SunShot
U.S. Department of Energy

CSP Program Summit 2016

Advanced Low-Cost Receiver for Parabolic Trough Solar Power—

Design for Manufacturing

SunShot SolarMat award DE-EE0006813

2.5 Years ($1.4M DoE SunShot Funding)

Joel Stettenheim, President & Principal Investigator

NORWICH TECHNOLOGIES

Partners

Creare – *50+ PhD researchers, 40,000 ft² SOA fabrication and laboratory facilities*

Thayer School of Engineering at Dartmouth – *development partnership with the Liu Group at Dartmouth related to novel air stable solar selective coating*

NREL National Renewable Energy Laboratory – *third party testing and validation of novel receiver*

Solar Dynamics – *replacing partnership with Abengoa related to design analysis*

Shipulski Design – *industry leading expert on Design for Manufacturability*

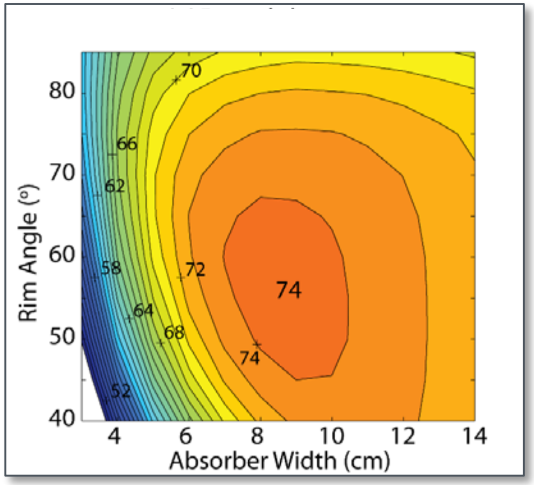
Vetted Technology

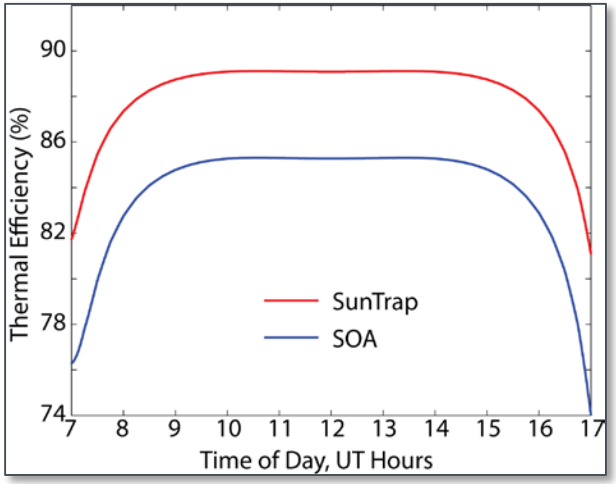
- $2.1M in grant development funding

SunShot U.S. Department of Energy

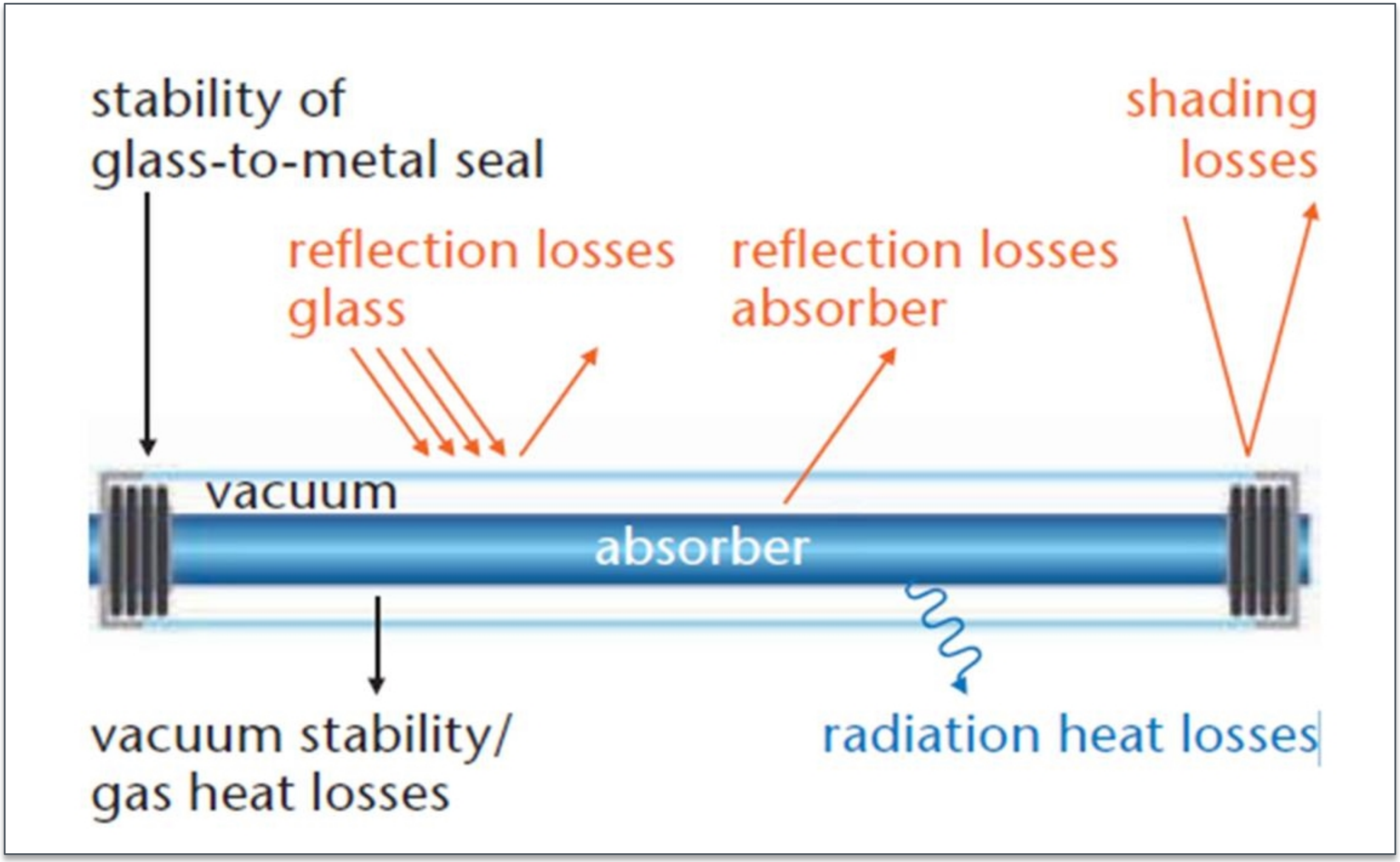
National Science Foundation

- Current follow-on funding based on proven prototypes





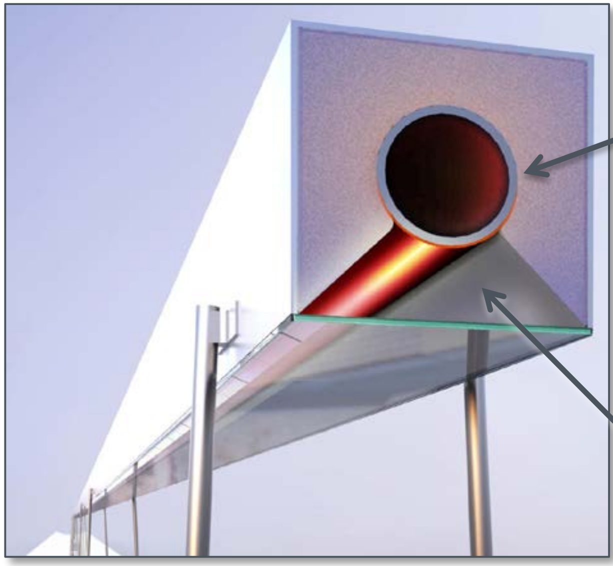
SOA Receiver



http://www.schott.com/newzealand/english/download/schott_solar_csp_memorandum_en_medium_resolution.pdf

SunTrap™ Receivers Value Proposition:

- Improved price-performance over SOA Vacuum receivers
- Flexible design can be optimized for different applications



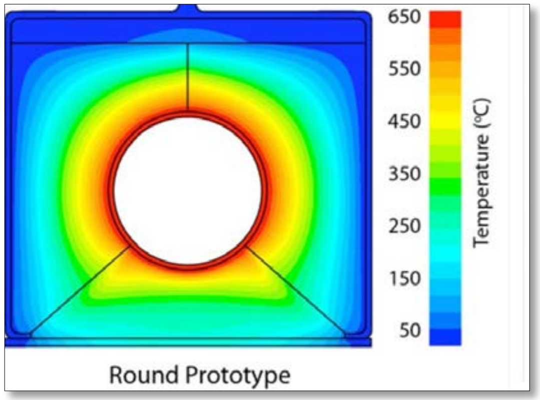
- Cover majority of radiating surface with SOA microporous insulation
- Reduces radiative losses at high temperatures

