Concentrating Solar Technologies at the NSTTF

Sandia National Laboratories
Dr. Margaret Gordon, Manager

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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8920 Line (RE Program)

8920
Renewable Energy Technologies
Abraham Ellis

8821	8822	8823	8824	8825	8866
Wind Energy	Water Power	Concentrating Solar	PV Materials & Technologies	Energy Water Sys Integration	Geothermal
Geoff Klise	Peter Kobos	Margaret Gordon	Tony Martino	Stephanie Kuzio	Giorgia Bettin

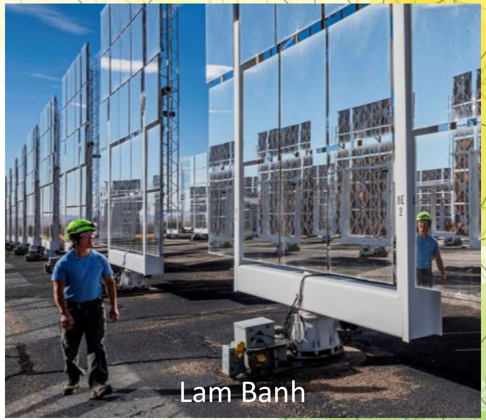
113 Research Staff & Students

4 Test Facilities: NSTTF, PSEL, SWEPT, & SWiFT
Multiple Wet Chemistry & Light Electrical Labs

A unique set of Modeling, Experimental, Engineering, & Testing capabilities

Concentrating Solar Technologies

8923


Lam Banh


Andrea Ambrosini

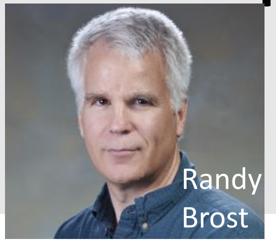

Benson Tso

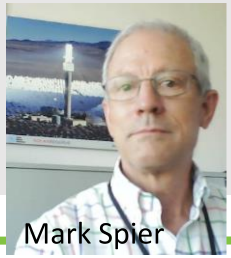

Ken Armijo

Rip Van Winckel


Cliff Ho


Kevin Albrecht


Randy Brost


Mark Spier


Margaret Gordon

Daniel Ray


Ben Jackson


Francisco Alvarez

13 of 26 members not pictured: Roger Buck, Jeremy Sment, Robert Crandell, Luis Garcia Maldonado, Kevin Good, Nathan Schroeder, Laura Achola, Evan Bush, Aaron Overacker, Dmitri Madden, Micah Mann
Scott Garcia

THE NATIONAL SOLAR THERMAL TEST FACILITY (NSTTF)

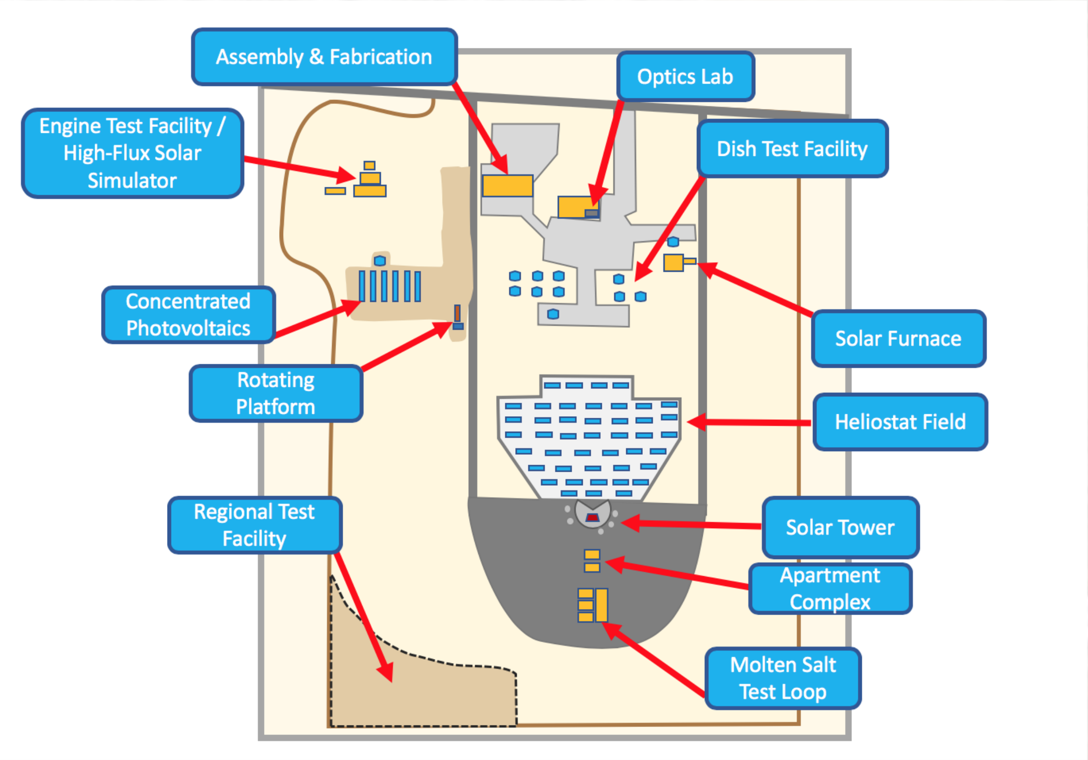
Operated by Sandia for the U.S. Department of Energy, the NSTTF is the only test facility of this type in the United States.

The goal of the NSTTF is to provide experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants planned for large-scale power generation.

- 6 MW multi-test bay Solar Tower
- High-flux solar furnace
- Testing of industry heliostat designs
- Various other solar, thermal, optics, chemistry, and autonomy facilities

FACILITY MAP

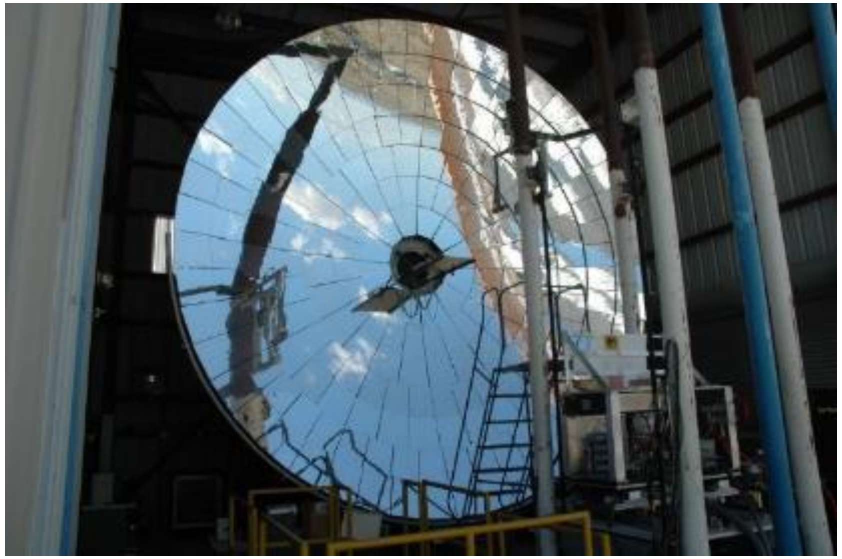
Albuquerque, New Mexico



Concentrating Solar Power

- 218 heliostats – 37 m^2 each
- 6 MW optical power
- > 3,000 suns (with canting tool optimization)
- 200 ft concrete tower with 3 test bays and large "module"
- "Module" includes an 800,000 lb (400 ton) elevator for 45 ft testing structure on top of tower

