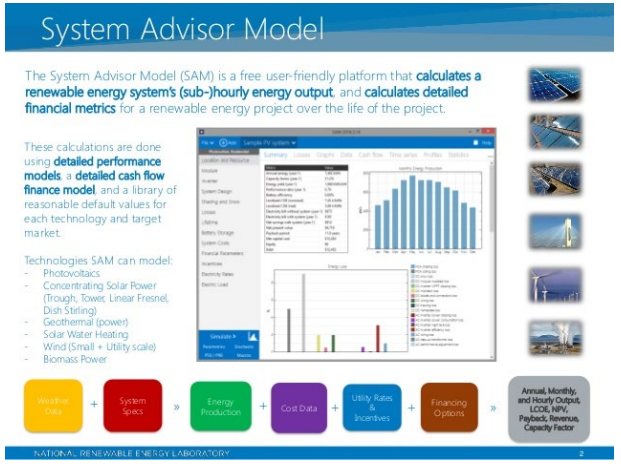


More Than Just Installation Cost

- **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?







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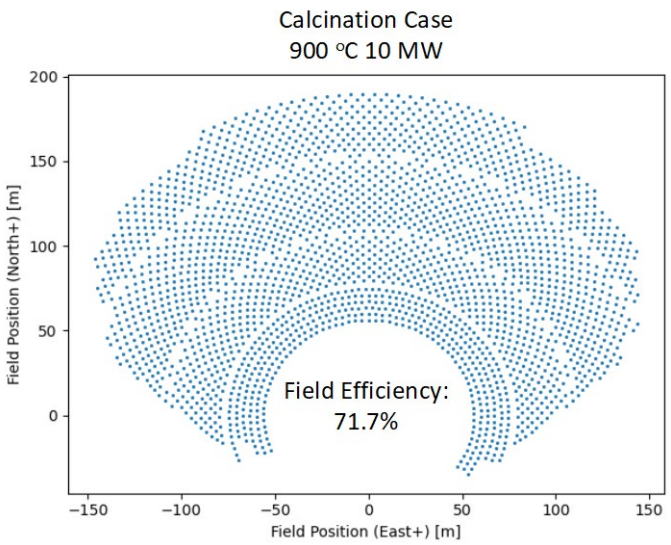
More Than Electricity Generation

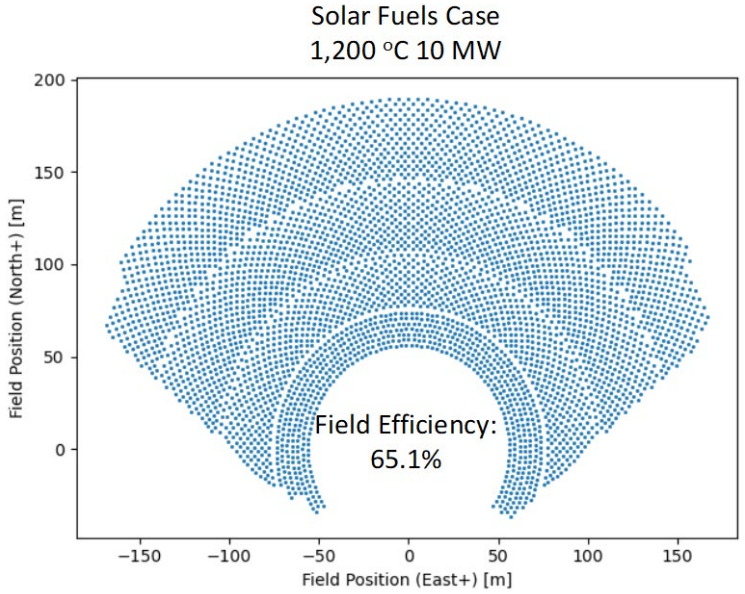
- CSP for industrial process heat and solar fuel
- Three example solar field configurations

