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

Status Update on Metrology and Standards in the Heliostat Consortium (HelioCon)

Guangdong Zhu, NREL
Randy Brost, Sandia National Laboratories

With contribution from: Rebecca Mitchell, Tucker Farrell, Devon Kesseli, Braden Smith

July 11th, 2023 • 2023 HelioCon Workshop • ASME Energy Sustainability conference

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

HelioCon Roadmapping Study in 2022

- Roadmap report is released in September, 2022
- Categorize study into six topic areas
  - Advanced manufacturing
  - **Metrology and standards**
    - Special topic: Soiling
  - Components and controls
  - Field deployment
    - Special topic: windload
  - Techno-economic analysis
  - Resources, Training and Education
- Roadmapping study for each topic
  - State of the art
  - Gaps to a fully competitive product
  - Gap analysis
  - Recommended addressing strategy

Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power

Guangdong Zhu,[1] Chad Augustine,[1] Rebecca Mitchell,[1] Matthew Muller,[1] Parthiv Kurup,[1] Alexander Zolan,[1] Shashank Yellapantula,[1] Randy Brost,[2] Kenneth Armijo,[2] Jeremy Sment,[2] Rebecca Schaller,[2] Margaret Gordon,[2] Mike Collins,[3a] Joe Coventry,[3b] John Pye,[3b] Michael Cholette,[3c] Giovanni Picotti,[3c] Maziar Arjomandi,[3d] Matthew Emes,[3d] Daniel Potter,[3a] and Michael Rae[3a]

1 National Renewable Energy Laboratory
2 Sandia National Laboratories
3 Australia Solar Thermal Research Institute (ASTRI)
3a The Commonwealth Scientific and Industrial Research Organization
3b Australian National University
3c Queensland University of Technology
3d University of Adelaide

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5700-83041
September 2022

HelioCon.org

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

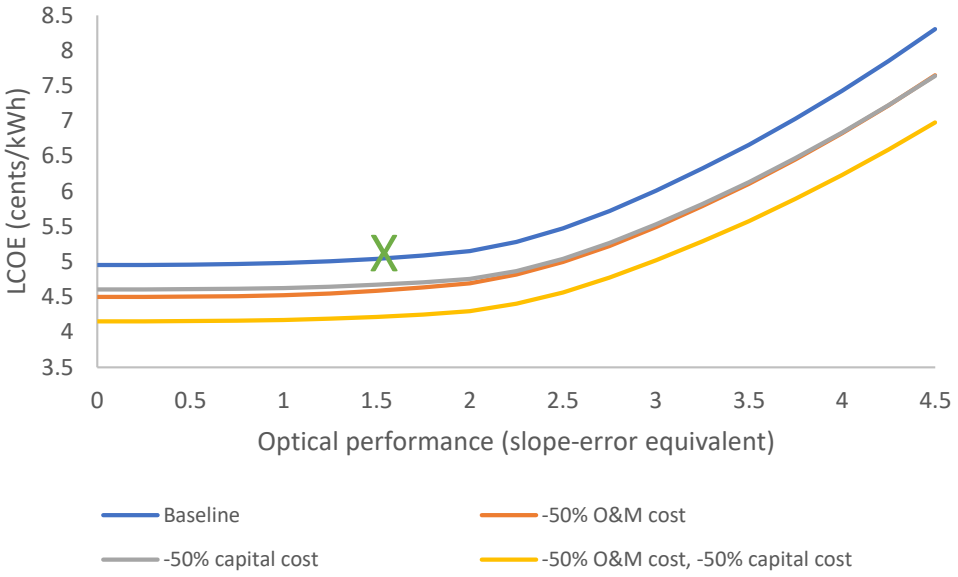
Metrology & Standards: Why

- **If you can not measure, you can not improve it. By Lord Kelvin**

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

Metrology & Standards: Optics Matters

- In a utility-scale solar field, a heliostat may be 1,500 m away from receiver.
  - Over 10,000 heliostats in a field
  - Optical precision: 1.5 ~ 2.5 mrad
    - Additional 2 mrad would result into 20% energy loss



Metrology & Standards: Scope

- 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**
- Structural/wind load (a separate subtopic discussed later in this report)
- Receiver coating properties (excluded from HelioCon)
- Receiver geometry (excluded from HelioCon)
- **Reflected beam quality**

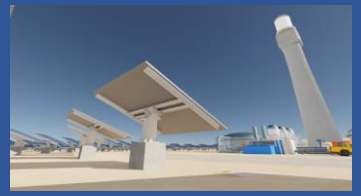
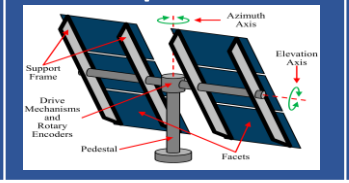
Metrology

Criteria to determine if there is a gap:

- At least two viable metrology techniques for a given measurement parameter are available for the whole CSP industry

- Any viable metrology technique is validated against a different trusted metrology technique or ground-truth article.