Replace vacuum with stratified air cavity that reduces costs

Technology Development Protocol

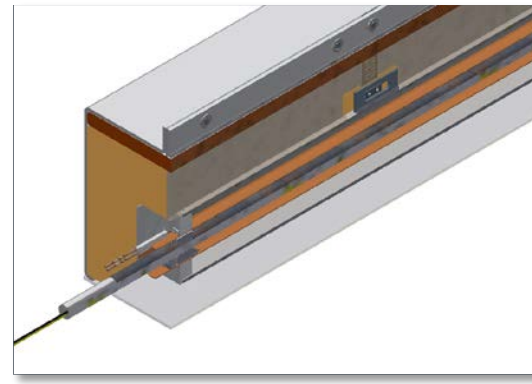
Modeling

Develop/Refine optical and thermal models



Analysis and Design

Optimize design based on efficient analysis of 1000’s of permutations

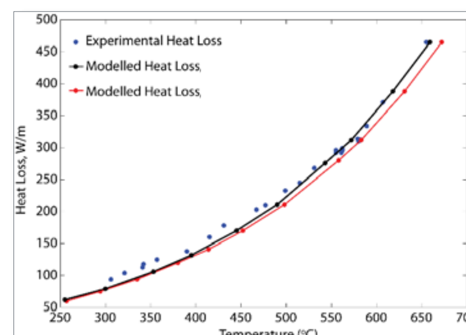


Prototypes

Build optical and thermal prototypes and test facilities and implement novel testing protocols

Testing and Validation

Optical and thermal testing validate performance and models



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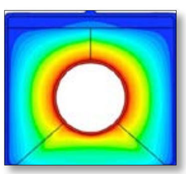
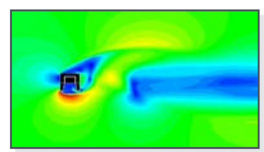
Thermal Analysis

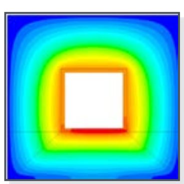
- Developed sophisticated set of **ANSYS Fluent** models and validated with NREL and proprietary experimental data
- Analyzed **radiative, convective, and conductive loss pathways**
- **Loss models coupled** in the FLUENT solver through the energy equation and the core Navier-Stokes equations.
- **Discrete-ordinates (DO)** for radiative heat transfer losses



Constant-T heat loss
Analysis of radiative, convective and conductive losses with fixed receiver T