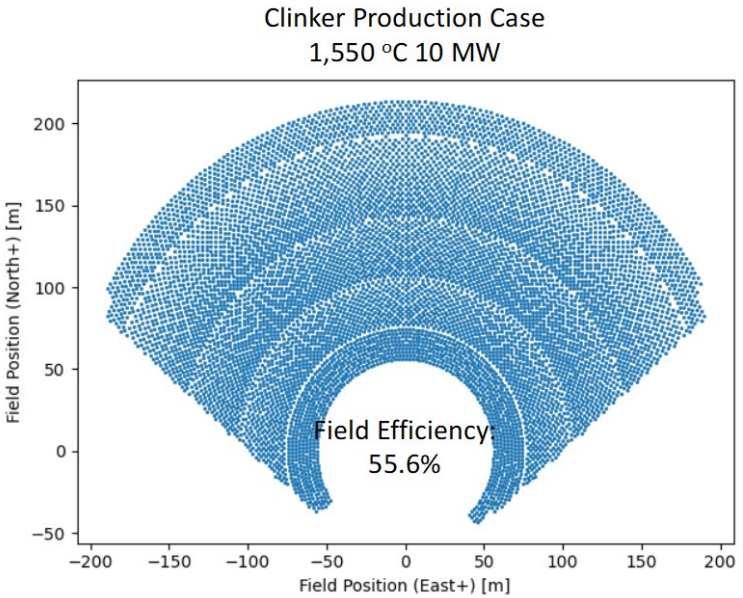
Electricity Generation – Large Solar Field	Electricity Generation – Small/Modular Field	Industrial Process Heat – Small Field
~100 MW_e/727 MW_{th}	~20 MW_e/100 MW_{th}	~10 MW_{th}
Surround Field	Polar Field	Polar Field
External Receiver	Cavity Receiver	Cavity Receiver
575°C (Gen 2) 1 MW_{th}/m^2	575°C (Gen2) 1 MW_{th}/m^2	1,000°C (High-Temp) ~2 MW_{th}/m^2

More Than Electricity Generation

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







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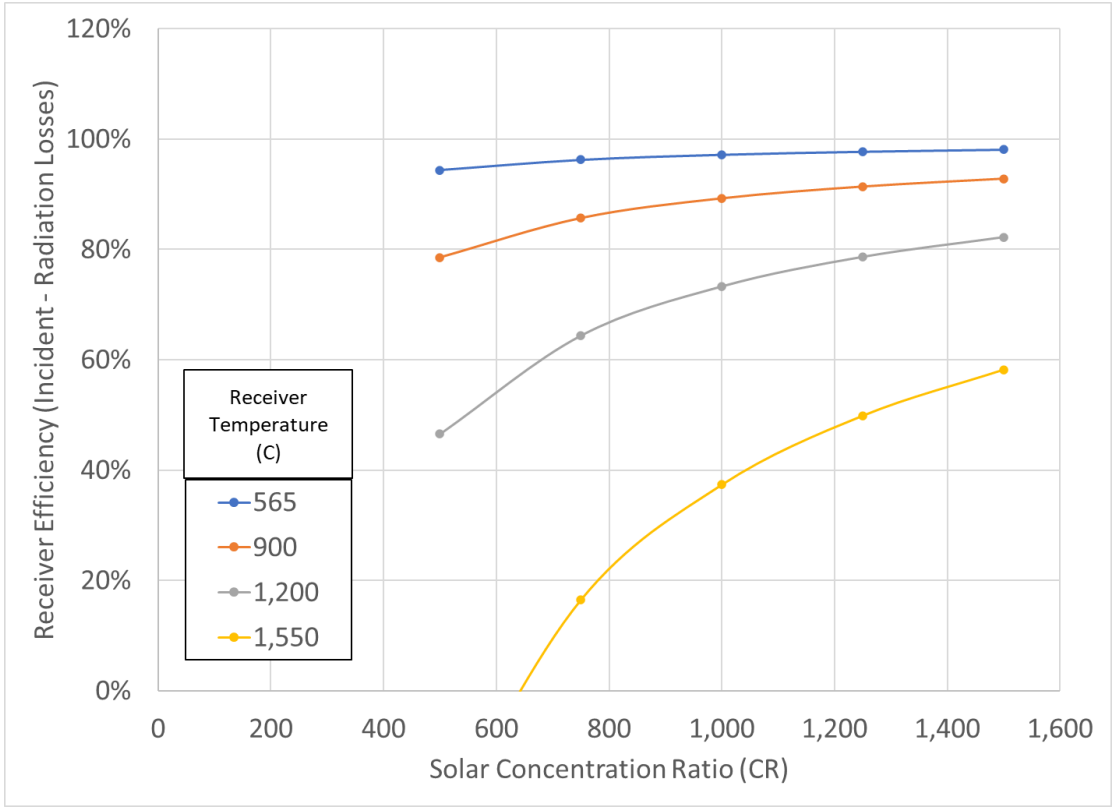
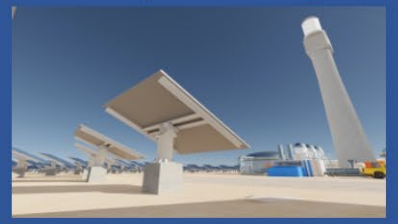
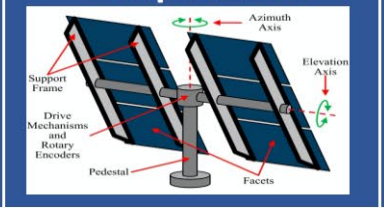


More Questions Than Answers

- How to
  - Reduce the installation cost
  - Improve solar field performance
  - Optimize solar field operation & maintenance
  - 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 Development Cycle	Conceptual Design:	Heliostats Components:	An Integrated Heliostat:	Mass Production of Heliostats:	A Heliostat Field:
					

