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

Heliostat Consortium: Scoping Optical Metrology Tools for Heliostat Evaluation and Building a Power Tower Concentrating Solar Power Plant Database

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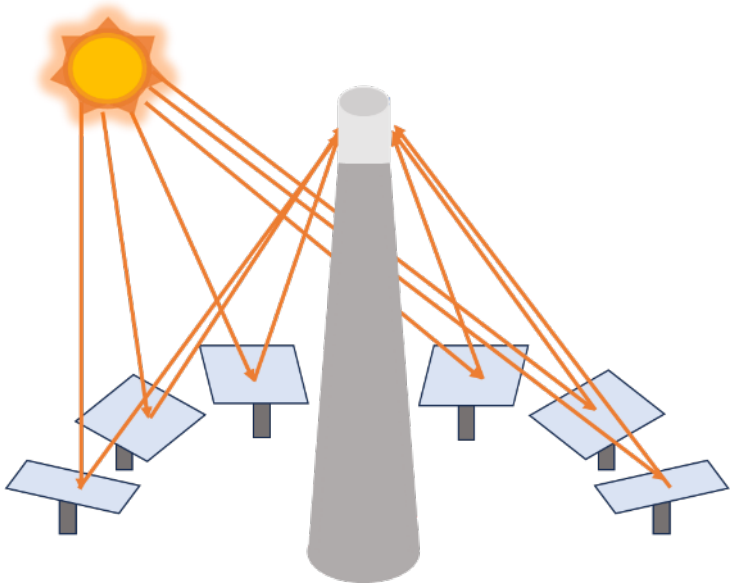
conceptual design • components • integration • mass production • heliostat field

Concentrating Solar Power (CSP)

- CSP: Using mirrors to concentrate a large area of sunlight onto a small area to generate energy, which will be used to produce electricity.
  - Technology types: parabolic troughs, solar towers, linear Fresnel reflectors and dish systems.
- Heliostats: the mirrors in solar tower configuration CSP plants, which can track the sun and reflect sunlight towards the receiver.
  - Heliostat Optical Metrology:
    - Measuring and analyzing the optical performance of heliostats
      - ❖ Ensure each heliostat accurately focusing solar radiation
      - ❖ Help identifying misaligned or damaged heliostats, facilitating timely maintenance and reducing time.
      - ❖ Increase overall plant efficiency and optimizing the performance of the solar field.