Wind effects
2D open domain model

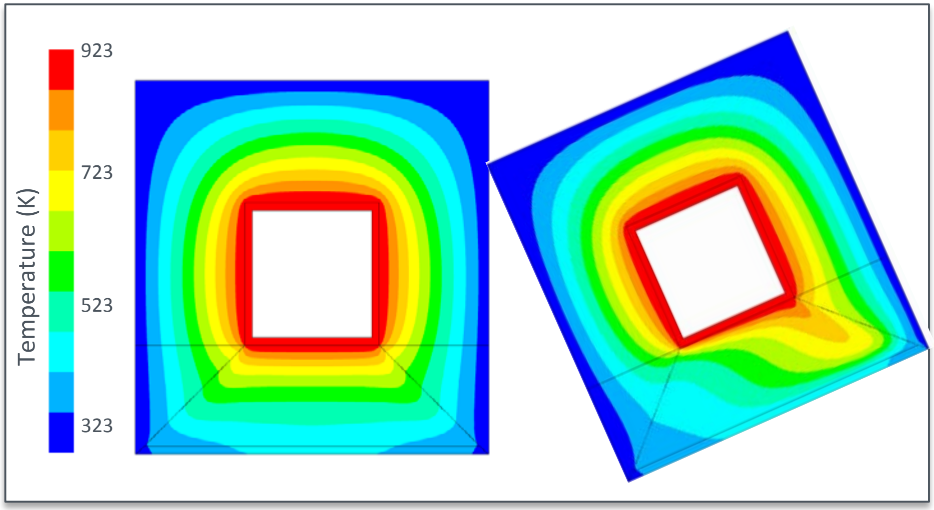


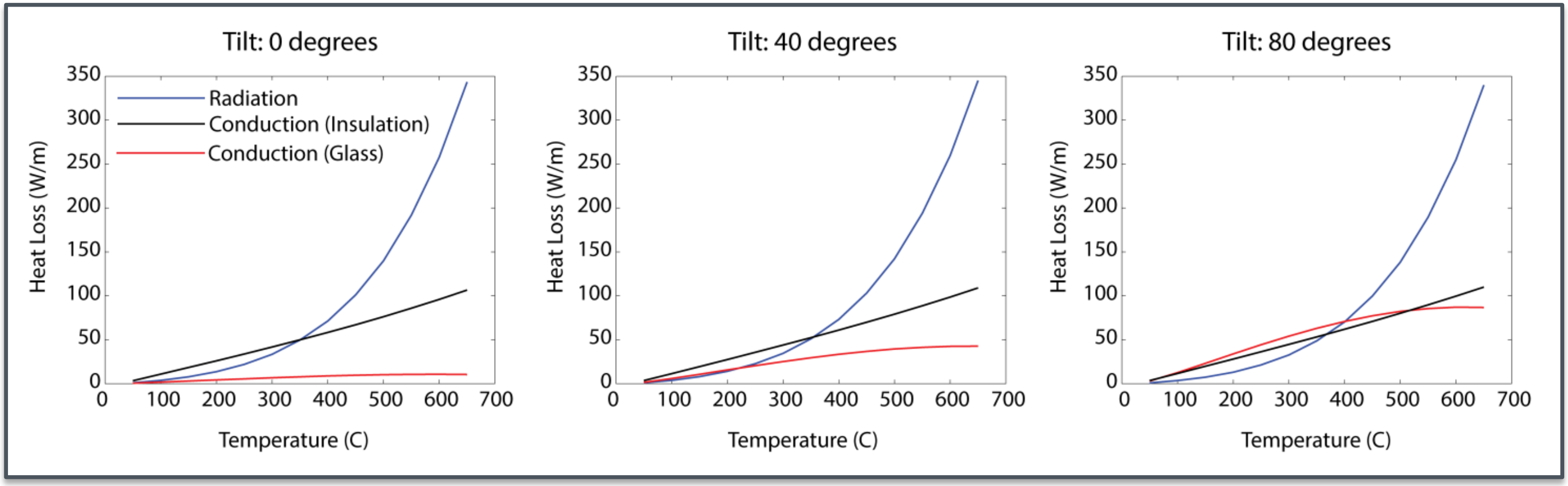
Insolation BC
2D model with radiation BC from Zemax optical analysis

3D pipe flow model
Examine heat transfer from pipe to HTF

Tilt Angle & Heat Loss Mechanisms

- Analyze heat loss pathways
- Convection cells appreciable after > 50°
- Majority insolation at low angle
- **Tilt losses not significant factor**