After all, metrology tool for heliostat technologies is not a temperature senor or like.

Heliostat Development Cycle	Conceptual Design:	Heliostats Components:	An Integrated Heliostat:	Mass Production of Heliostats:	A Heliostat Field:
					

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

Work Plan 1: Develop and Benchmark Metrology Techniques

Objective: Possess validated metrology technologies sufficient to assess opto-mechanical performance of heliostat designs and heliostats in the field.

Approach:

- Develop ground truth reference standards and methods, both indoor and outdoor
  - Physical calibration standards
  - Fundamental measurement methods
- Conduct international round-robin test by working closely with the international community and programs
  - Identify the most advanced metrology technology in each metrology category
- Refine the existing opto-mechanical tool development
  - In-situ NIO and UFACET
  - SOFAST and NIO-a
  - Beam characterization system (BCS)
  - Surface contact measurement technique - for laboratory scale heliostat surface error measurement (including software for statistical analysis)
  - Tower mounted camera array - targeted towards calibration system but also could provide BCS
- Develop innovative new metrology methods to address identified gaps.
  - BCS++, Screenless deflectometry

Impact:

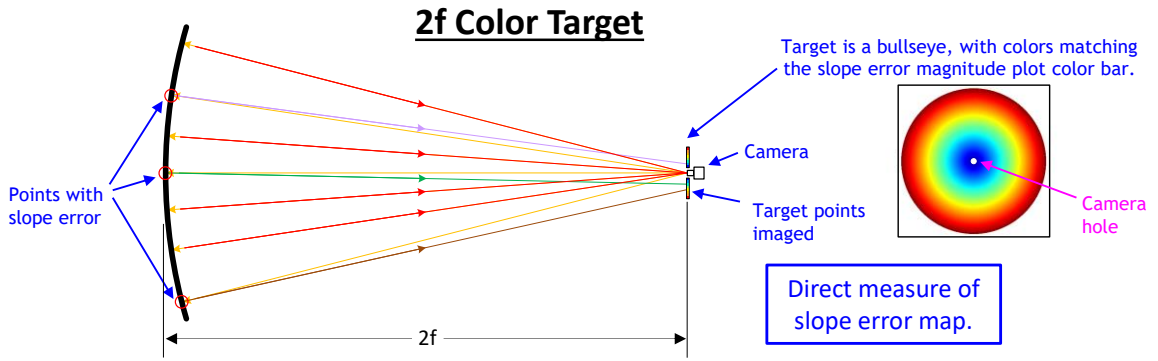
- Ensure/Improve heliostat performance

Addressing gaps: M1, M2, M5 (roadmap)

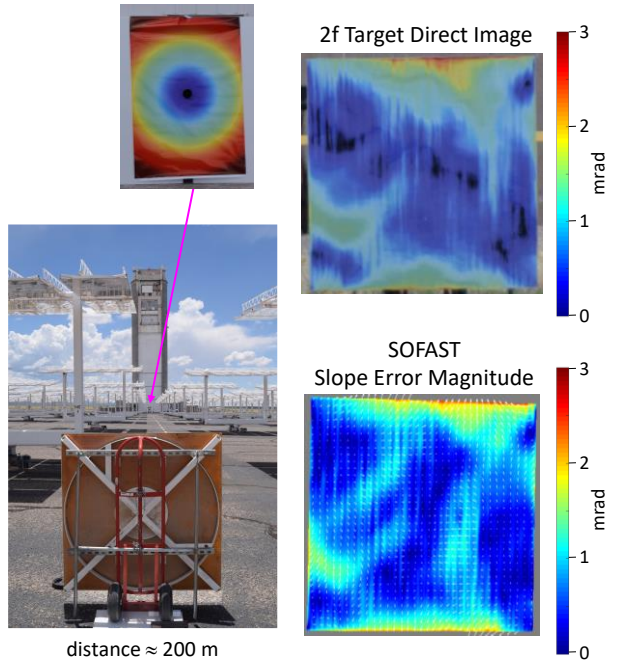
conceptual design • components • integration • mass production • heliostat field