HelioCon Database

https://heliocon.org/plant_information_overview.html

HelioCon

https://heliocon.org/

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Resources

https://heliocon.org/resources/resources-1.html

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HelioCon Database

https://heliocon.org/plant_information_overview.html

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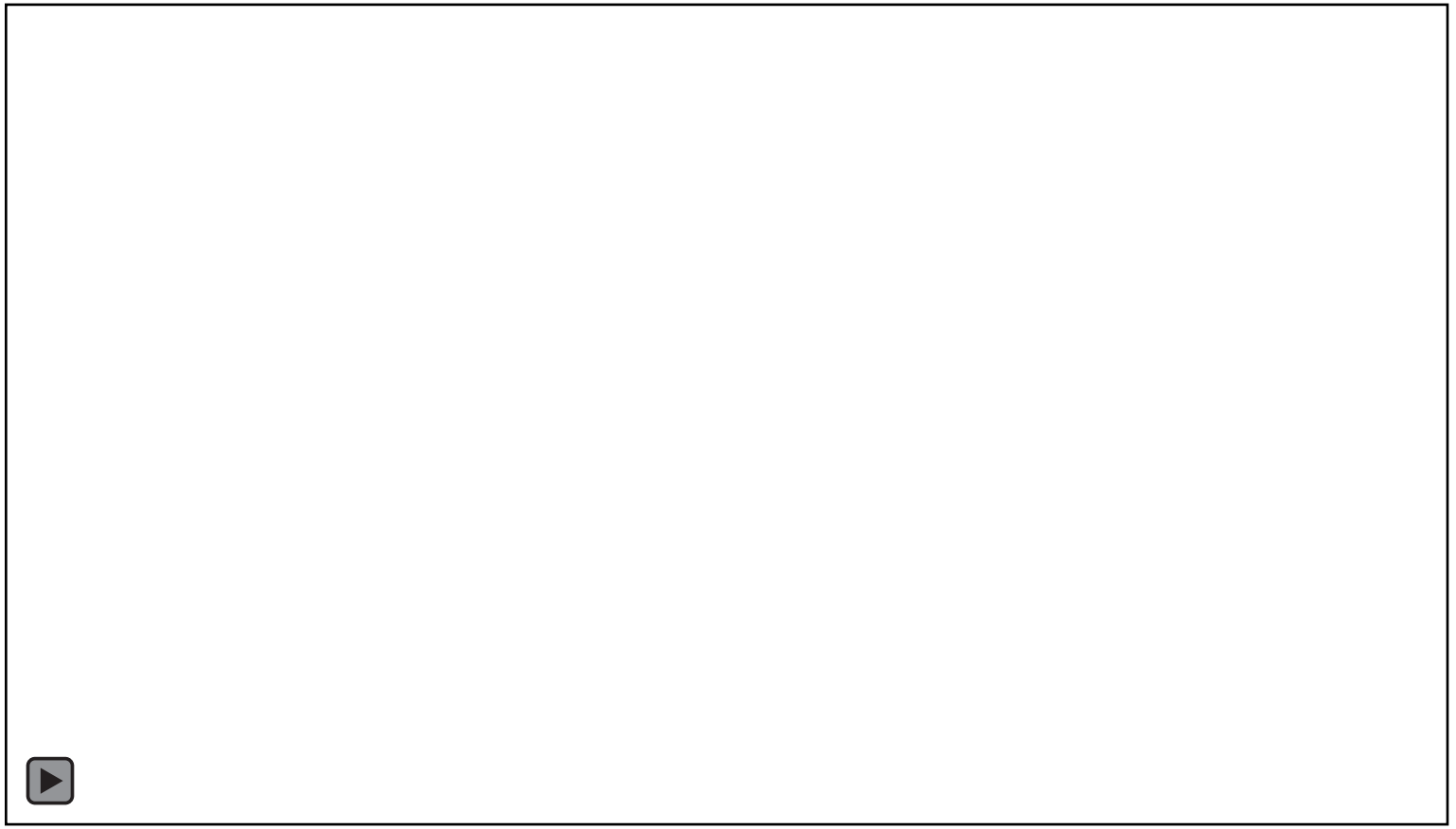
Tool and Supplier/Developer List