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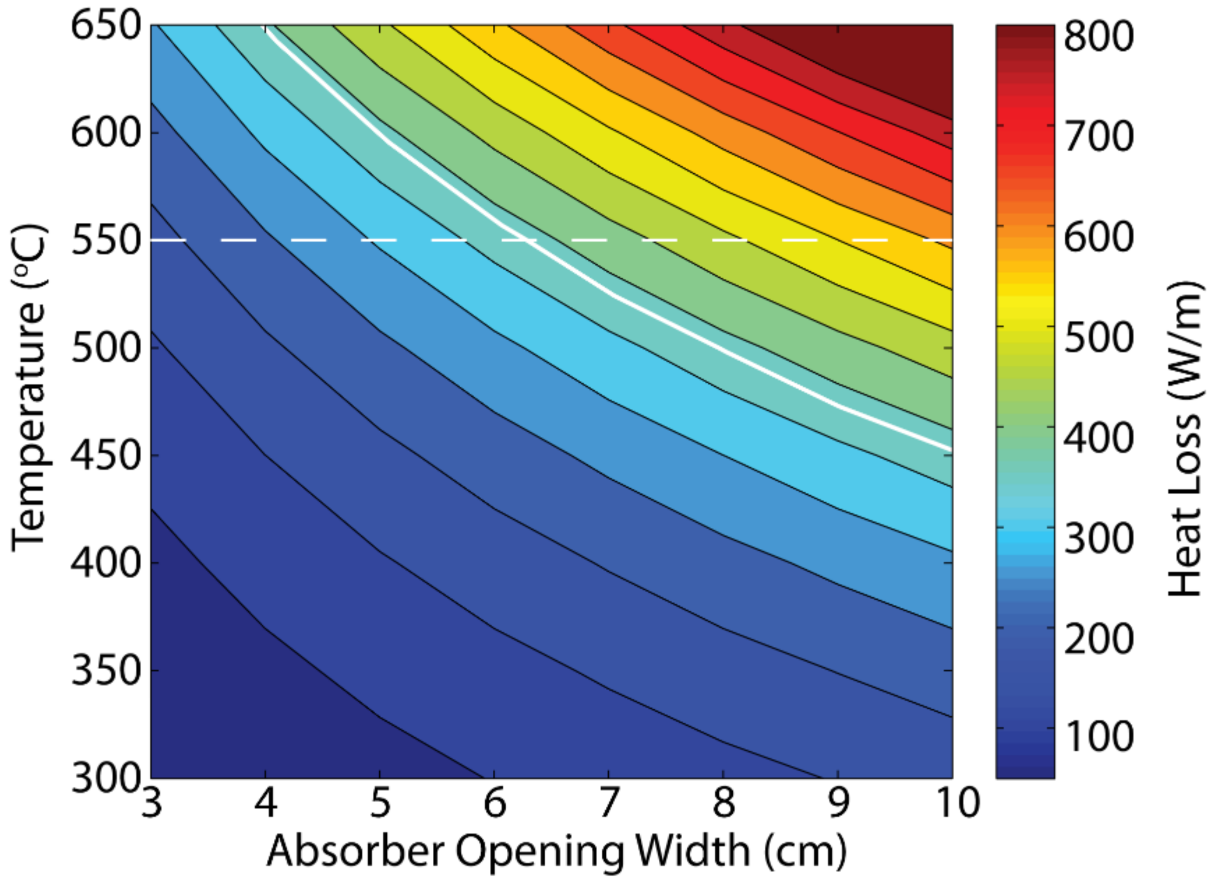