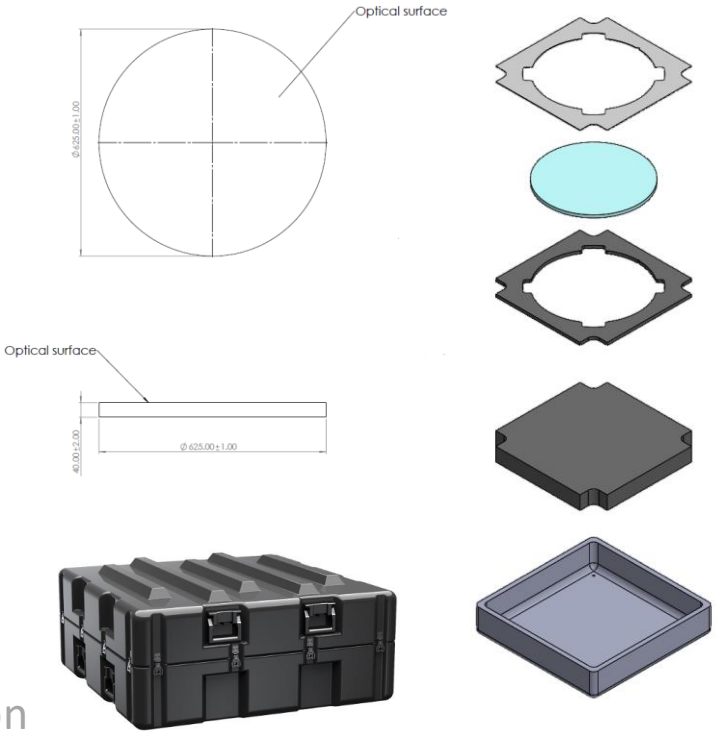
Work Plan 1: Progress on Ground Truth

- **Objectives**
  - Develop simple, fundamental references for cross-checking more complex metrology systems.
  - Increase confidence in metrology systems used in high-consequence situations (e.g., final design, factory production).
- **Approach**
  - Ground truth methods and physical standards.
  - Simple methods exploiting optics.
  - High-precision physical standards.
  - Share with the CSP community.
- **Status**
  - Prototypes of multiple methods, both facets and full heliostats.
  - High-precision mirror expected soon.



f = 100 m Calibration Mirror Design



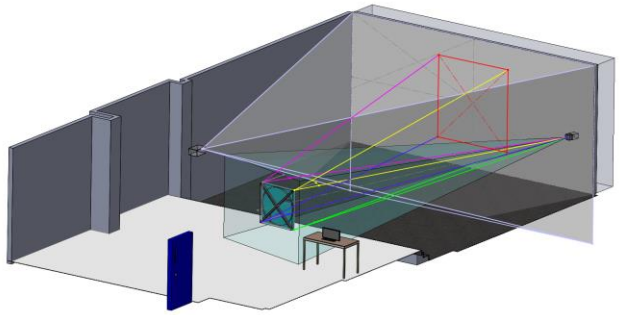


conceptual design • components • integration • mass production

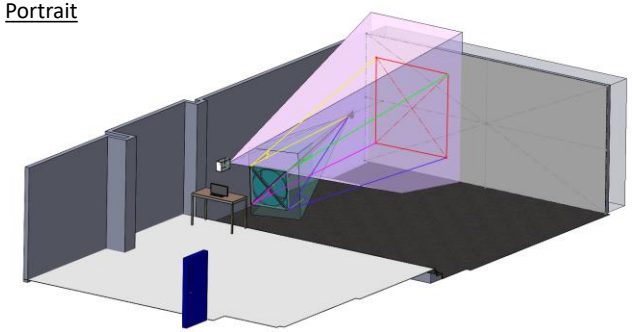
Work Plan 1: Progress on SOFAST

- **Objectives**
  - High-resolution, fast, slope measurement for both facets and full heliostats.
  - Suitable for:
    - Prototype development
    - Manufacturing process development
    - High-volume factory production
  - Multiple improvements in code quality, extensibility, flexibility, ease of use, application to key new problems.
- **Approach**
  - Deflectometry.
  - High-quality code, simplify calibration.
  - Check against ground truth.
- **Status**
  - Version 1 in commercial use.
  - Version 2 nearing completion.

Landscape



Portrait



Ideal Design

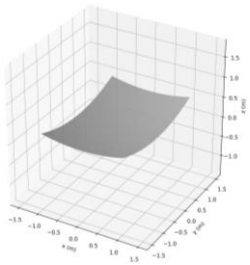
$$z = \frac{x^2}{4f_x} + \frac{y^2}{4f_y}$$