Standard and Guidelines

Zotero Reference

Plant Database

CSP Plant Video Links



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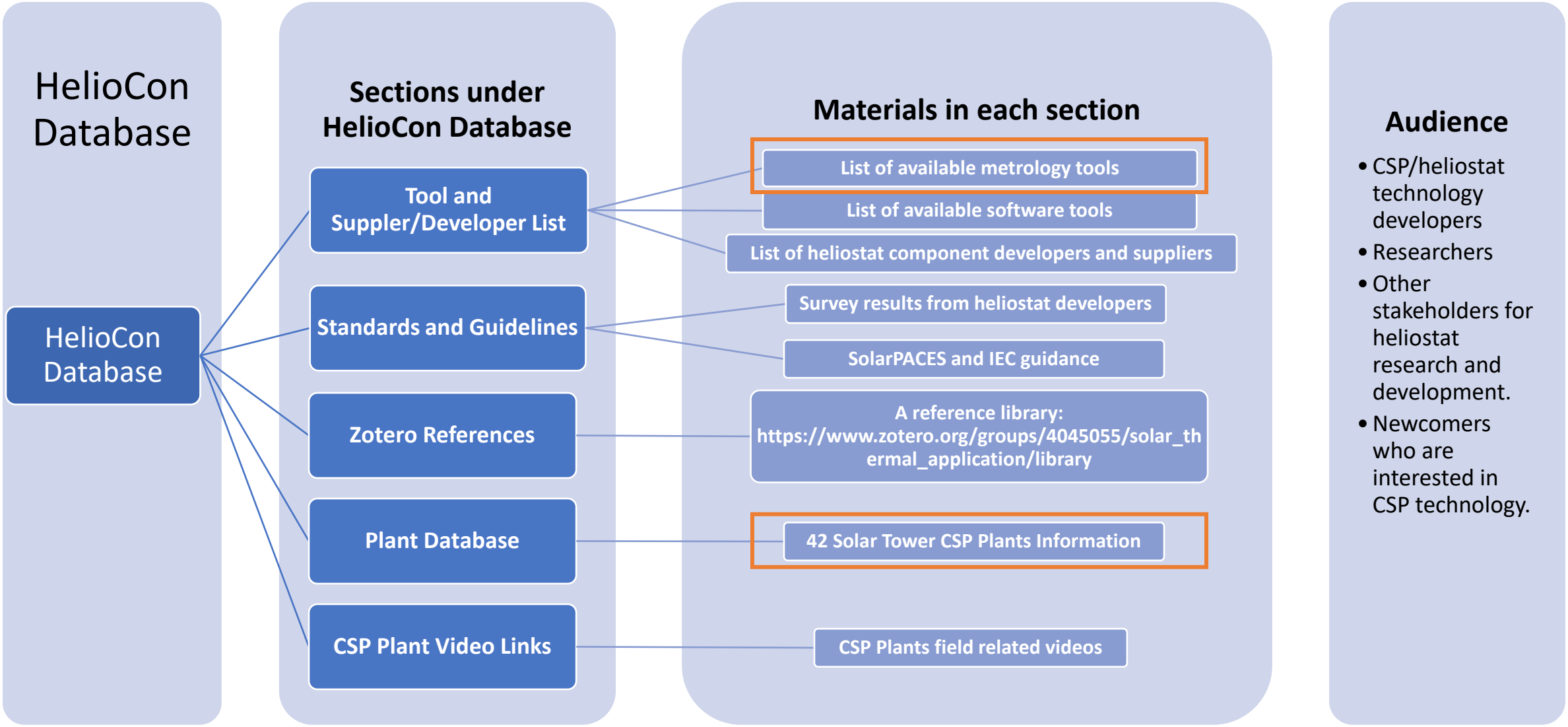


Optical Metrology Tools for Heliostat Evaluation

- Scoping study: provide current heliostat relevant metrology capabilities
- Information includes brief description, supplier info, cost, maturity, area requirement, uncertainty, other technical specifications, a ray-trace analysis, and recommendations of tools to be deployed at Flatiron's campus.
- Tools are categorized in the following types according to HelioCon Roadmap Report (2022),

Core metrology
- Sun shape
- Atmospheric Attenuation
- Heliostat reflectance
- Heliostat surface shape
- Heliostat opto-mechanical errors
- Heliostat beam quality
- Heliostat soiling
- Heliostat wind loads

: established

: some established, some still in development

: not established

- Information collected from: interviewing with experts at NREL, literature review, wind loads related measurement tools were based on instrumentation installed at Crescent Dunes.

HelioCon Roadmap Report 2022: G. Zhu et al., "Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power," NREL/TP-5700-83041, 1888029, MainId:83814, Sep. 2022. doi: 10.2172/1888029.

Optical Metrology Tools for Heliostat Evaluation- Motivation

- Minor deviations in alignment can significantly affect the efficiency of solar energy concentration and consequently, the overall efficiency of the CSP plant.

- Gaps discussed in HelioCon roadmap report:
  - Lacking at least two reliable metrology methods for each heliostat metrology type.
  - Lacking validation of the metrology technique against another verified standard.
  - Developing technologies to accurately understand the wind loads and soiling conditions of heliostats.

- The scoping study: provide current heliostat relevant metrology capabilities, help the CSP community to find the appropriate tools to meet their needs, and could promote further development in heliostats' metrology.

HelioCon Roadmap Report 2022: G. Zhu et al., "Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power," NREL/TP-5700-83041, 1888029, MainId:83814, Sep. 2022. doi: 10.2172/1888029.

Optical Metrology Tools for Heliostat Evaluation

- Sun shape: the radial angular distribution of radiance surrounding the center of the sun.

Tools Name	Rotating Shadowband Irradiometer (RSI)	Fast clear-sky model for sunshape determination (Data from libRadtran+AERONET)	CSR Camera
Developer	CSP Services GmbH	University of Evora	Fraunhofer ISE
Accuracy	2%-2.9%	In development	In development
Cost	$14,000	In development	In development

- Atmospheric attenuation: the decrease in intensity of solar radiation as it passes through the atmosphere before reaching the ground.