High Temperature/High Flux testing



Solar Furnace

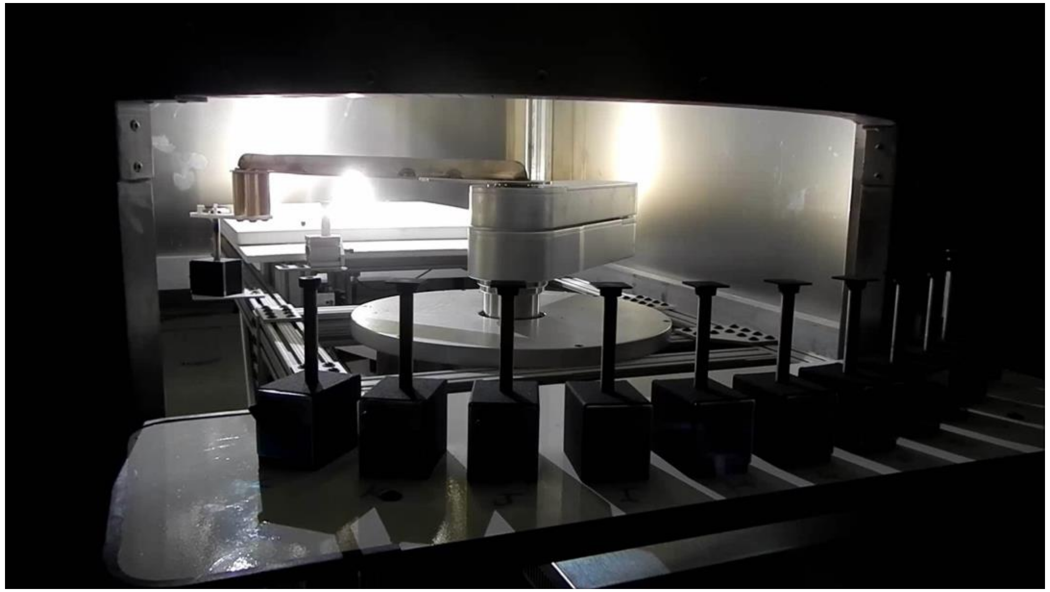
- 16 kW
- Peak flux ~600 W/cm^2 (6000 suns)
- 5 cm spot size

High-Flux Solar Simulator with Automated Sample Handling and Exposure System (ASHES)

Four 1.8 kW lamps

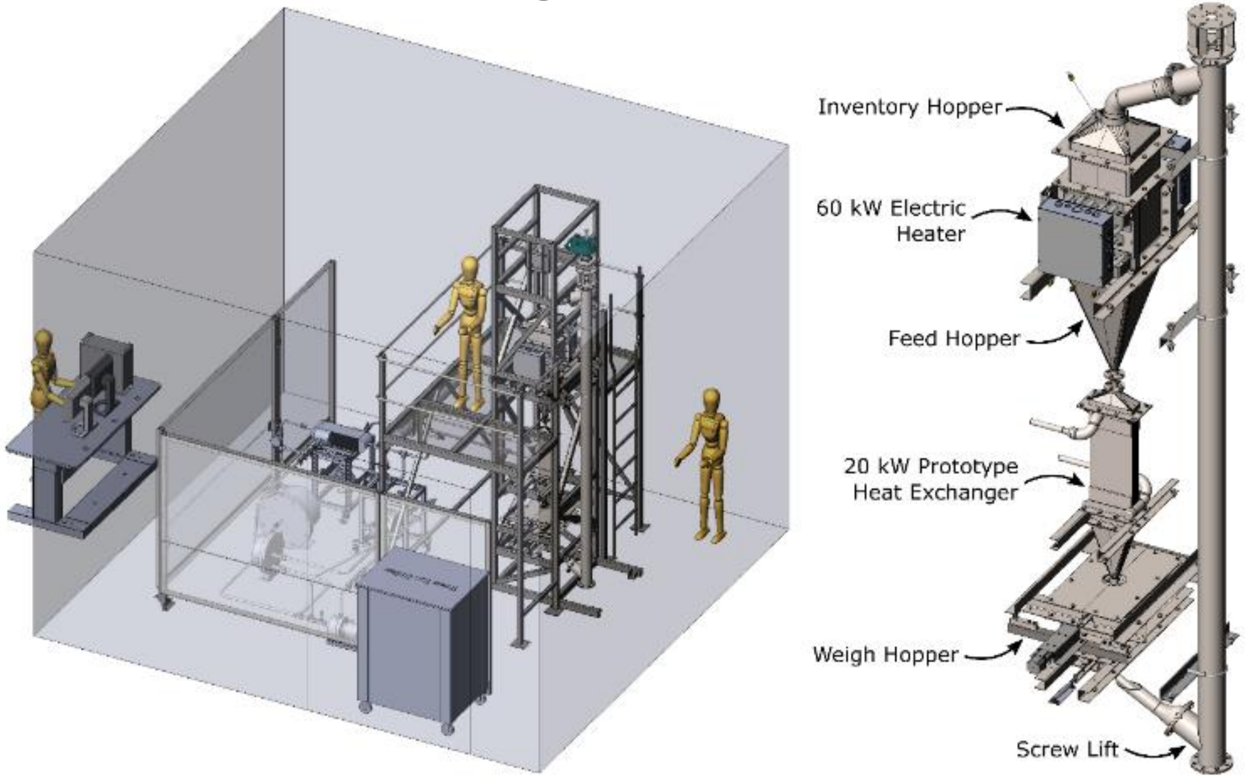
- 7.2 $kW_{electric}$, 6.2 $kW_{radiative}$

1100 kW/m^2 peak flux over 1 inch spot size



Heat Exchanger Test Stand

High-Temperature Particle/sCO_2 Test Loop for Accelerated Heat Exchanger Performance Testing, PI: Kevin Albrecht



A heat exchanger testbed available to future particle heat exchanger and component developers for performance evaluation of prototypes