$f_x = 100$ m

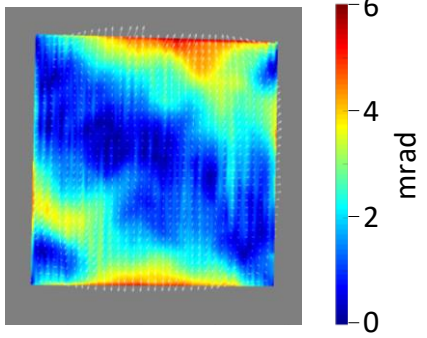
$f_y = 100$ m

$l_x = 1.22$ m

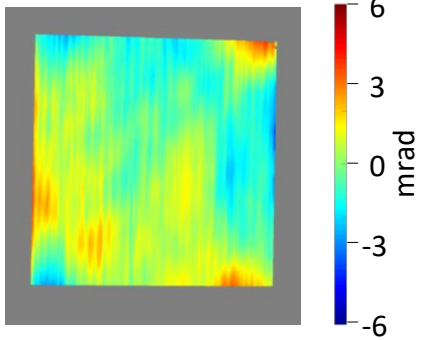
$l_y = 1.22$ m



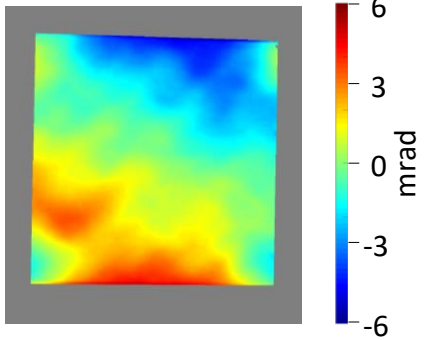
Slope Error Magnitude



X Slope Error



Y Slope Error



5-12 Heliostat Consortium 2: Wednesday, July 12, 2023, 9:00-10:30am:
Extending Deflectometry Metrology Capability for CSP (Randy Brost)

Work Plan 1: Progress on ReTNA

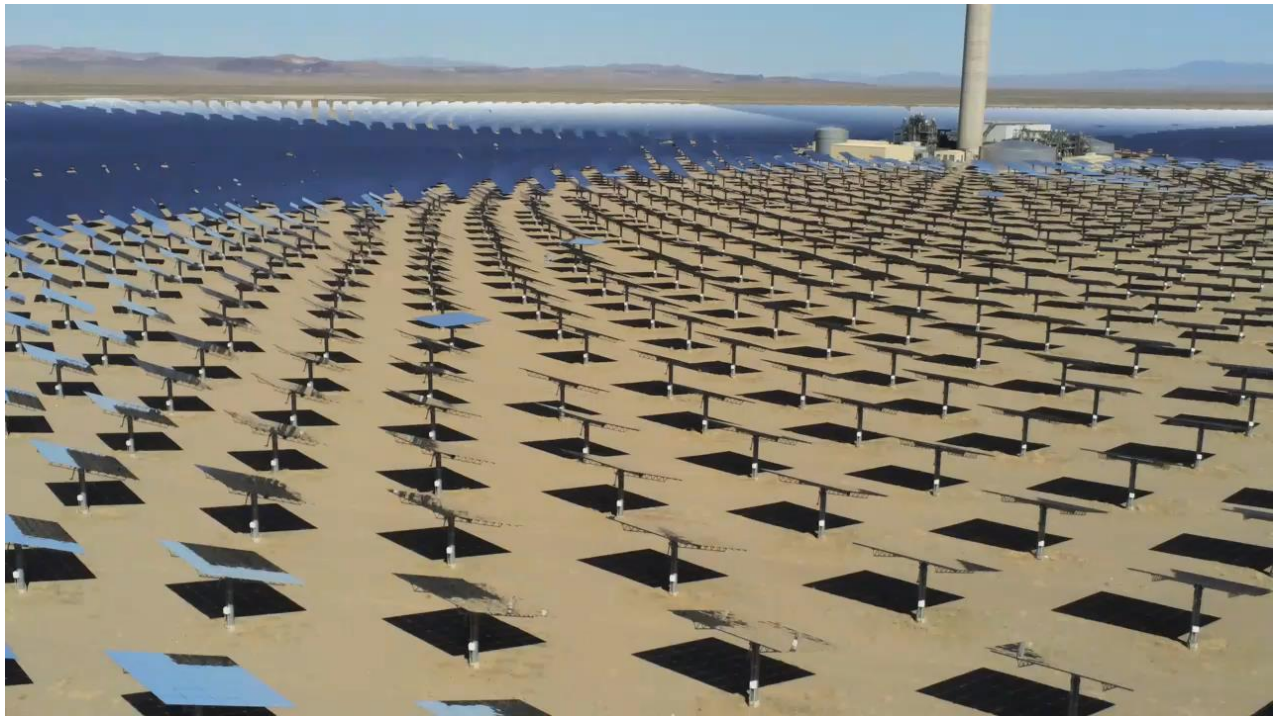
- **Objectives**
  - Laboratory technology suitable for single heliostat prototype
  - Portable, efficient and automatic
  - Measure slope error, canting error
    - Varying orientation
    - Varying load
- **Approach**
  - Reflectometry & deflectometry
  - Automated image-processing through computer vision and machine learning
- **Status**
  - Completed concept-proof stage
  - Building a prototype at NREL