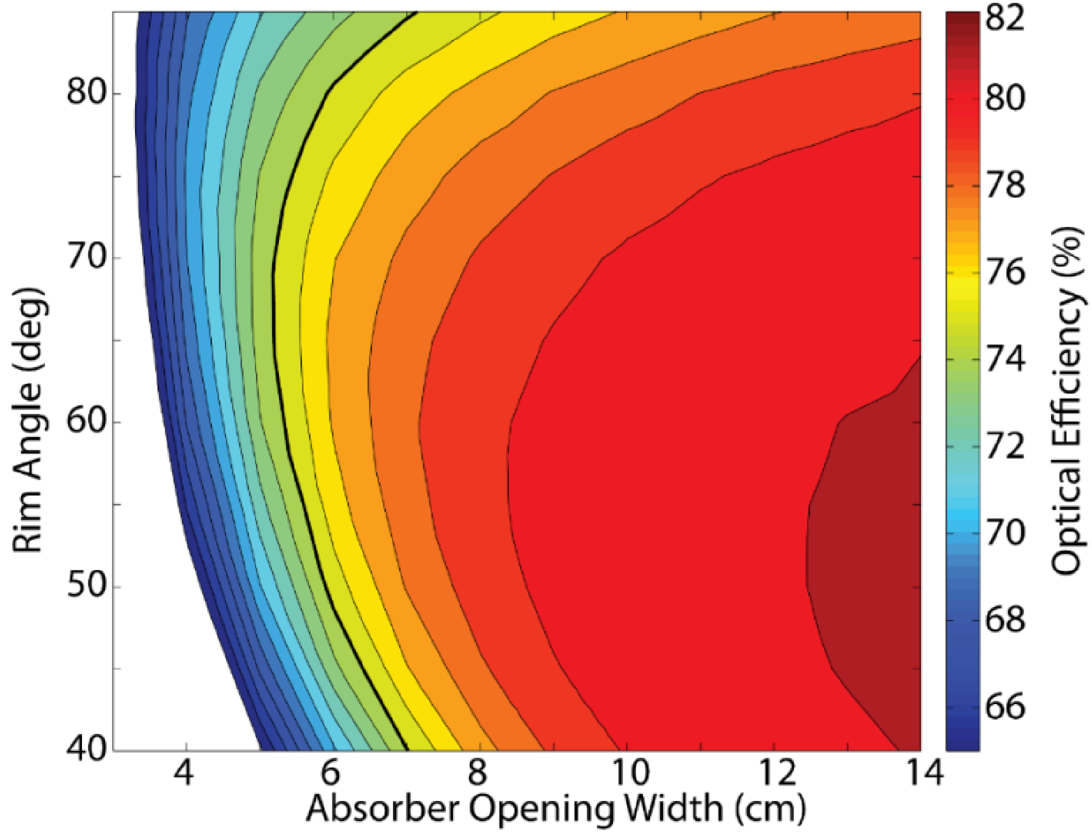
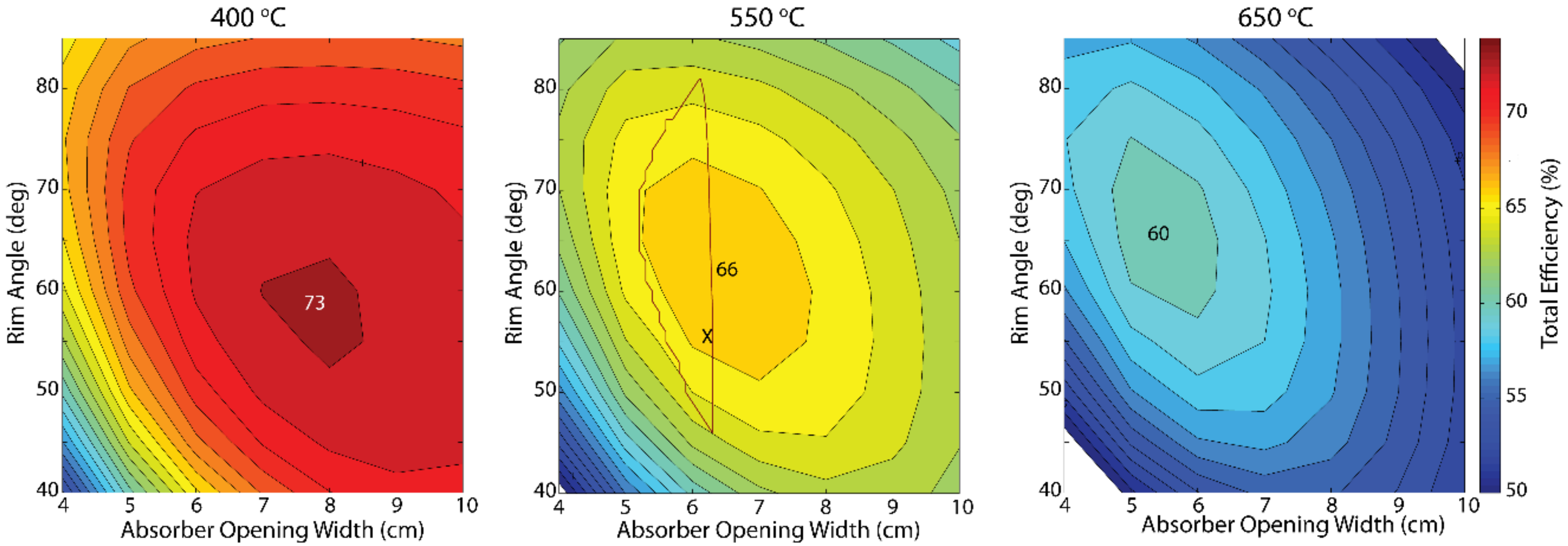
Thermal Performance - $\eta_{thermal}$