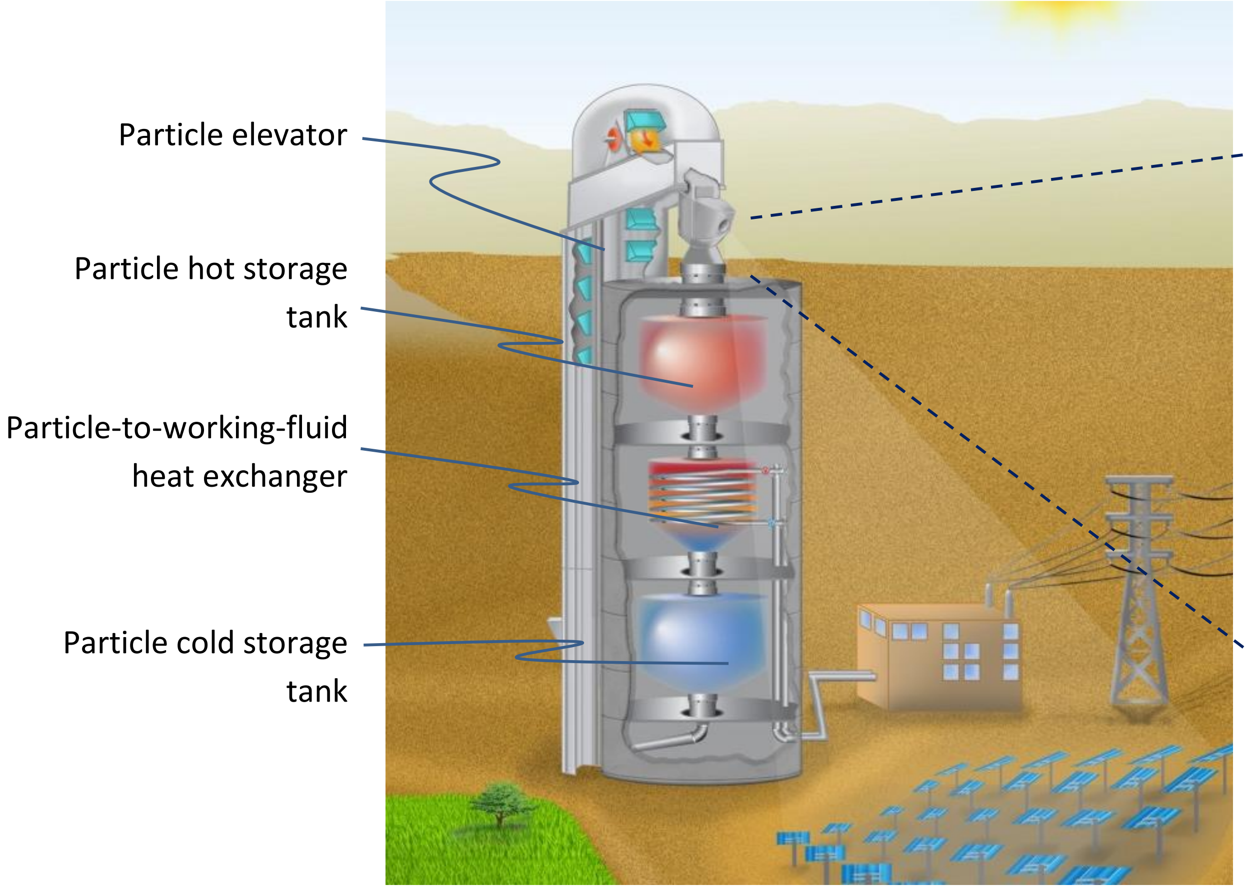
- Gen3 operating temperatures (800/700 °C) and pressures (20 MPa)
- Prototype heat exchangers with design temps> 800 C and heat transfer coefficient > 400W/m2-K
- Heat exchanger performance testing
- Control system studies

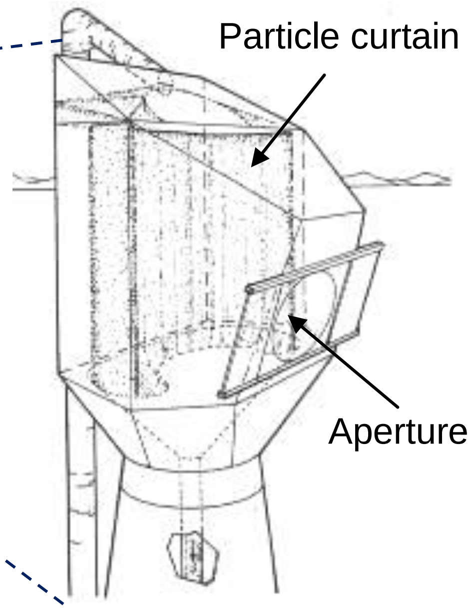
Target Use: Gen3 pilot plant with particle thermal energy storage (ramp rate ≥10 °C/min)

Result: The observed overall heat transfer coefficient for the 20 kW_t prototype is between a factor of 4-6 times better than any other known particle-to-sCO_2 heat exchanger in existence.

High-Temperature Particle-Based CSP

PI: Cliff Ho





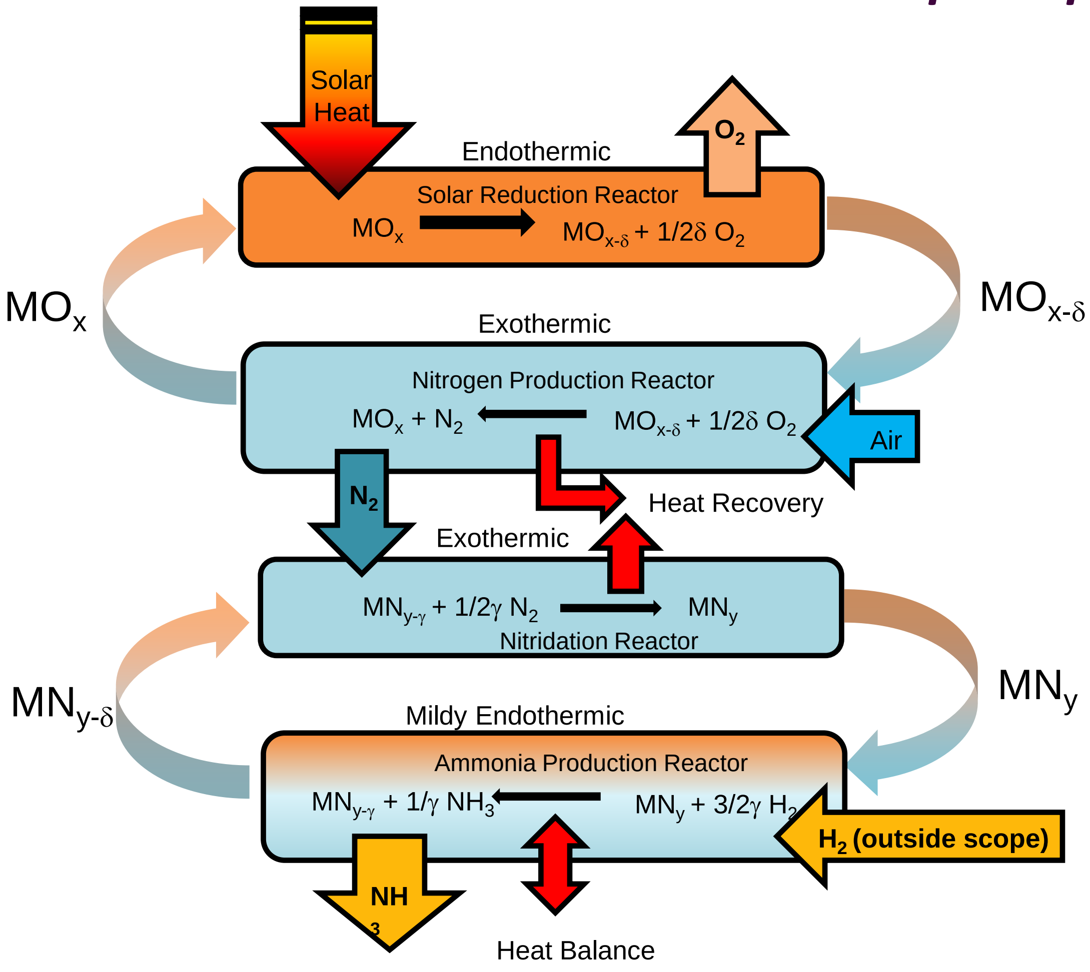
Falling particle receiver

- Higher temperatures (>1000 ˚C) than molten nitrate salts
- Direct heating of particles vs. indirect heating of tubes
- No freezing or decomposition
  - Avoids costly heat tracing
- Direct storage of hot particles

Solar Thermal Ammonia Production

PI: Andrea Ambrosini

An advanced solar thermochemical looping technology to produce and store nitrogen (N_2) from air for the subsequent production of ammonia (NH_3) via an advanced two-stage process