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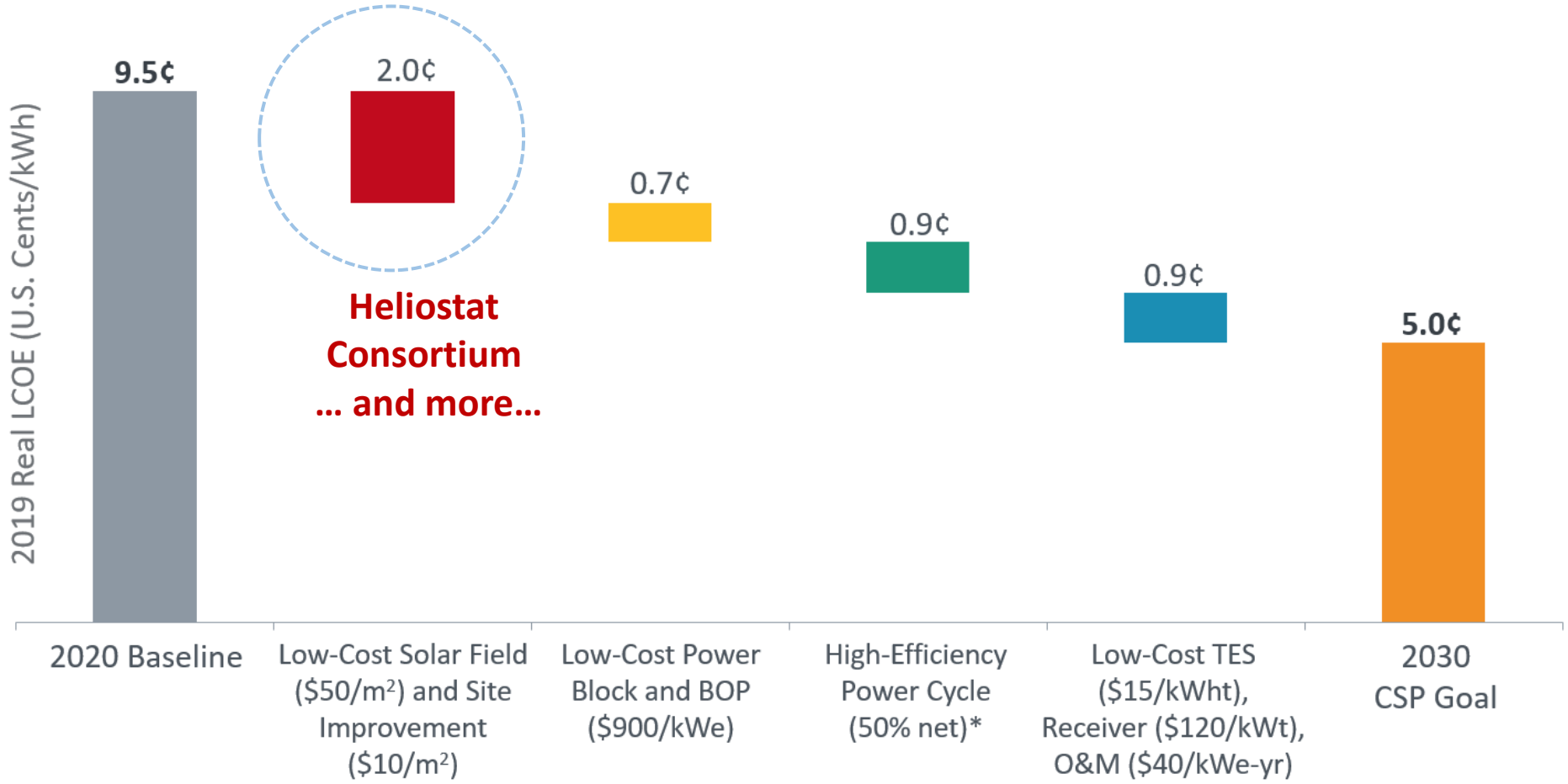
Heliostat Consortium (HelioCon)

- 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.