Optical Performance



Co-optimized Efficiencies - η_{total}



SolarMat2 Project Objectives

1. Design for 30 Year Service Life
2. Design for Ease of Manufacture

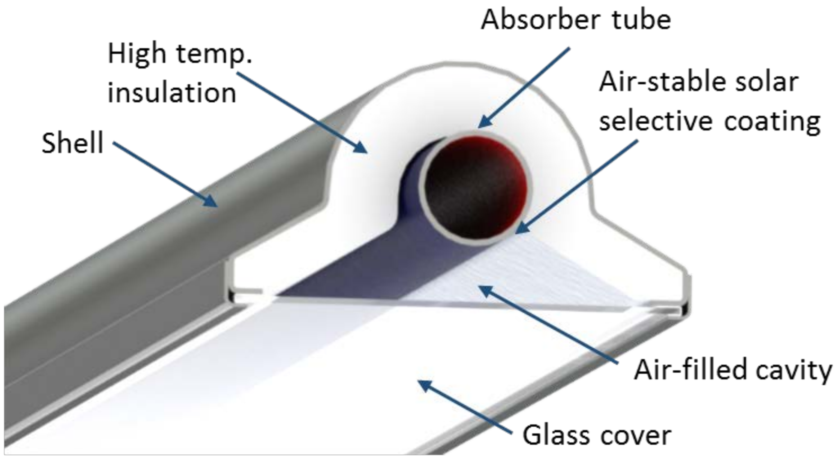
Approach

- **Analysis, Design, Build, & Testing**

Receiver Components

- Expansion Joints
- Structure stiffness
- Seals
- Air Stable Selective Coating
- Microporous insulation