- Inputs are sunlight, air, and hydrogen; the output is ammonia
- Significantly lower pressures than Haber-Bosch
- Greatly decreases or eliminates carbon footprint
- The process consumes neither the oxide nor the nitride particles, which actively participate cyclically

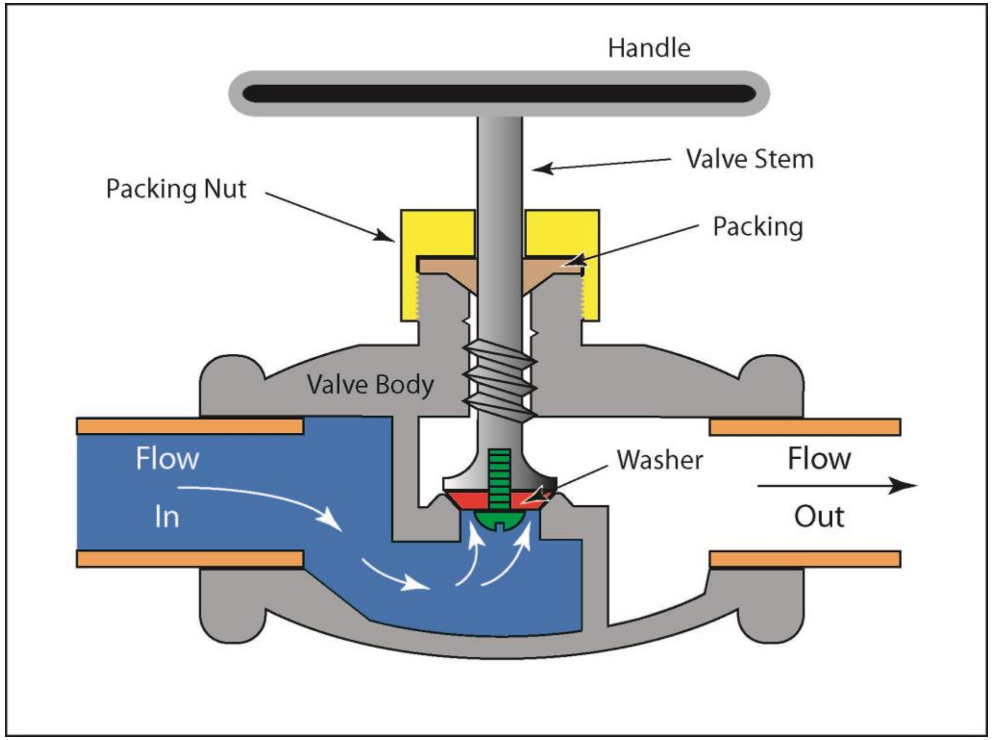
High Temp Advanced Molten Salt Valve

PI: Ken Armijo

Molten salt test pots

- Temperature up to 750 C
- Controlled atmosphere transfer vessel
- Materials corrosion testing
- Component testing

Example Simplistic Globe Valve



Component testing with molten-salt test

Sandia Results in Optics

Prior work:

- Barstow beam quality and tracking (King 1982)
- Beam Characterization System (Strachan 1992)
- Heliostat cost reduction study (Kolb, et al 2007)
- Heliostat aiming calibration (Khalsa, Ho, and Andraka 2011)
- PHLUX (Ho and Khalsa 2012)
- HFACET (Sproul, Chavez, Yellowhair 2011)
- SOFAST/AIMFAST (Andraka et al, 2014 and 2019)
- Long-Distance Heliostat Target (Sment, Ho, Goya, and Ghanbari 2014)
- Wind deflection analysis (Moya 2013, Griffth 2015)
- Gravity deflection analysis (Yuan, Christian, Ho 2015)
- Avian hazard reduction (Ho, Wendelin, Horstman 2017)
- UFACET-1 (Yellowhair, et al 2020)
- LIDAR canting measurement (Little, Small, Yellowhair 2020)

Ongoing work:

- SOFAST 2.0
- UFACET-s high speed scan
- Beam Characterization System (BCS) extensions

Beam Characterization System (BCS)