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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

RoadMap report at HelioCon.org

7 New 2023 projects Industry & Academia Awardees

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

Improved tools and access to National Laboratory resources

- SAMS
- C&C Testbed at NSTTF
- OpenCSP
- Flatirons Campus
- NSTTF Heliostat Field + tower

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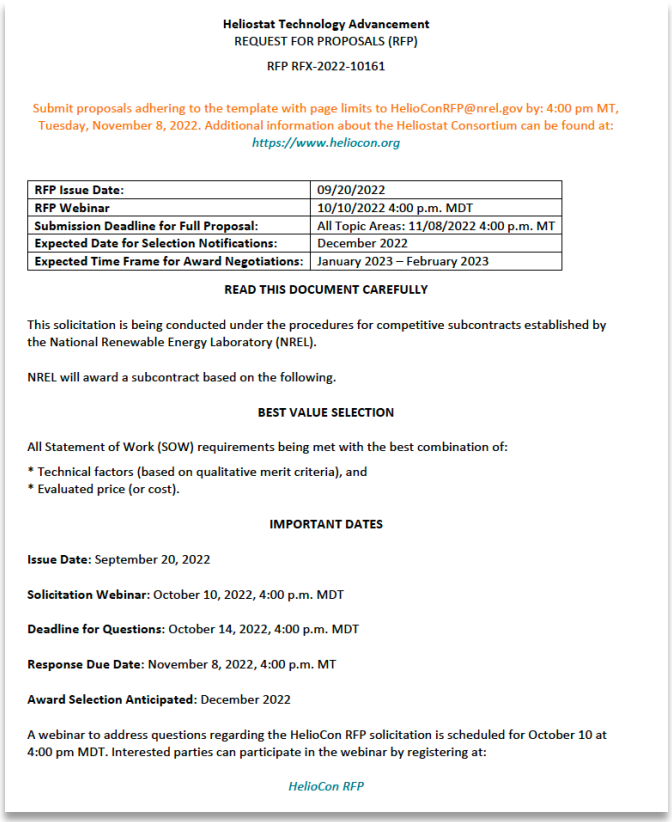
NREL Transforming ENERGY

Sandia National Laboratories

ASTRI Australian Solar Thermal Research Institute



Heliostat Technology Advancement
REQUEST FOR PROPOSALS (RFP)

RFP RFX-2022-10161

Submit proposals adhering to the template with page limits to HelioConRFP@nrel.gov by: 4:00 pm MT, Tuesday, November 8, 2022. Additional information about the Heliostat Consortium can be found at: *https://www.heliocon.org*

RFP Issue Date:	09/20/2022
RFP Webinar	10/10/2022 4:00 p.m. MDT
Submission Deadline for Full Proposal:	All Topic Areas: 11/08/2022 4:00 p.m. MT
Expected Date for Selection Notifications:	December 2022
Expected Time Frame for Award Negotiations:	January 2023 – February 2023

READ THIS DOCUMENT CAREFULLY

This solicitation is being conducted under the procedures for competitive subcontracts established by the National Renewable Energy Laboratory (NREL).

NREL will award a subcontract based on the following.

BEST VALUE SELECTION

All Statement of Work (SOW) requirements being met with the best combination of:

* Technical factors (based on qualitative merit criteria), and
* Evaluated price (or cost).

IMPORTANT DATES

Issue Date: September 20, 2022

Solicitation Webinar: October 10, 2022, 4:00 p.m. MDT

Deadline for Questions: October 14, 2022, 4:00 p.m. MDT

Response Due Date: November 8, 2022, 4:00 p.m. MT

Award Selection Anticipated: December 2022

A webinar to address questions regarding the HelioCon RFP solicitation is scheduled for October 10 at 4:00 pm MDT. Interested parties can participate in the webinar by registering at:

HelioCon RFP

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:

- Lac
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  opp

Audrey Soum-Glaude – Women in CSP Earlier Today!
Rebecca Mitchell – Update on RTE development for CSP Wed. 4:35
Solar Collector 3

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

HelioCon Seminar Videos

Date	Title	Instructor	Video Link	Training Documents
April 10, 2023	CSP Tower Technology: 10+ Years of Innovation and 35+ Years of Mature Prior Innovation	Yoel Gilon	video	Slides, Flyer
March 1, 2023	Introduction of the 2022 CSP Blue Book of China	Zhifeng Wang	video	Slides, Flyer
February 1, 2023	Solar Field for CSP Tower Technology: Best Practices and Lessons Learned in Operational Commercial Projects	Raul Gonzalez Marcelo	video	Slides, Flyer
November 9, 2022	Mitigating Unconscious Bias in Work Teams	Anelisa Simons SNL	video	Slides, Flyer
October 19,	Transferring Photovoltaic lessons	Dr. Matthew Muller,	video	Slides, Flyer
June 29, 2022	Soiling Losses for Concentrating Solar Power – Prediction, Assessment, and Mitigation	Dr. Michael Cholette, Queensland University of Technology	video	Slides, Flyer
June 8, 2022	Bottom-up Analyses for Two Heliostat Collectors and an Initial Heliostat Supply Chain	Parthiv Kurup, NREL	video	Slides, Flyer
May 18, 2022	Heliostat Components and Controls	Dr. Ken Armijo, Sandia	video	Slides, Flyer
April 13, 2022	Economies of Scale – Field Deployment Considerations to Accommodate Evolving Energy Markets	Dr. Jeremy Sment, Sandia	video	Slides, Flyer
March 30,	What's Looking Up Down Under?	Mike Collins, CSIRO	video	Slides, Flyer

Resources

The resources in this section include background on concentrating solar power (CSP), available scientific publications, videos, and additional information on heliostats.