Integrated Prototype

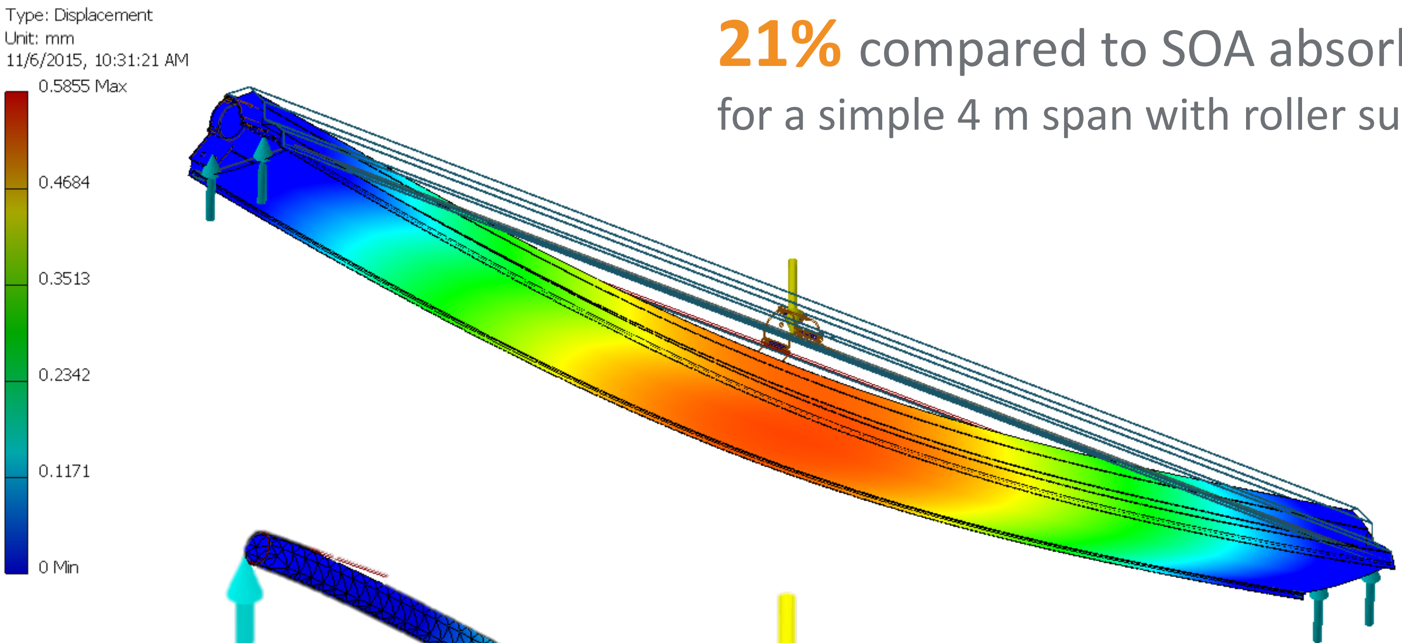


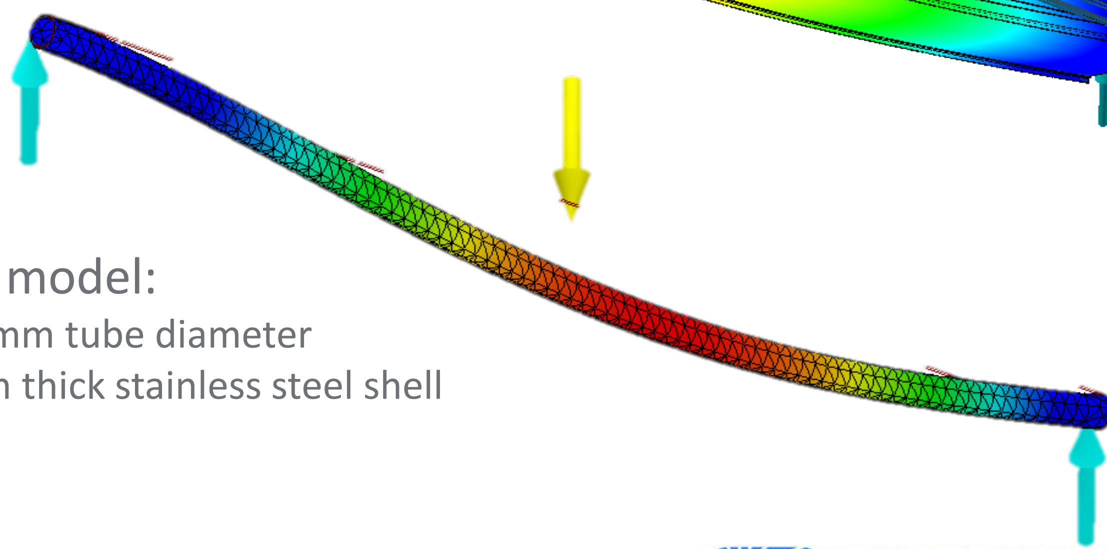
Service Life Analysis: Mechanical Structural Stiffness