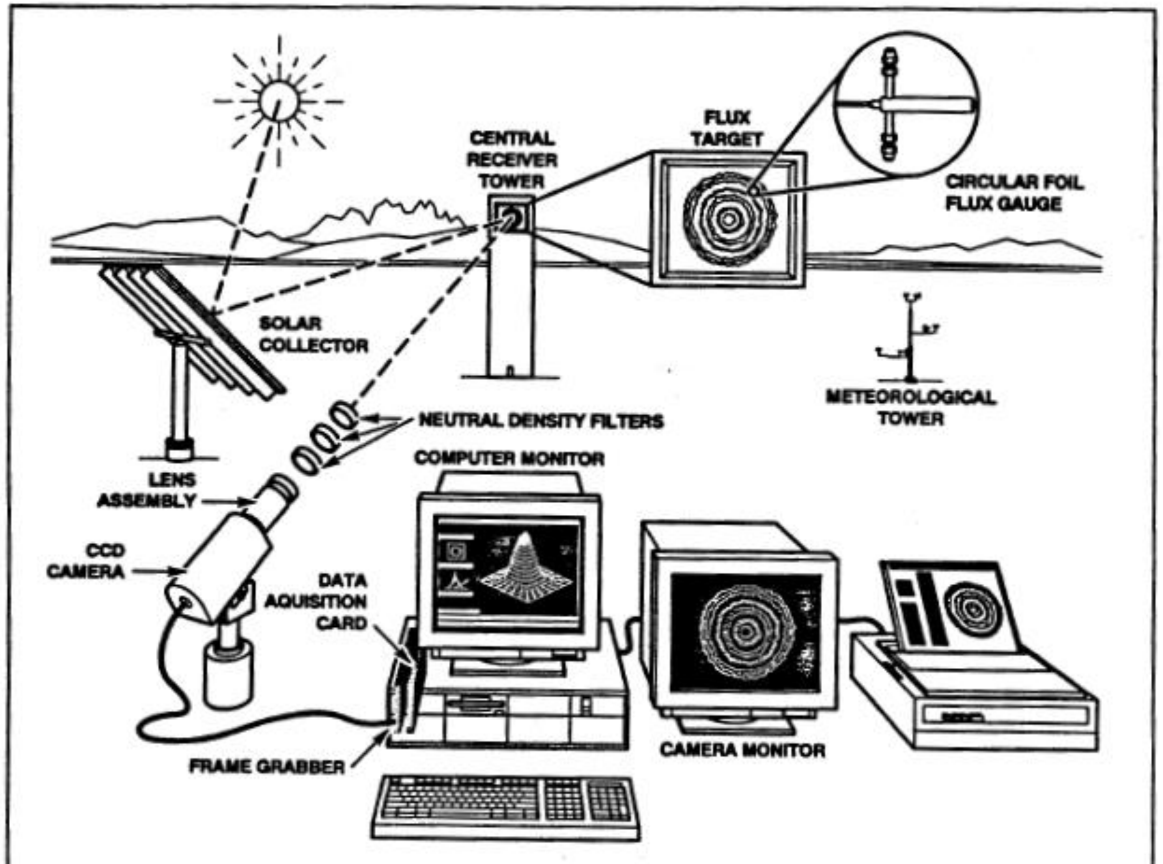


Figure 1: The Beam Characterization System for Heliostat Evaluation

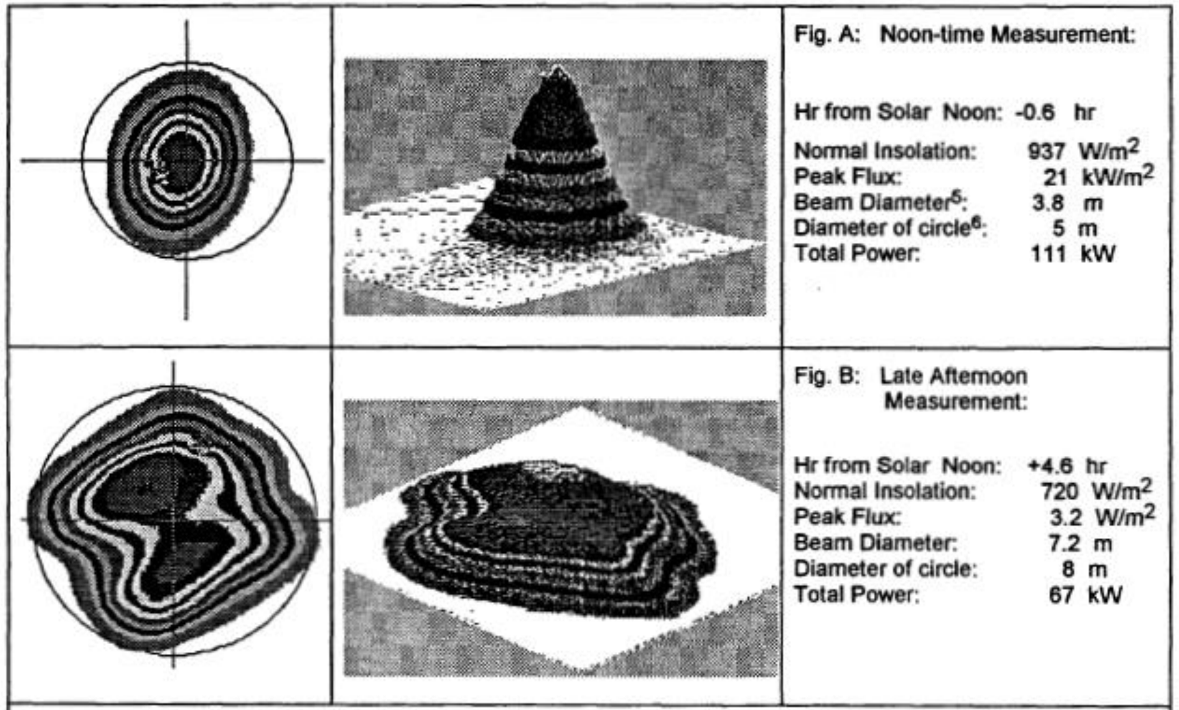
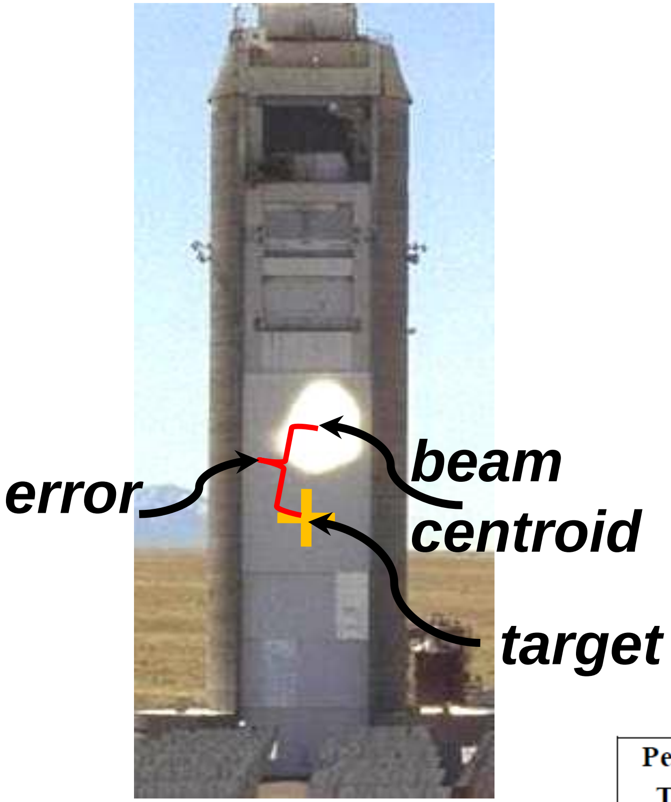
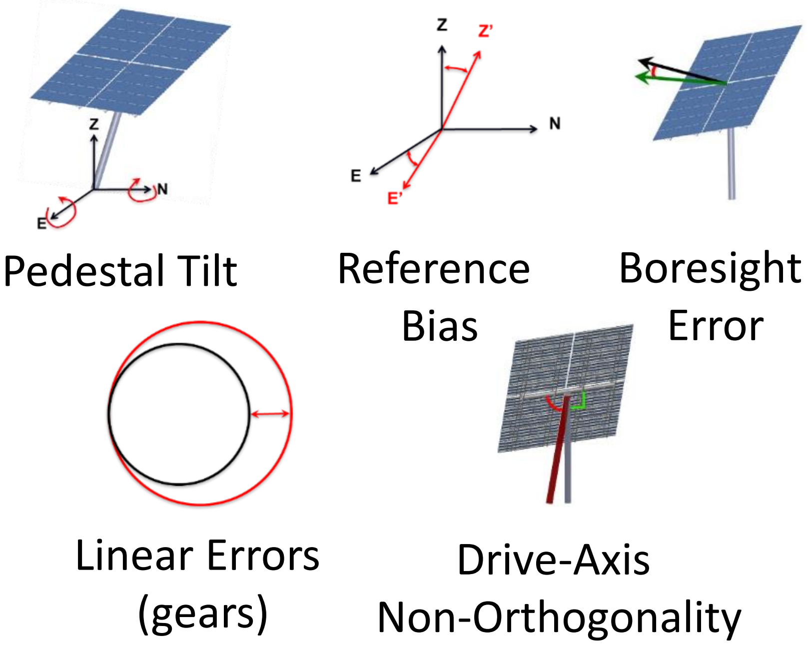


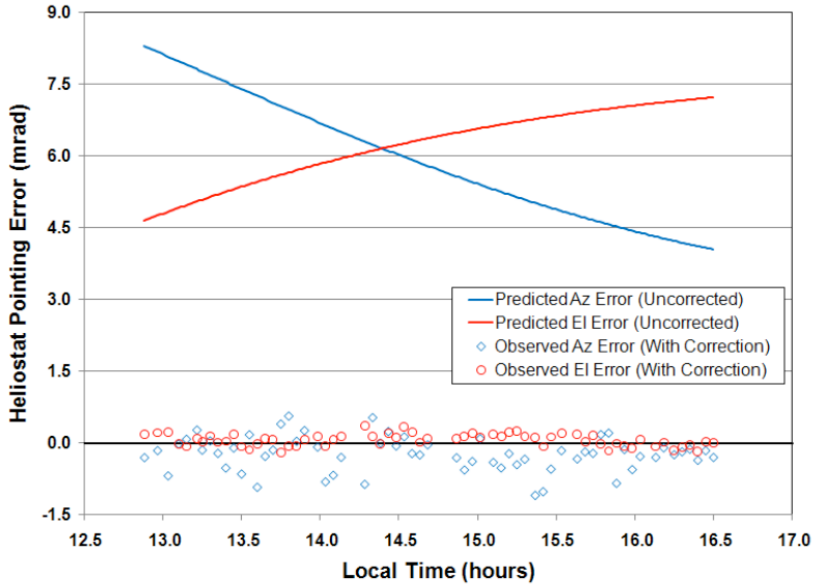
Figure 3: Sample BCS Flux Maps

J. Strachan. Revisiting BCS, a Measurement System for characterizing the Optics of Solar Collectors. Sandia Report SAND92-2789C, 1992.