- Background on Concentrating Solar Power
- HelioCon Seminar and Educational Videos
- Zotero References
- HelioCon Publications

August 1, 2022	HelioCon SolTrace Tutorial Session II: Implementing Advanced Geometries	Al Lewandowski	video	Files

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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.

Wind Loading
Lead: Matt Emes (ASTRI)

Objectives

Develop detailed measurement procedure to re
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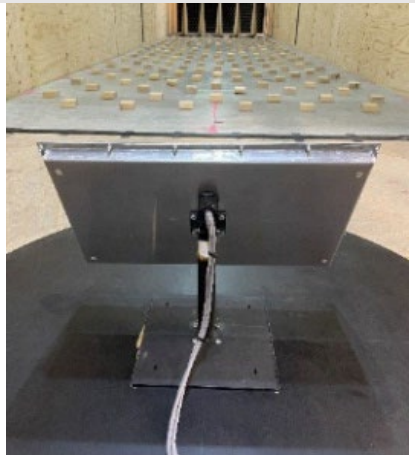
Approa

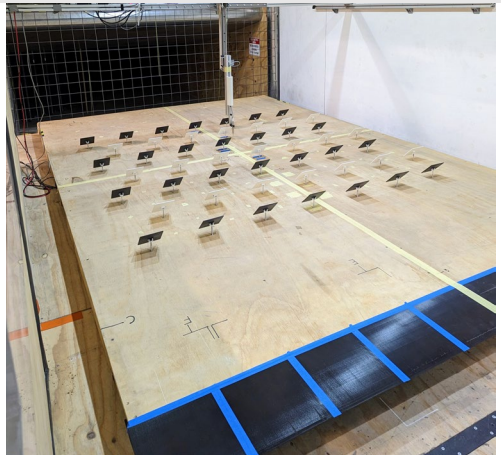
Fie
Layer Facility (ABLRF) Roseworthy campus to verify single heliostat loads with wind tunnel data
Heliostat field array load and flow measurements in different rows of linear staggered field array

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

M. Arjomandi	Impact of Atmospheric Wind turbulence	Wed. 10:50
	Session: Solar Collection Systems 1	
Matt Emes	Field Measurement & Analysis of Wind Loads on a Single Heliostat at ABLRF	Wed. 11:30
	Session: Solar Collection Systems 1	





Metrology & Standards

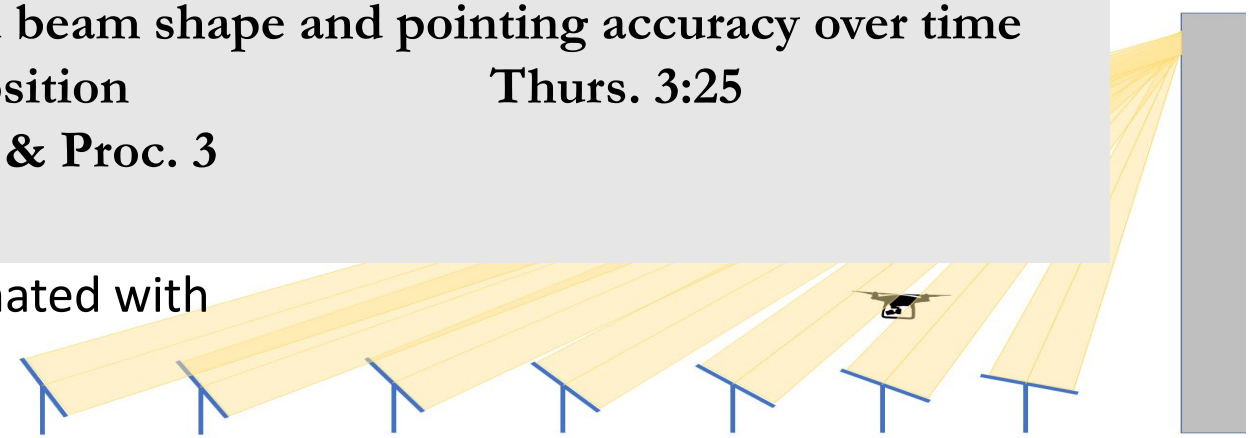
Major gaps

- Lack of > two validated metrology techniques for a given measureme
  laboratory
  for the glob
- Standards:
  field design
  solar field a
  guidelines (

Progress to d

- SOFAST nea
  labs, includ
- Drone-base
  deflectome
- 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**	**Thurs. 11:10**
	Msrmt Sys. Devices, & Proc. 2	
Braden Smith	**Variation in reflected beam shape and pointing accuracy over time**	
	and heliostat field position	**Thurs. 3:25**
	Msrmt Sys. Devices, & Proc. 3	



Metrology in action:

On-Going Work

Addressing unsolved problems:

- Temperature optical effect?
- Tilt angle optical effect?
- Mobile SOFAST.