Tools Name	ATMOS	Vaisala FS11 (replaced by FD70) scatterometer + CIMEL sun photometer/AERONET	AATTENUATION with a look up table	Solar Attenuation Measurement System
Developer	ZEPREN Solutions	Vaisala, CIMEL	DLR, NREL	BCB, CIEMAT
Accuracy	1%	5.4-5.7%	<5%	+/-2%
Cost	$100,000	$119,953	-	-

Optical Metrology Tools for Heliostat Evaluation

- Heliostat reflectance : Reflectance measurement evaluates the ability of a heliostat's reflective surface to reflect solar radiation.

Tool Name	Developer	Accuracy	Cost
410 Solar	Surface Optics	+/- 2%	$34,086
SOC-410 DHR	Surface Optics	+/- 3%	$57,570
Condor	Abengoa	+/- 0.2%	$25,720
15R-USB	Device & Service Co.	+/- 0.2% (at 660nm)	$19,000
15R-RGB	Device & Service Co.	+/- 0.2%	$23,500
SSR 6	Device & Service Co.	+/- 0.2%	$41,500
AE1 RD1	Device & Service Co.	-	$4,550
ET 100 Emissometer	Surface Optics	+/- 3%	$41,952
LAMBDA 1050	PerkinElmer	UV/Vis: ±.080 nm; NIR: ±.300 nm Photometric accuracy: ±.0003~±.008 A	$122,000
CM-700d/600d	Konica Minolta	-	$9,940
CM-26d 26dG	Konica Minolta	-	$13,331-$14,331
TraCS	CSP Services GmbH	+/-1.8%	$8,960

Other information: measurement time, wavelength band, acceptance angle(for specular reflectance), incidence angles are also included in the scoping study report.

Optical Metrology Tools for Heliostat Evaluation

- Surface shape: it directly impacts the heliostat's ability to focus sunlight. Regular and precise measurement of the heliostat's surface shape allows for accurate adjustments.

Tool Name	Developer	Accuracy
Dynamic photogrammetry	DLR	2mm
Close range photogrammetry	DLR	1mm
LiDAR	Sandia National Laboratory	1mm

Optical Metrology Tools for Heliostat Evaluation

- Heliostat Opto-mechanical Errors: the inaccuracies in the positioning and structure of heliostat, which impact the efficiency of the heliostat and CSP solar field.

Tool Name	Developer	Accuracy	Measurement Parameter	Cost
ReTNA	NREL	<0.2 mrads	Slope error and canting error	-
NIO	NREL	0.25-0.5 mrad	Slope error, canting error, and tracking error	-
LiDAR with FARO S70	Sandia National Laboratories	0.25 mrad	Canting error	FARO S70 : $57,000
Q-dec	DLR, CSP Services	0.2 mrad	Slope error, focus deviation	-
SOFAST	Sandia National Laboratories	0.03-0.05 mrad	Slope error	$16,000
AIMFAST	Sandia National Laboratories	< 0.25 mrad RMS on dish systems	Slope error	-
H-FACET	Sandia National Laboratories	1.19 mrad on five heliostats	Canting error	-
Beam Characterization System	NREL	0.2 mrad	Tracking error	

Optical Metrology Tools for Heliostat Evaluation

- Heliostat Beam Quality: evaluating the intensity of reflected sunlight
  - Flux Mapping Method: heat flux sensors, which can measure the distribution of heat flux on the receiver and the data is used to generate a flux map. CCD or CMOS Cameras are also used to measure the solar flux by capturing images of the reflected beam and then creating a flux map.
- Heliostat Soiling: The soiling condition can be measured by directly measuring reflectance, monitoring the aerosol or comparing the expected output based on DNI to actual power output.