Heliostat Tracking Error Correction







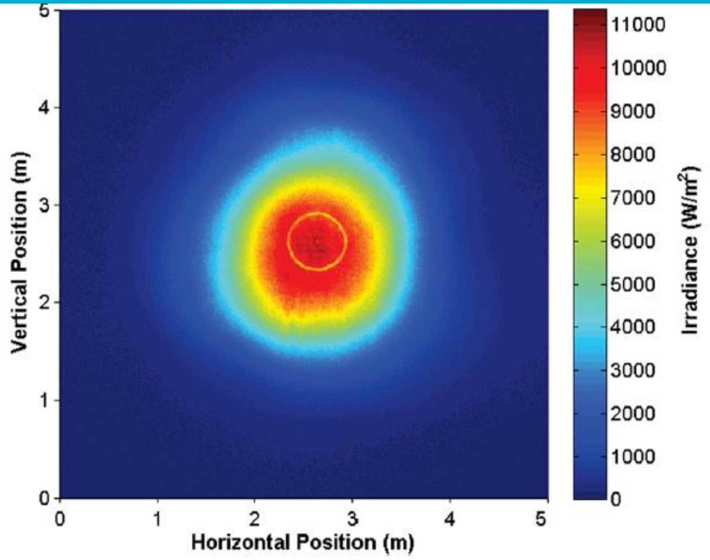
Pedestal Tilt to North or South, ε_1	Pedestal Tilt to East or West, ε_2	Azimuth Reference Bias, ε_3	Elevation Reference Bias, ε_4	Azimuth Linear Error, ε_5	Elevation Linear Error, ε_6	Drive-Axis Non-Orthogonality, ε_7	Boresight Error, ε_8
9.06×10^{-4} rad	8.84×10^{-3} rad	-1.10×10^{-4} rad	-1.40×10^{-3} rad	-6.84×10^{-5}	1.23×10^{-3}	-3.47×10^{-3} rad	3.87×10^{-3} rad

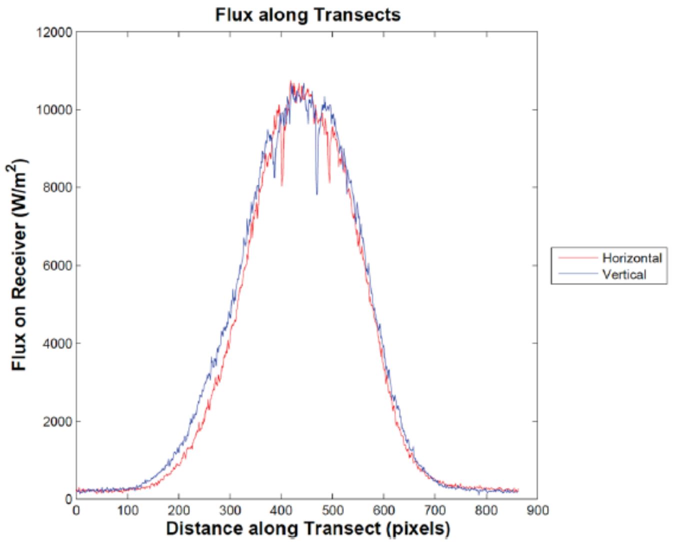
Khalsa et al. (2011, SolarPACES); Smith and Ho (2014, SolarPACES)

Flux Characterization with Phlux system

Data collection:

Analysis result:

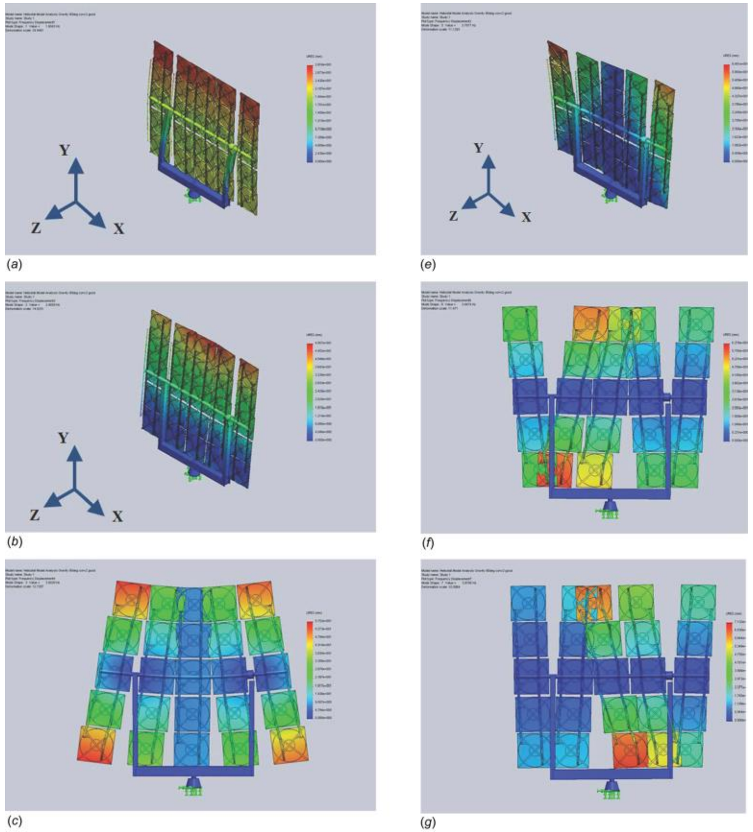




C. Ho and S. Khalsa. A Photographic Flux Mapping Method for Concentrating Solar Collectors and Receivers. *Journal of Solar Energy Engineering,* 2012.

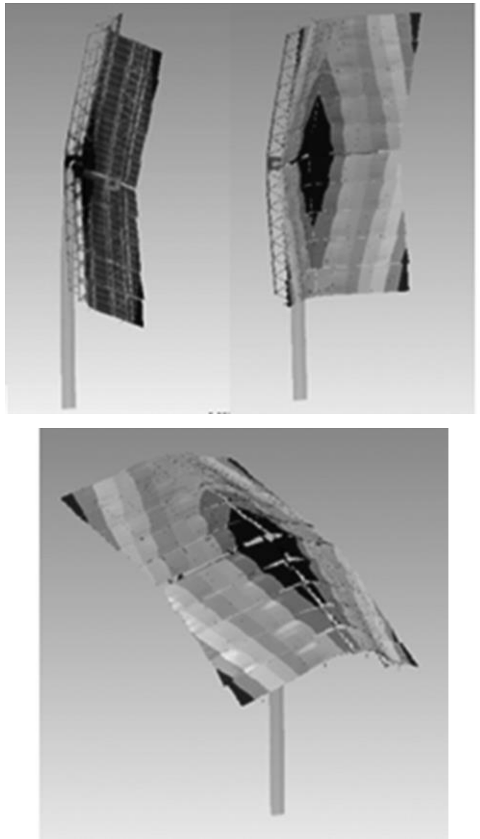
Heliostat Deflection Analysis

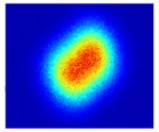
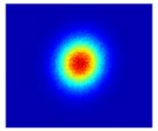
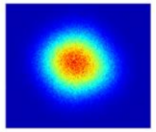
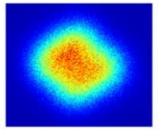
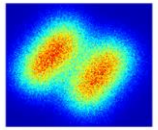
Wind-induced deformation:



D. T. Griffith, A. Moya, C. Ho, and P. Hunter. Structural Dynamics Testing and Analysis for Design Evaluation and Monitoring of Heliostats. *Journal of Solar Energy Engineering,* 2015.