} Available for industry support

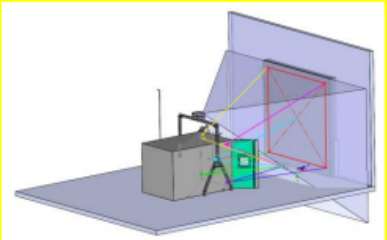
Increasing benefit:

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

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

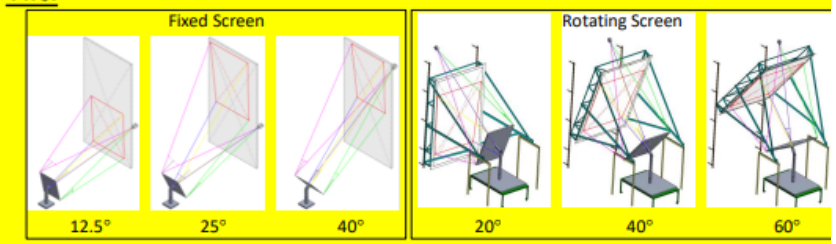
Temperature:[1]

CFV Labs Chamber: -40°C → +85°C

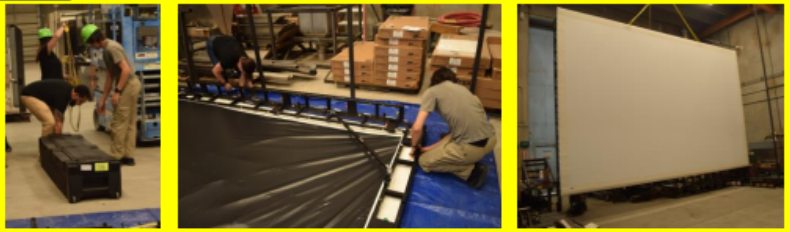


SOFAST Layout with Temperature Chamber

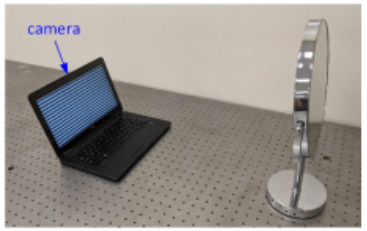
Tilt:[2]

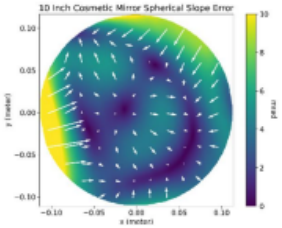


Mobile:



Education:





Related work:

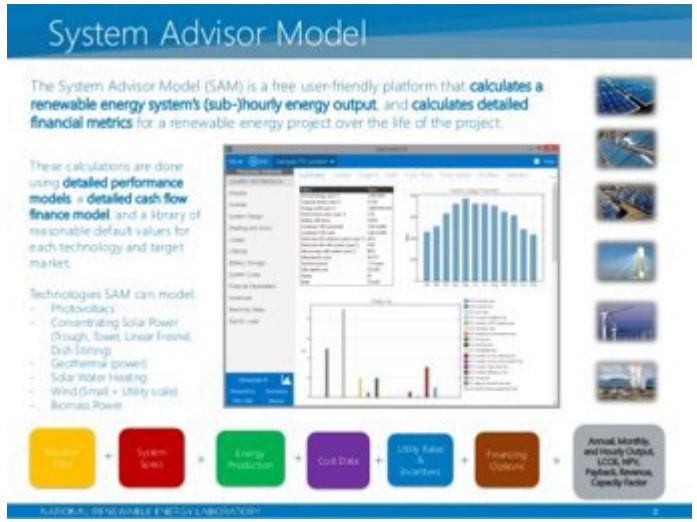
[1] Sartori, et al. Composite Mirror Shape Deviations Due to Temperature Changes. AIP Conference Proceedings **2303**, December 2023.

