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

Heliostat Consortium Roadmap: Advanced Manufacturing Gap Analysis

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

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Outline

- HelioCon overview
- HelioCon Advanced Manufacturing Gap Analysis
- Observations on High-Performance Manufacturing
- Pointer to HelioCon Request for Proposals.

HelioCon Objectives and Scope

- **Heliostat Consortium (HelioCon): a DOE initiative to advance heliostat technologies**
- **Objectives**
  - Form U.S. center of excellence focused on heliostat technologies.
  - Develop strategic core validation and modeling capabilities and infrastructure at DOE’s national laboratories (NREL and Sandia).
  - Promote workforce development by integrating academia, industry, and all stakeholders.
- **Scope – 6 Topics**
  - Metrology and Standards
  - Components and Controls
  - Advanced Manufacturing
  - Resource, Training and Education
  - Field Deployment
  - Techno-Economics Analysis
- **Heliostat Consortium (HelioCon): a DOE initiative to advance heliostat technologies**
  - 1/3 of the budget is allocated for external funding in order to expand the consortium member base.
  - A request for proposal (RFP) was recently issued to solicit proposals for this funding.
- **Support but not develop specific heliostat designs**

HelioCon Advanced Manufacturing Gap Analysis

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Topic: Advanced Manufacturing

Roadmap Study – Advanced Manufacturing Study Method (Co-Lead: Parthiv Kurup)

Inputs:

- Estimating value of autonomy survey (prior work).
- HelioCon Roadmap Workshop, Advanced Manufacturing breakout sessions.
- Interviews with industry experts. Companies contacted include:
  - BrightSource Energy
  - COBRA
  - Gonzalez Group
  - Heliogen
  - SkyFuel (retired)
  - Solar Dynamics
  - Solar Reserve (retired)
  - Tewer
  - University of Arizona

Topic: Advanced Manufacturing

Roadmap Study –

Initial List of Gaps

No.	Gaps
Knowledge for product design	
AM1	Lack of a stable market enabling continuous improvement
AM2	Wind load data/analysis to enable mass reduction
AM3	Optimum heliostat utilizing composite facet/array designs not fully understood
AM4	Lack of experience designing heliostats for high-productivity manufacturing: o Access to expertise in early design phases (e.g., high-volume, automotive) o Developers don't know how to find automation providers
AM5	Trade-off between face-up and face-down stow not fully understood
AM6	Variable focus heliostats and their economic benefit not understood
AM7	Rules of thumb for fabrication, material, and component costs
AM8	CAD-based tolerance analysis for mirror array backing structures
Knowledge for process design	
AM9	Facet/array fabrication process knowledge, with multiple prescriptions: o Injection molding o Wide-area adhesive application o Sandwich construction o Frame attachment o Canting control o Knowledge and use of fastening technologies o Material alloy and thickness selection for efficient manufacture
AM10	Lack of experience designing high-productivity manufacturing lines: o Access to expertise in early design phases (e.g., high-volume, automotive) o Developers don't know how to find automation providers o Risks from lack of automation experience o Perception of required capital not sufficient
AM11	Field installation automation support
Standard designs	
AM12	Standard facet specification
AM13	Standard facet production, including multiple prescriptions
AM14	Standard baseline design
Metrology and calibration	
AM15	Specialized metrology tools not mature enough for factory use o Not compatible with factory environment o Calibration checks o Statistical process control
AM16	Metrology for molds
AM17	Metrology for mirror array backing structures

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Selected industry comments (paraphrased):

There are two fundamental design approaches to heliostat design which we have seen succeed. In one approach, facets are designed as self-supporting structures that are responsible for achieving optical tolerances as a stand-alone unit. These are then assembled into an array, and canting angles set to achieve overall heliostat optical shape. In the second approach, individual mirror facets are not self-supporting, and do not achieve their final optical shape until included in a mirror array which simultaneously determines the facet optical shape and overall heliostat canting and optical shape. Among these, the second method can achieve the lowest cost, but it requires very rigorous execution of the final assembly step.

Our future vision of heliostats is facet mirrors that are composite structures, with 1.1 mm commercial glass mirrors supported by a rigid backing structure. This has several advantages: Reduced material cost, weight and reduced structural support, all of which reduce cost, increased reflectivity (from 94% to 96%), increased stiffness, and increased operation in wind, all of which increase energy production, plus additional cost reduction due to decreasing the solar field size by 2%.

Engaging automation developers early in the heliostat design process is important achieve high automation performance.

Some heliostat developers do not have experience designing with material alloys and thicknesses that are customized for high-volume manufacturing. This is common practice in the automotive industry. Automotive Advanced High Strength Steels (AHSS) can offer significantly higher strength but retain good weldability and formability. Automotive steel grades that come in coil form are also typically readily available with galvanized coatings. Automotive aluminum grades are available with pretreatments for adhesive bonding so surface prep, which is critical in adhesive bonding of aluminum, isn't necessary.