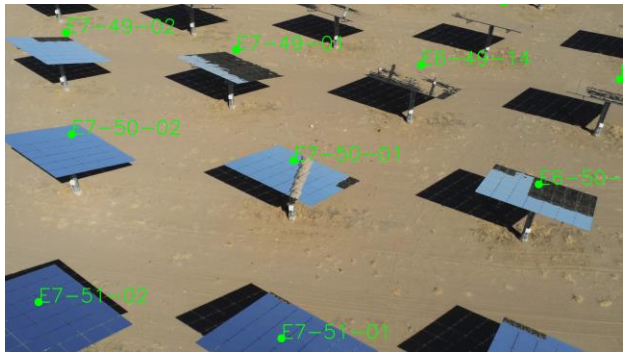
5-12 Heliostat Consortium 3: Wednesday, July 12, 2023, 11:00am-12:30pm :

An Indoor Reflected Target Optical Measurement System for Concentrated Solar Power Mirrors (Devon Kesseli)

Work Plan 1: Progress on NIO

- **Objectives**
  - In-situ technology suitable for utility-scale heliostat fields
  - Measure slope error, canting error and tracking error
- **Approaches**
  - Drone-driven camera
  - Reflectometry
  - Automated image-processing through computer vision and machine learning
- **Status**
  - Entered into demonstration stage
    - NSTFF (done)
    - Crescent Dunes (done)
    - Cerror Dominador (planned)



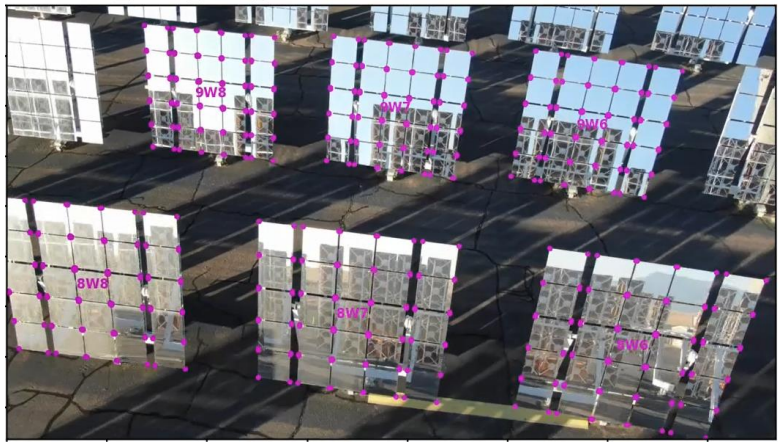


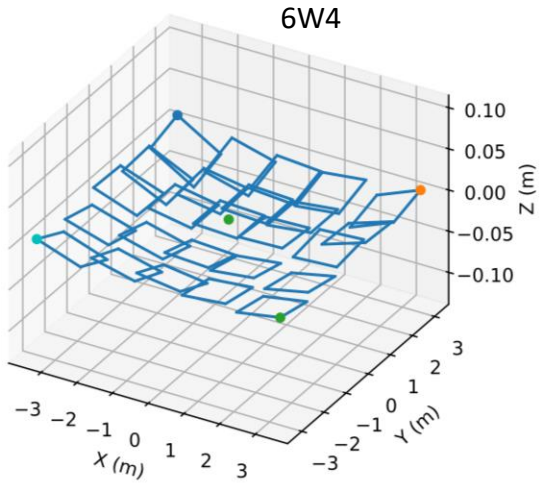
5-12 Heliostat Consortium 2: Wednesday, July 12, 2023, 9:00-10:30am:

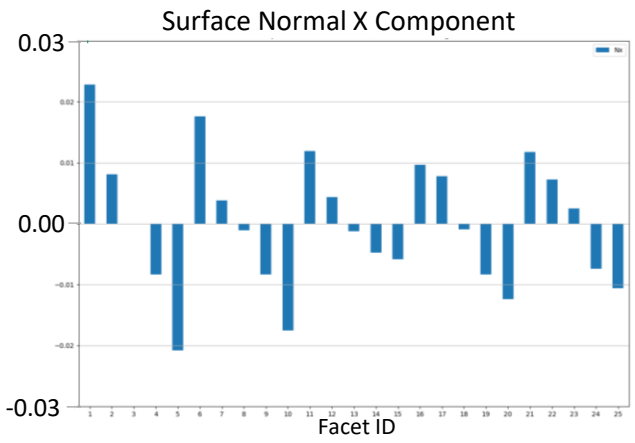
Characterizing Heliostats at a Commercial Scale With Non-Intrusive Optics (Devon Kesseli on behalf of Tucker Farrell)

Work Plan 1: Progress on UFACET

- **Objectives**
  - High-speed measurement of full solar fields.
  - Support optical assessment and accelerated heliostat calibration.
  - Measure full solar fields without interrupting operation.
- **Approach**
  - Use drone with smooth, high-speed scanning passes.
  - Photogrammetry and reflectometry.
  - Automated video processing using engineered analysis algorithms.
- **Status**
  - Substantial progress, not complete.