Tool Name	Developer	Accuracy	Cost
DustTrak DRX Aerosol Monitor	TSI	Flow accuracy: +/- 5%	$12,635
Dust Master Pro 7000	Thomson Environmental Systems	Flow accuracy: +/- 1%	$15,878

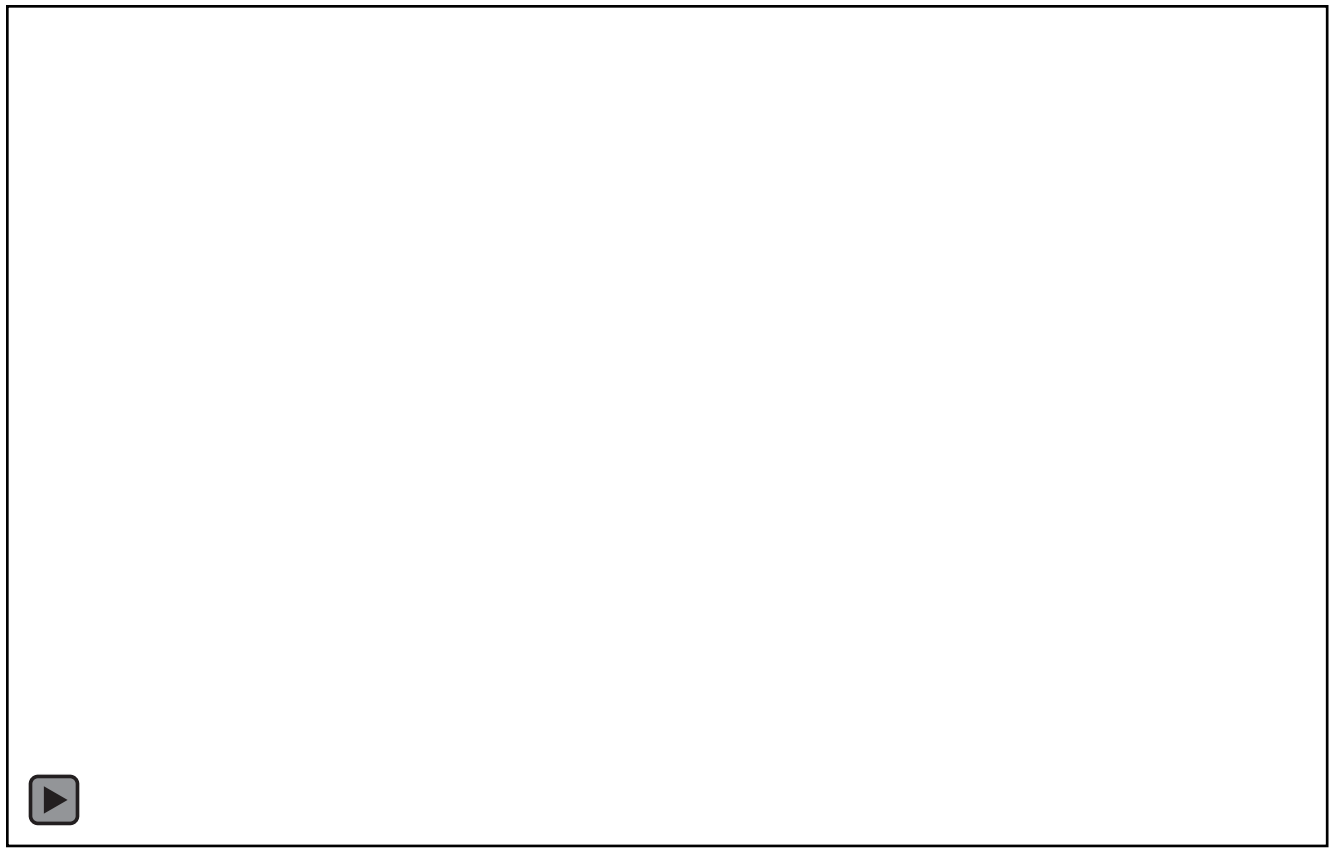
- Heliostat wind loads: precise estimation of static and dynamic wind load.

Tool Name	Developer	Accuracy	Cost
Strain Gages	Micro-Measurements	Resistance tolerance: +/-0.4% Strain range: +/-5%	W250B:$224.34, W250D: $510.6
Accelerometers	Silicon Designs	Sensitivity: 400mV/g; Bias Calibration error: 0.25% of span (Typical);0.6% of span (Max)	2460-10: $1,875
Laser Displacement sensor	Baumer	Repeat accuracy: 2 … 30 µm Linearity error: ± 0.1 % Mr , 50 … 200 mm; ± 0.15 % Mr , 50 … 350 mm	OM30-L0350: $1,500
Dynamic Inclinometer	2GiG	0.05° accuracy	BH1-1800-0-2M: $329
Sonic Anemometers	Gill	Wind Speed accuracy: <1.5% RMS @12 m/s; <1% RMS @12 m/s (Custom)	WindMaster: $3,380
Automatic Total Sky Imager	Yankee Environment Systems	-	TSI-880: $30,000