Gravity-induced deformation:

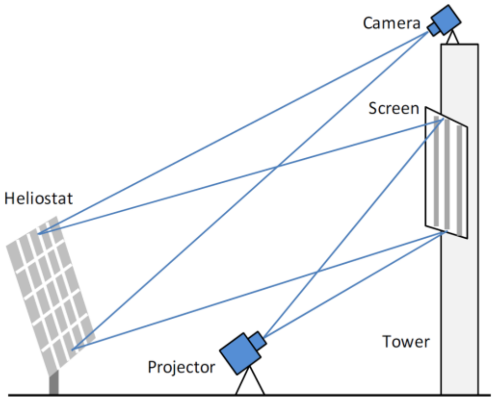


Time of Day	Contour plot from testing	Beams from simulated, as-built ATS heliostat
10:03 AM		
12:30 PM		
3:12 PM		
4:12 PM		
5:45 PM		

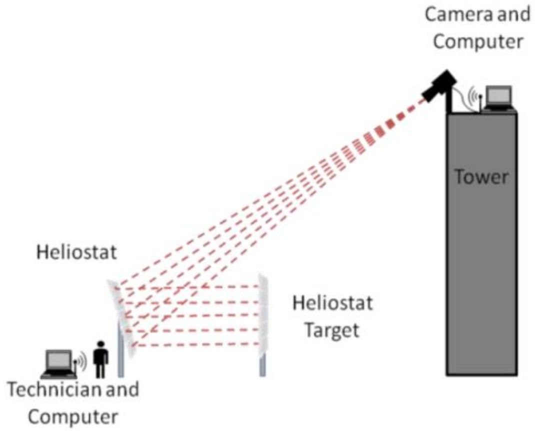
J. Yuan, J. Christian, and C. Ho. Compensation of Gravity Induced Heliostat Deflections for Improved Optical Performance. *Journal of Solar Energy Engineering,* 2015.

Sandia Tools in Optics

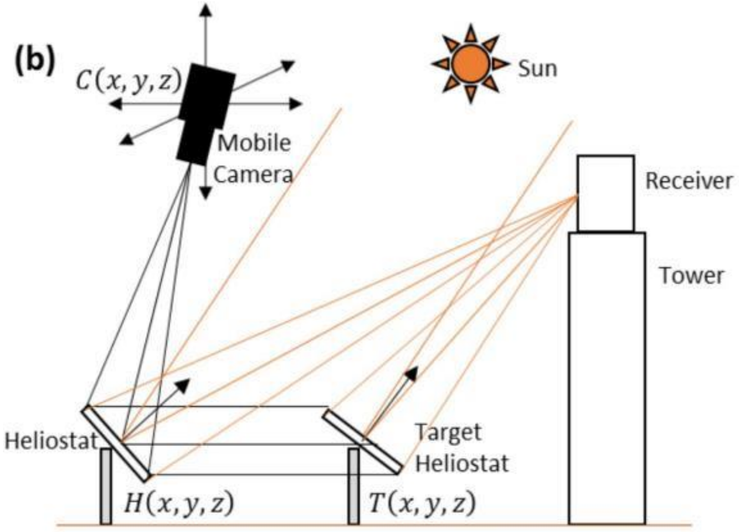
- SOFAST
  - Sandia Optical Fringe Analysis Slope Tool
- H-FACET
  - Heliostat Focusing and Canting Enhancement Technique
- U-FACET
  - Universal Field Assessment, Correction, and Enhancement Tool
    - Use drones to characterize slope errors, canting errors, tracking errors