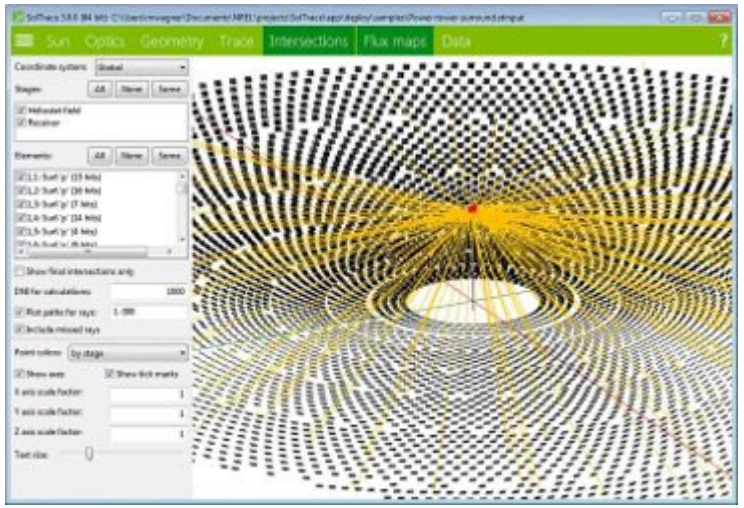
[2] Yuan, et al. Compensation of Gravity Induced Heliostat Deflections for Improved Optical Performance. *Solar Energy Engineering*, 2015.

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

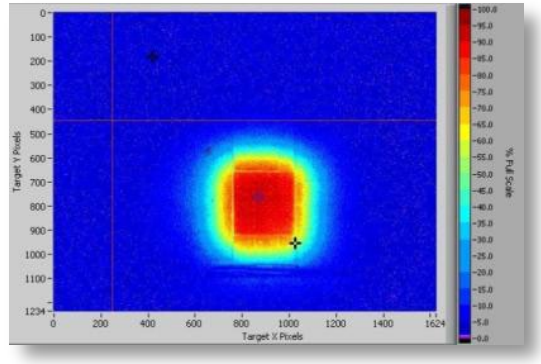
Major gaps:

- Lack of lower-cost design for heliostats
- Lack of c
  higher f
  alignment/calibration processes
- Missing wireless systems approaches, including standardized requirements and testing capabilities

Ken Armijo – NSTTF Wireless Closed loop Controls Testbed
Wed. 4:55 Solar Collector 3

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 productivi
- Innovative heliostat mirror facet/array designs needed, materials (composites) needed
- Insufficient facet/array fabrication process knowledge

Kyle Kattke – SunRing Heliostat: Minimizing Slope Error with Smart Design and Assembly Wed. 2:05 Solar Collector Systems 2

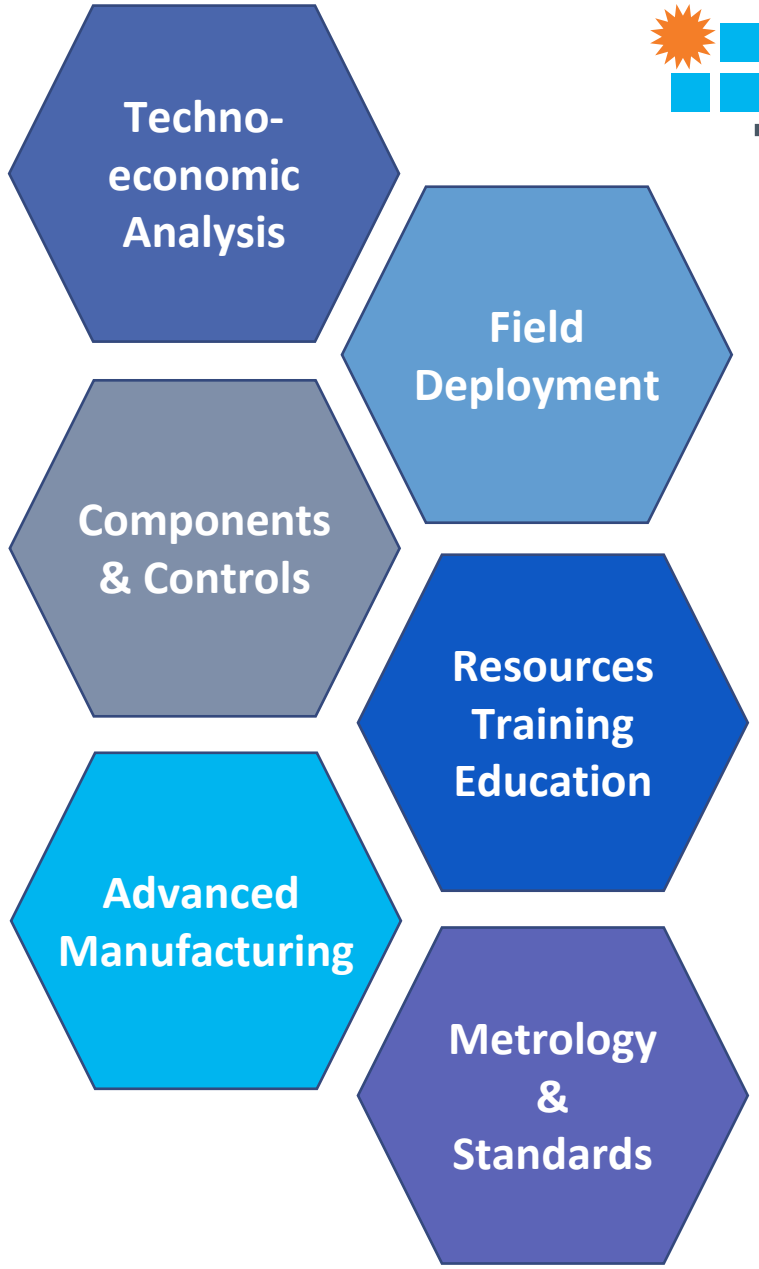
HelioCon Progress to date:

- 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

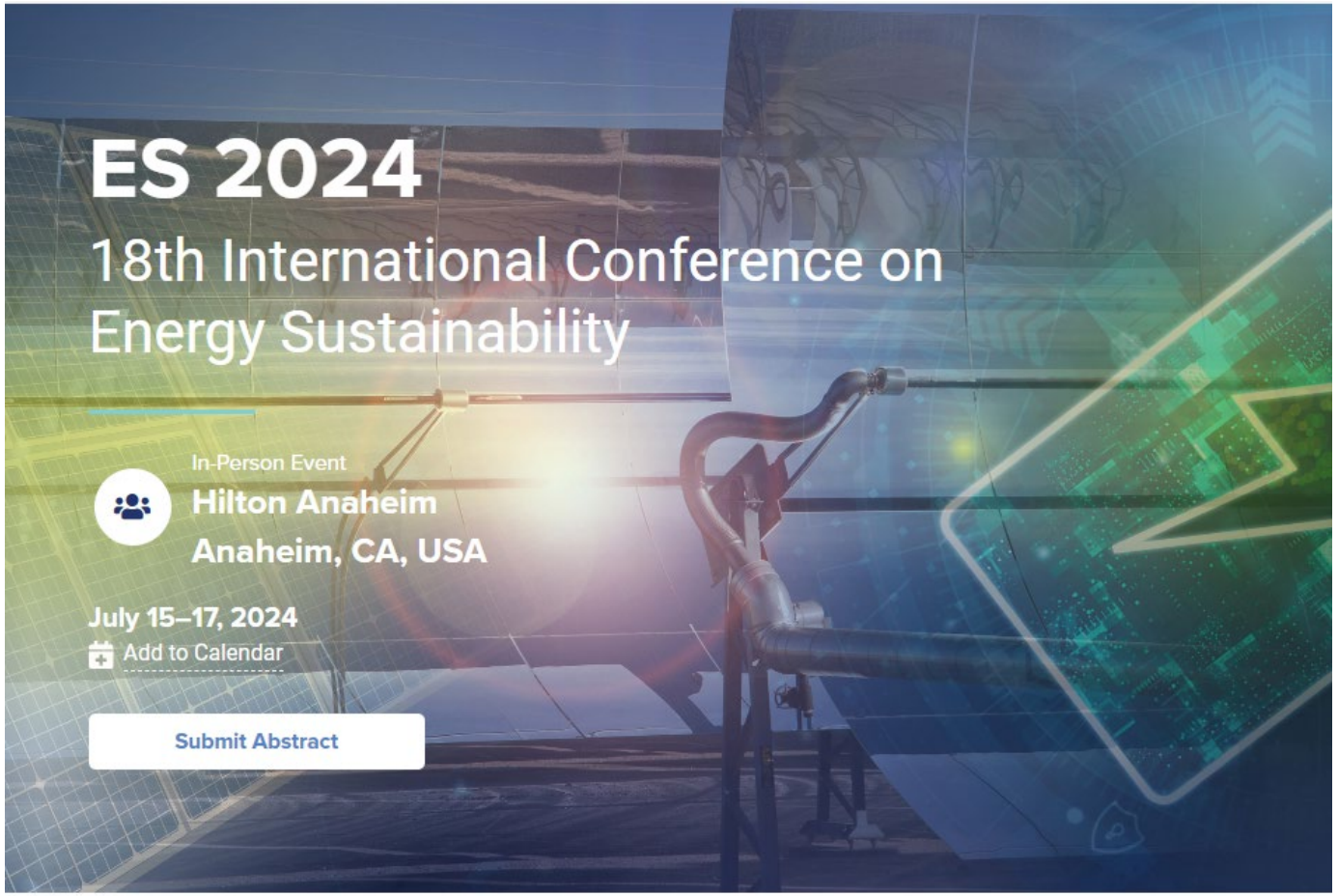
- Please watch for the Round 2 HelioCon RFP
  - Expect to award $3M total external to US Nat'l Labs
  - To fund 3-7 projects
  - Cost Share requirement minimum 20%
  - Open topic area (international proposals welcome) with cost share

- 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!

NREL Transforming ENERGY

Sandia National Laboratories

ASTRI Australian Solar Thermal Research Institute

conceptual design • components • integration • mass production • heliostat field