Power Tower Concentrating Solar Power Plant Database

HelioCon Website (https://heliocon.org/)
→ **RESOURCES**
(https://heliocon.org/resources/resources-1.html)
→ **HelioCon Database**
(https://heliocon.org/plant_information_overview.html)

- **Plant Database**



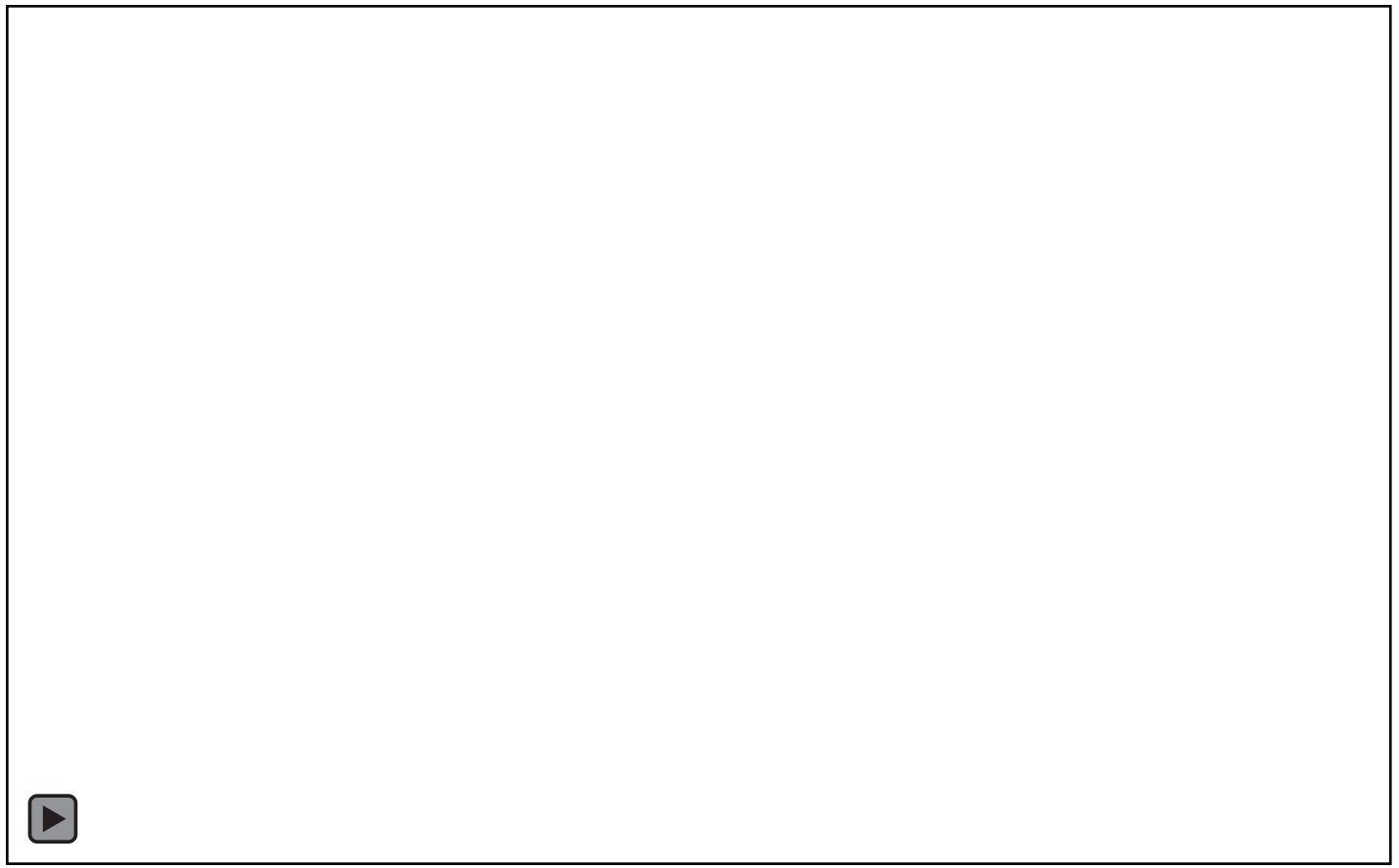
Now having information for 42 tower CSP power plants (also include the power tower info for CSP+PV hybrid projects)around the world.