SOFAST Technique



H-FACET Technique

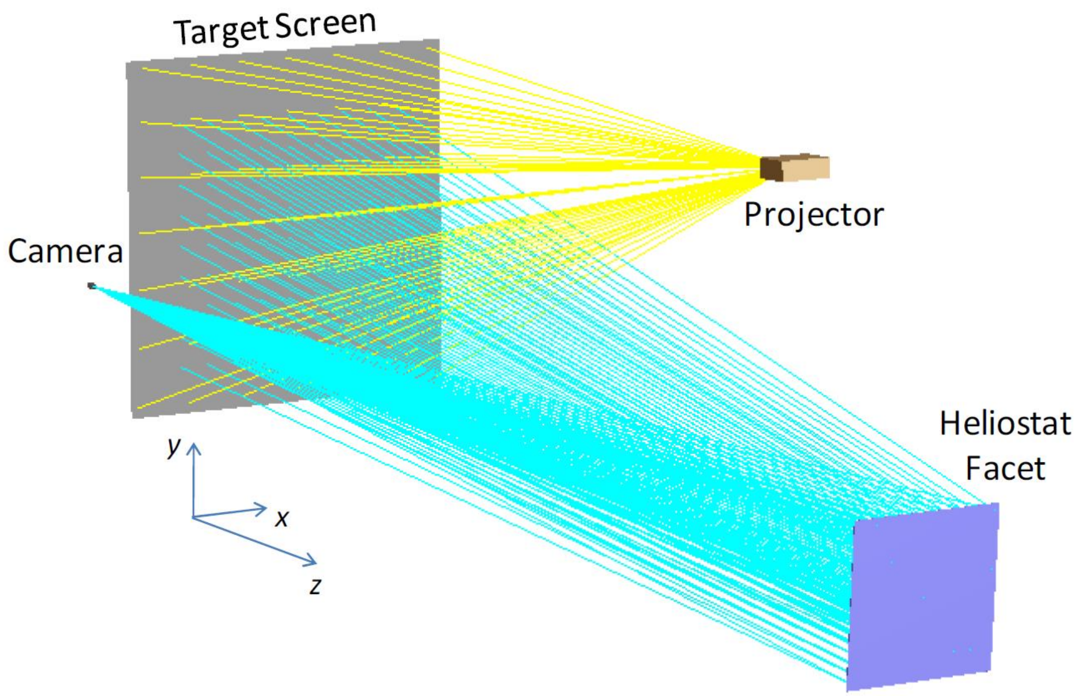


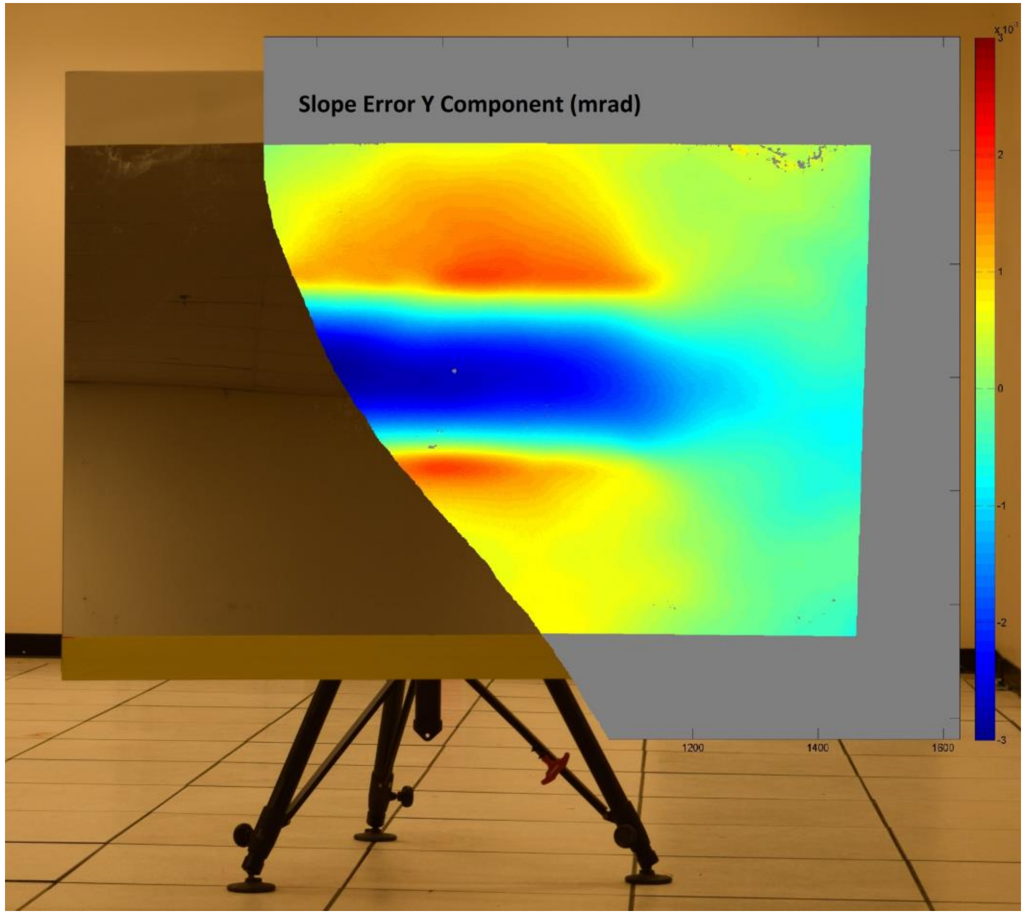
Camera on Mobile Platform – Heliostats In-Situ

https://www.energy.gov/sites/default/files/2019/04/f62/CSP%20Summit2019%20SNL-NREL%20Yellowhair-Zhu%20UFACET-NIO.pdf

High Resolution Mirror Measurement

SOFAST indoor mirror facet measurement:



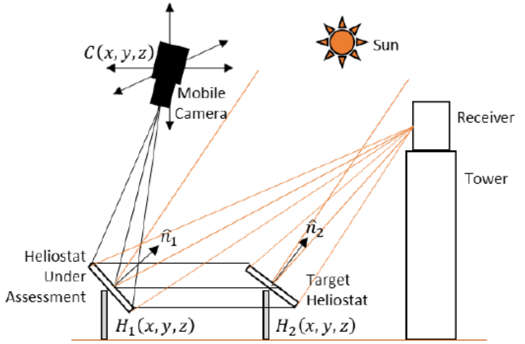


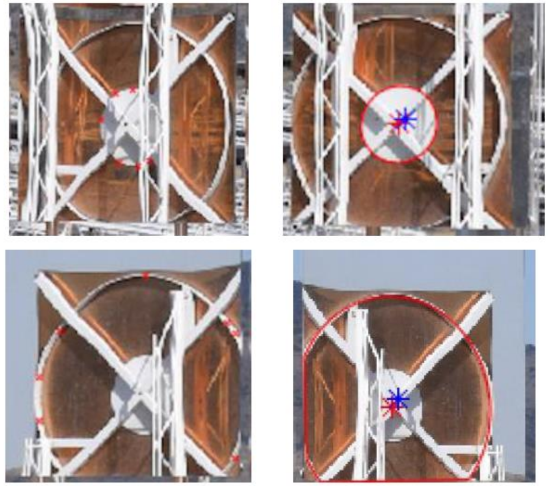
C. E. Andraka, et al. Rapid Reflective Facet Characterization Using Fringe Reflection Techniques. *Journal of Solar Energy Engineering,* 2014.

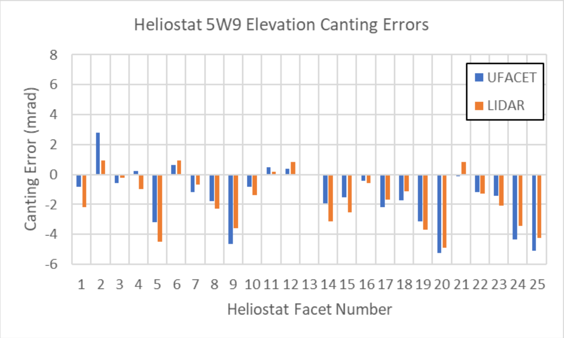
J. Yellowhair, C. E. Andraka, and N. Finch. Heliostat Focal Length Impacts on SOFAST Sensitivity. SAND2011-5664C, 2011.

Outdoor Facet Canting Measurement

UFACET-1: in field, after installation







J. Yellowhair, P. A. Apostolopoulos, D. Small, D. Novick, and M. Mann. Development of an Aerial Imaging System for Heliostat Canting Assessments. *SolarPACES* 2020.

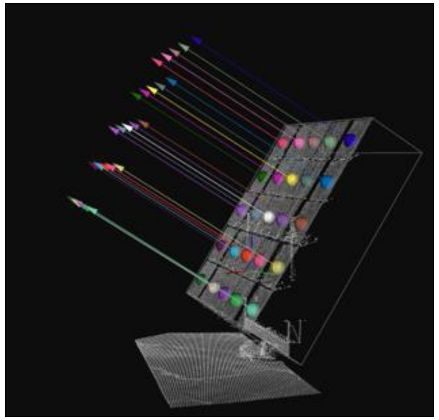
LIDAR:

Scanner

Photo

Scan

Scan Close-up



Analysis Result

C. Little, D. Small, and J. Yellowhair.
LiDAR For Heliostat Optical Error Assessment.
SolarPACES 2020.

HelioCon Topic Areas

- Advanced Manufacturing: *Randy Brost (Sandia), Parthiv Kurup (NREL)*
  - Metrology in the field, wind loading concerns, self-calibration, easy field deployment
- Metrology and Standards: *Guangdong Zhu (NREL) and Randy Brost (Sandia)*
  - More tools for wind impacts, common definition of optical errors, establish a reference standard, round robin testing
- Components and Controls: *Ken Armijo (Sandia), Matt Muller (NREL)*
  - Component design and testing guidelines/standards, durability testing for components (HALT testbed), closed loop control evaluation
- Field Deployment: *Jeremy Sment (Sandia), Alex Zolan (NREL)*
  - Site analysis, calibration during install, planning for wind mitigation
- Technoeconomic Analysis: *Chad Augustine (NREL), Ken Armijo (Sandia)*
  - Touches each other topic area!
- Resources, Training and Education: *Rebecca Mitchell (NREL), Mark Speir (Sandia)*
  - Touches each other topic area!

Thank you!

Acknowledgements

- Work depicted on slides:
  - Randy Brost, Ken Armijo, Jeremy Sment, Cliff Ho, Kevin Albrecht, Andrea Ambrosini
- Current and former members of the NSTTF team!

https://energy.sandia.gov/programs/renewable-energy/csp/

Next Seminar January 12th

HelioCon Seminar Series: CSP Capabilities at the National Renewable Energy Laboratory

Speaker: Mark Mehos, NREL

When: 3-4pm Wednesday January 12th

How to participate: Zoom info coming soon!