5-12 Heliostat Consortium 3: Wednesday, July 12, 2023, 11:00am-12:30pm :

High-Speed Assessment of Heliostat Fields without Disrupting Operations (Randy Brost)

conceptual design • components •

Work Plan 2: Develop Third-Party Heliostat Performance Assessment

Objectives: Make available third-party heliostat performance assessment capabilities to serve CSP industry.

- To provide third-party evaluation of heliostat designs under indoor and outdoor conditions
- To provide third-party validation of newly developed metrology technologies by others

Approach:

- Acquire, install and calibrate most-advanced metrology technologies within HelioCon:
  - Ground truth physical standards and methods.
  - Opto-mechanical tools:
    - two indoor metrology techniques; two outdoor metrology techniques
  - Sunshape characterization metrology
  - Attenuation characterization metrology
  - Soiling assessment metrology
- Demonstrate the test capability with a case study
- Call for test services on commercial heliostat designs

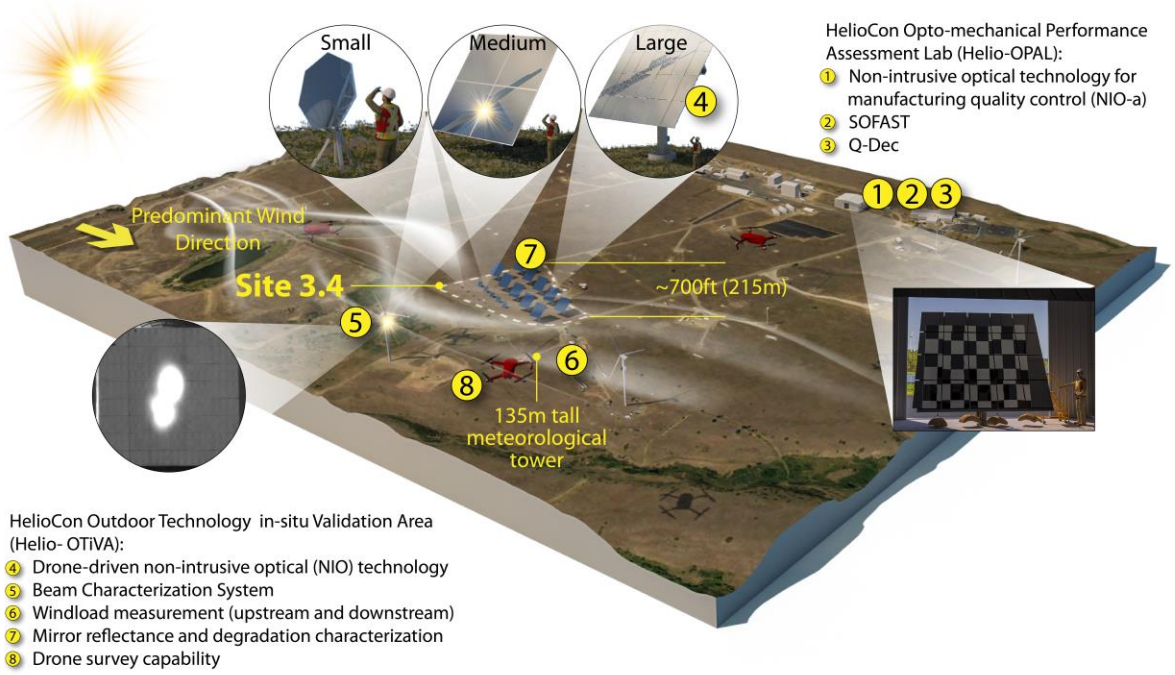
Impact:

- Improve heliostat performance
- Reduce heliostat technology deployment risks.

Addressing gaps: M1, M2, M5, S4, S5 (Refer to HelioCon Roadmap Study report)

Work Plan 2: Progress at NREL's Flatirons Campus

- **Objectives**
  - Make available third-party heliostat performance assessment capabilities to serve CSP industry.
    - evaluation of heliostat designs under indoor and outdoor conditions
    - validation of newly developed metrology technologies by others
- **Approach**
  - Develop/acquire, install and calibrate most-advanced metrology technologies within HelioCon
  - Demonstrate the test capability with a case study
  - Call for test services on commercial heliostat designs
- **Status**
  - Developing new techniques



Work Plan 2: Progress at Sandia's NSTTF

- **Objectives**
  - Support high-temperature, high productivity industrial processes.
  - Deliver high-intensity flux to G3P3 receiver.
  - Support CSP industry, research, and education.
  - Develop mobile systems that can operate at industry sites. (Both indoor and outdoor.)
  - Accurately calibrate NSTTF heliostat field and share as a reference for testing other metrology systems.
- **Approach**
  - Ground truth foundation, chain of provenance.
  - Advanced outdoor deflectometry.
  - Advanced calibration and control.
  - Measure across range of operating conditions.
- **Status**
  - Mixture of high and low TRL.