Power Tower Concentrating Solar Power Plant Database

For Each Power Plant:

- Summary table
  - Plant's general information
  - Heliostats design
  - Receiver details
  - Tower design
- Section for each aspect followed by 1-2 photos (plant, heliostats, receiver, tower and field layout pictures)
- Lessons learned
- Plants environmental conditions
- Plant generation plots

Contact heliostat.consortium@nrel.gov for corrections/edits/additions



Metrology Capabilities at NREL Flatiron Campus

- The following metrology tools will be ready by the end of this year Fall 2024
  - Opto-mechanical errors: ReTNA, NIO, Beam Characterization System, SOFAST.
  - Heliostat surface shape: photogrammetry.
  - Reflectance: 15R-USB, 15R-RGB, LAMBDA 1050.

- We will have 10 commercial heliostats prototype installed at NREL by Fall 2024.

- Hope to have the following tools in 2025 - 2027
  - Sun shape and atmospheric attenuation: Rotating Shadowband Irradiometer, ATMOS, Scatterometer with sun photometer, BCB solar attenuation measurement system
  - Reflectance: 410 Solar, ET100 Emissometer.
  - Opto-mechanical errors and Heliostat surface shape: LiDAR.
  - Soiling: DustTrak DRX Aerosol Monitor, Dust Master Pro 7000.
  - Wind loads: Strain gages, Accelerometers, Laser displacement sensor, Dynamic inclinometer, Sonic Anemometers, Sky Imager.

Photo from Tucker Farrell, NREL

Contact Us

- HelioCon Website: https://heliocon.org/
- For answers to high-level or generic questions: heliostat.consortium@nrel.gov.
- Projects leads and co-leads contact information can be found: https://heliocon.org/contact_us.html
- Reach out to us if you want to use any facilities at the NREL Flatirons Campus.

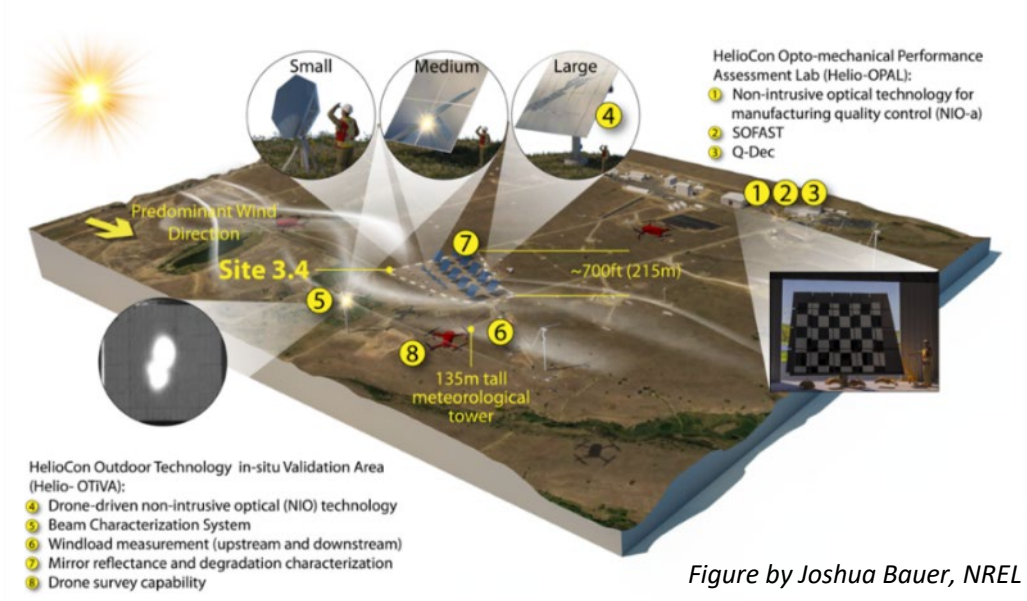


Figure by Joshua Bauer, NREL