Ranked Gaps

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From the Roadmap:

Tier 1 Gaps (Most Important)	
AM1	Innovative heliostat mirror facet/array designs needed o Example: composite designs
AM2	Insufficient facet/array fabrication process knowledge, including: o Injection molding o Wide-area adhesive application o Laminated mirrors o Sandwich construction o Frame attachment o Canting control o Knowledge and use of fastening technologies o Material alloy and thickness selection for efficient manufacture o Composite structures
AM3	Heliostats not designed for high-productivity manufacturing, due to: o Lack of access to expertise in early design phases (for example, high-volume, automotive) o Developers don't know how to find automation providers
AM4	Lack of heliostat developers' experience designing high-productivity manufacturing lines, due to: o Lack of access to expertise in early design phases o Difficulty finding automation providers o Risks from lack of automation experience o Perception of required capital is not sufficient
Tier 2 Gaps	
AM5	Trade-off between face-up and face-down stow not fully understood[1]
AM6	Variable focus heliostats and their economic benefit not understood
AM7	Lack of field installation and quality assurance automation support
AM8	Specialized metrology tools not mature enough for factory use o Not compatible with factory environment o Calibration checks o Statistical process control
AM9	Lack of knowledge about creep behavior of adhesives and PU foams (used for sandwich constructions)
AM10	Lack of knowledge of typical ground conditions for foundation design
AM11	Lack of low-cost production method for concrete foundation elements
AM12	Lack of a standard baseline design
Tier 3 Gaps (Least Important)	
AM13	Lack of rules of thumb for fabrication, material, and component costs
AM14	No CAD-based tolerance analysis for mirror array backing structures
AM15	Lack of a standard facet specification
AM16	No standard facet production methods, including multiple prescriptions
AM17	Metrology for molds not widely understood
AM18	Metrology for mirror array backing structures not widely understood

[1] Reviewer pointer: Blackmon, J. B, "Non-Inverting Heliostat Study", Sandia Report SAND78-8190, July 1979.
https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/1978/788190.pdf

Observations on High-Performance Manufacturing

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High-Performance Manufacturing Notes*

The most important takeaway:

- Many companies design a product, and then consider manufacturing. This is a lost opportunity.

  The highest-performance manufacturing results from considering high-productivity manufacturing from the start of design.

- High-performance manufacturing vendors actively support this.
  Nonetheless, they still encounter customers who engage them after design.

Key principles:

- Take work out of the design.
- Take parts out of the design.
- Take material out of the design.
- Seek solutions which simultaneously increase quality and reduce work.
- Select processes which inherently produce high quality at high speed.
- Select materials which enable these processes.
- Invent to fill gaps if needed.
- Select tooling for high productivity, considering production volume and target takt time.
- Ensure high quality control at many steps along the process – don't add value to defective work.
- Employ automation for the benefits it brings to each specific design, not "for automation's sake."

* Drawn from author's experience.

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High-Performance Manufacturing Notes

Examples:

- Screws vs. snap-fit.
  - *Screws:* Multiple parts, multiple handling operations $\Rightarrow$ speed limited.
  - *Snap-fit:* Single pick-and-place operation. Caveat: Screws are removable!
- "What's good for the robot, is also good for the human." – Professor Dan Whitney, MIT.
- IBM Pro Printer design for assembly (https://www.youtube.com/watch?v=spDYSKl3kmo).
- Consumer products – synchronous vs. flexible assembly (https://arthurgrussell.com/, https://flexomation.com/).
- Surface mount electronic components (http://www.surfacemountprocess.com/).

Assembly

- Injection mold hardness and cavity number selection (https://www.protolabs.com , https://www.fastradius.com/resources/single-cavity-vs-multi-cavity-injection-molding/, https://www.xcentricmold.com/).
- Roll-based manufacturing (https://www.superiorrollforming.com/)
- Precision machine design, fixturing, machine vision (https://www.americanmachinist.com/archive/features/article/21896912/the-many-parts-of-high-precision, https://www.xometry.com/capabilities/cnc-machining-service/, https://www.cognex.com/).
- Semiconductor manufacturing (Suppliers: Clean rooms, vacuum chambers, robots, process equipment, photolithography. Process control and high quality/yield are paramount. Speed is achieved through parallel production).

Fabrication

Listed web sites are exemplary and should not be viewed as endorsements.

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Remove parts and work

Our future vision of heliostats is facet mirrors that are composite structures, with 1.1 mm commercial glass mirrors supported by a rigid backing structure. This has several advantages: Reduced material cost, weight and reduced structural support, all of which reduce cost, increased reflectivity (from 94% to 96%), increased stiffness, and increased operation in wind, all of which increase energy production, plus additional cost reduction due to decreasing the solar field size by 2%.

Increase quality and performance

Engaging automation developers early in the heliostat design process is important achieve high automation performance.

Concurrent product and process design

High-speed, high-quality processes

Some heliostat developers do not have experience designing with material alloys and thicknesses that are customized for high-volume manufacturing. This is common practice in the automotive industry. Automotive Advanced High Strength Steels (AHSS) can offer significantly higher strength but retain good weldability and formability. Automotive steel grades that come in coil form are also typically readily available with galvanized coatings. Automotive aluminum grades are available with pretreatments for adhesive bonding so surface prep, which is critical in adhesive bonding of aluminum, isn't necessary.

Remove work

HelioCon Request for Proposals

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HelioCon Request for Proposals

Heliostat Consortium (HelioCon):

www.heliocon.org

HelioCon Roadmap Report:

www.heliocon.org/roadmap_report.html

HelioCon Request for Proposals (RFP):

https://heliocon.org/request_for_proposal.html

RFP Webinar:

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

https://nrel.zoomgov.com/meeting/register/vJItcu-prjMiHtbz5Pw_5yEkaELwEprnOGg

Questions to:

HelioCon.RFP@nrel.gov