Work Plan 3: HelioCon Outreach

Objective: integrate the international community to address the remaining Tier 1 gaps in metrology and standards which HelioCon cannot address

Approach:

- HelioCon will promote the value of addressing the pre-identified top-tier heliostat metrology and standards gaps through public presentations, workshop and conferences
- HelioCon will share the learned knowledge, resource, and lessons with the international society
- HelioCon will support members or non-members (such as ASTRI, researcher institutes elsewhere) to pursue other funding opportunities

Impact:

- Reduce commercial risks

Addressing gaps: M3, M4, M6, and other Tier 2 and Tier 3 gaps (Refer to HelioCon Roadmap Study report)

Work Plan 3: Progress

- Objectives:
  - Round robin tests of various metrology techniques
  - International collaboration on research
- Approach:
  - Collaboration with ASTRI (HelioCon core member)
  - Recruit new HelioCon members with prestigious institutes around the world.
  - Work with international community through SolarPACES
- Status:
  - Created multiple-year plan with ASTRI members
  - Carrying out discussion with additional international institutes: DLR and CIEMAT
  - Collaborating with various working groups under SolarPACES
  - Collaborating with European institutes under EU programs

Heliostat Consortium Workshop: Summary Session, Wednesday, July 12, 1pm:

ASTRI Work Highlight (John Pye, ANU)

ASTRI
Australian Solar Thermal Research Institute

SolarPACES

1st of March 2023

Proposal title: Update of guideline "Recommendations for reflectance measurements on soiled solar mirrors"

Sponsoring task: SolarPACES Task III: Solar Technology and Advanced Applications.

SolarPACES Project "Analyze Heliostat Field" Kick off

CENER

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 823802.

- **PROJECT TITLE**

Concentrator Optical Metrology Evaluation and Test

- **ACRONYM**

COMET

Work Plan 4: Heliostat Technology Standards on Metrology

Objective: participate, or lead if needed, the development, review, improvement and validation of the standards or guidelines identified as Tier 1 gaps in topics of standards

- Definition of optical attributes for heliostats (S1)
- Site characterization guideline (S2)
- Heliostat design guideline (S3)
- Heliostat solar field design/simulation guideline (S4)
- Heliostat test guideline (S5)
- Heliostat solar field acceptance test guideline (S6)

Approach:

- HelioCon will form technical teams for each individual standards or guideline, who will participate, or lead if needed, the development of pre-identified guidelines.
- HelioCon will work closely with SolarPACES and other international agency to allocate the fund to support the development of pre-identified heliostat standards/guideline development
- HelioCon will establish a co-funding mechanism to
  - the guideline/standard development within the international society.
  - Validation/demonstration of the developed heliostat guidelines/standards

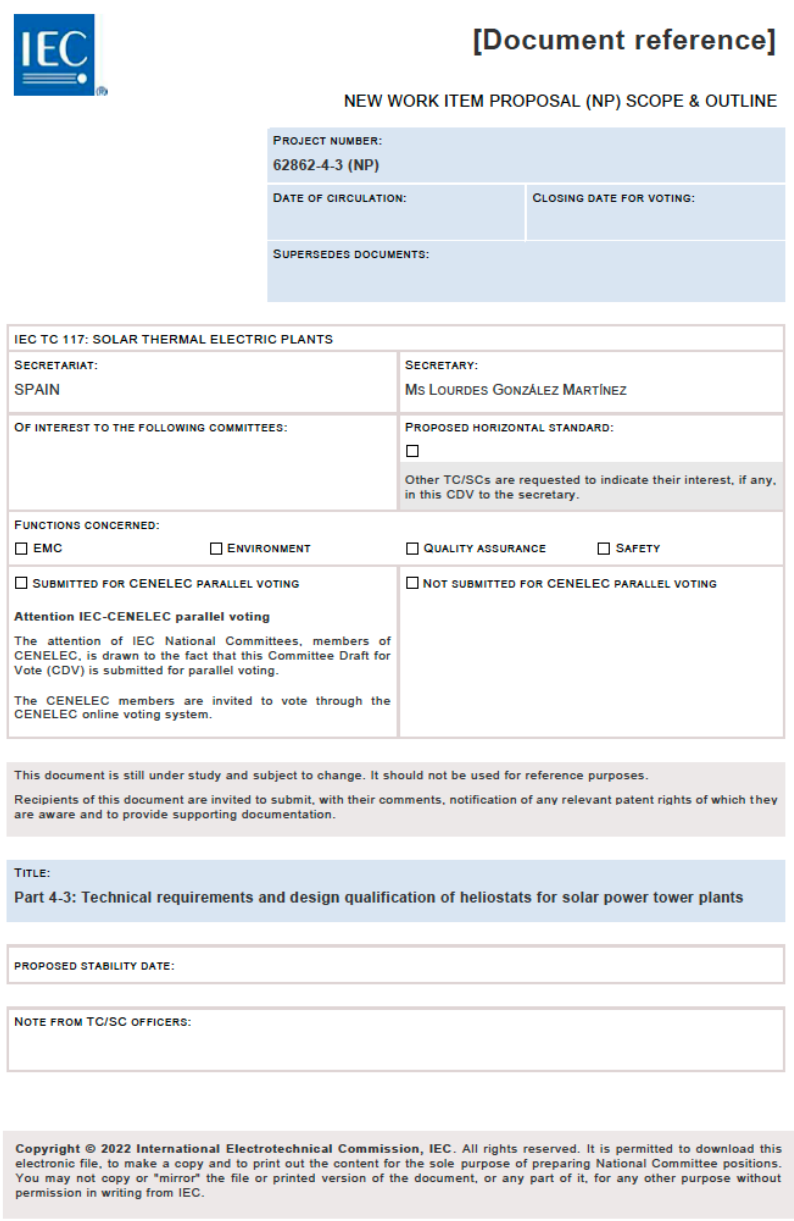
Impact:

- Improve heliostat system performance
- Reduce commercial risks

Addressing gaps: S1, S2, S3, S4, S5, S6 (Refer to HelioCon Roadmap Study report)

Work Plan 4: Progress

- Objectives:
  - Develop a standard on: Technical requirements and design qualification of heliostats for solar power tower plants
- Approach:
  - NREL is co-leading the development with Cosin Solar from China
- Status:
  - Working group has been formed
  - New standard proposal was just submitted to IEC for the NP approval.



IEC

[Document reference]

NEW WORK ITEM PROPOSAL (NP) SCOPE & OUTLINE

PROJECT NUMBER:
62862-4-3 (NP)

DATE OF CIRCULATION: | CLOSING DATE FOR VOTING:

SUPERSEDES DOCUMENTS:

IEC TC 117: SOLAR THERMAL ELECTRIC PLANTS

SECRETARIAT: SPAIN | SECRETARY: MS LOURDES GONZÁLEZ MARTÍNEZ

OF INTEREST TO THE FOLLOWING COMMITTEES: | PROPOSED HORIZONTAL STANDARD: ☐

Other TC/SCs are requested to indicate their interest, if any, in this CDV to the secretary.

FUNCTIONS CONCERNED:
☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY

☐ SUBMITTED FOR CENELEC PARALLEL VOTING | ☐ NOT SUBMITTED FOR CENELEC PARALLEL VOTING

Attention IEC-CENELEC parallel voting

The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this Committee Draft for Vote (CDV) is submitted for parallel voting.

The CENELEC members are invited to vote through the CENELEC online voting system.

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:
Part 4-3: Technical requirements and design qualification of heliostats for solar power tower plants

PROPOSED STABILITY DATE:

NOTE FROM TC/SC OFFICERS:

Copyright © 2022 International Electrotechnical Commission, IEC. All rights reserved. It is permitted to download this electronic file, to make a copy and to print out the content for the sole purpose of preparing National Committee positions. You may not copy or "mirror" the file or printed version of the document, or any part of it, for any other purpose without permission in writing from IEC.

Organizer
Tsvankin, Daniel Required

3 Accepted
George Kelly (solarexpert13@gmail.com) Required
Haobin Zhang (zhanghaobin@cosinsolar.com) Required
Kenneth Armijo (kmarmij@sandia.gov) Required

4 Tentative
Carl Chin Required
Eckhard Luepfert (eckhard.luepfert@dlr.de) Required
Giovanni Picotti (g.picotti@qut.edu.au) Required
Yoel Gilon (yoel_gilon@bezeqint.net) Required

46 Not Responded
Acutt, Calum (Energy, Newcastle) Required
Andreas Kämpgen | CSPS Required
Andreas Pfahl (Andreas@heliogen.com) Required
Prescod, Andru (CONTR) (HQ) Required
Antonio Avila Required
Avishai.C@Heliuss.Com Required

Please visit HelioCon.org for latest updates

Subscribe to HelioCon:

- Heliostat.Consortium@nrel.gov

---

www.nrel.gov **csp.sandia.gov**

HelioCon Annual Workshop: Summary Session Wednesday, July 12, 2023 Madison Hotel, Room: Potomac A		
Time	**Agenda Item**	**Speaker/Facilitator**
12:30 – 1:45 pm	Lunch served at conference	
1:15 – 1:25 pm	Welcome	Margaret Gordon
1:25 – 2:05 pm	Highlights from Topic Area technical work	Guangdong Zhu (NREL work) – 15 mins Margaret Gordon (Sandia work) – 15 mins John Pye (ASTRI progress) – 10 mins
2:05 – 3:15 pm	Intro to awarded RFP projects	RFP Project PIs (plan 8 min each) • Kyle Kattke, Solar Dynamics - SunRing