reduces maximum deflection by

21% compared to SOA absorber tube,

for a simple 4 m span with roller supports at 0° tilt





FEA model:

100 mm tube diameter

2 mm thick stainless steel shell

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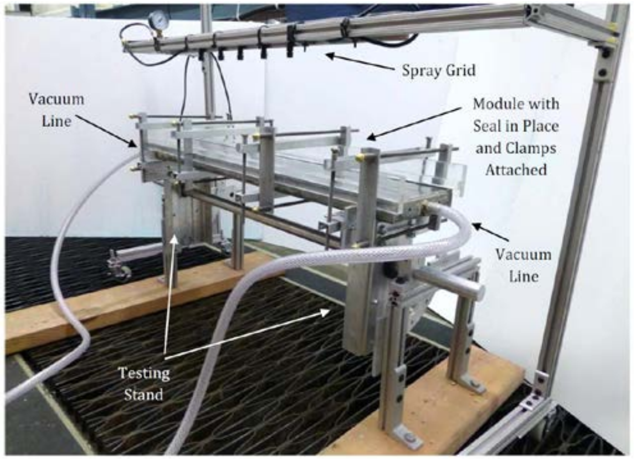
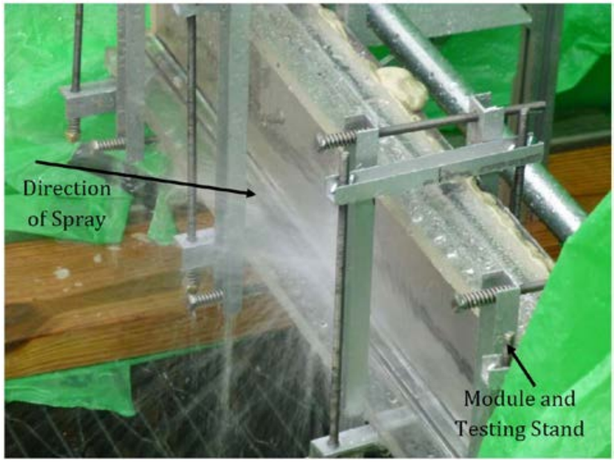
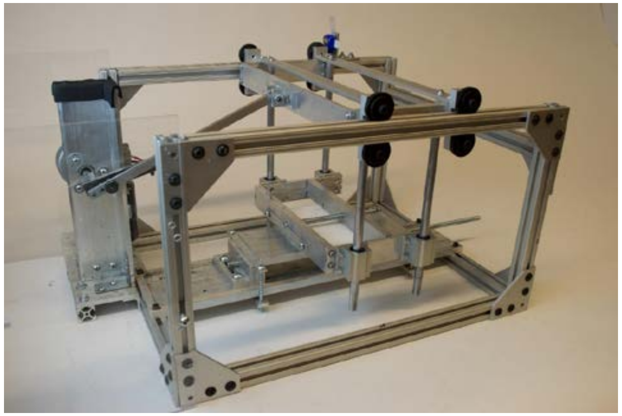
Service Life Testing

Water Intrusion Testing





Accelerated Wear Testing



Manufacturing Process Optimization

1. **Co-development of sourcing subassemblies and components**

   Collaborating closely with specialized suppliers of key parts:
   - Air Stable Solar-Selective Coating
   - Microporous Insulation
   - Anti-Reflective Glass

   Geometry and specifications tailored to fit manufacturing processes

   Quality control with reduced risk

2. **Pre-assembly of receiver modules**

   Efficient, standardized process using Design for Assembly (DFA) principles

   Controlled assembly environment optimally located

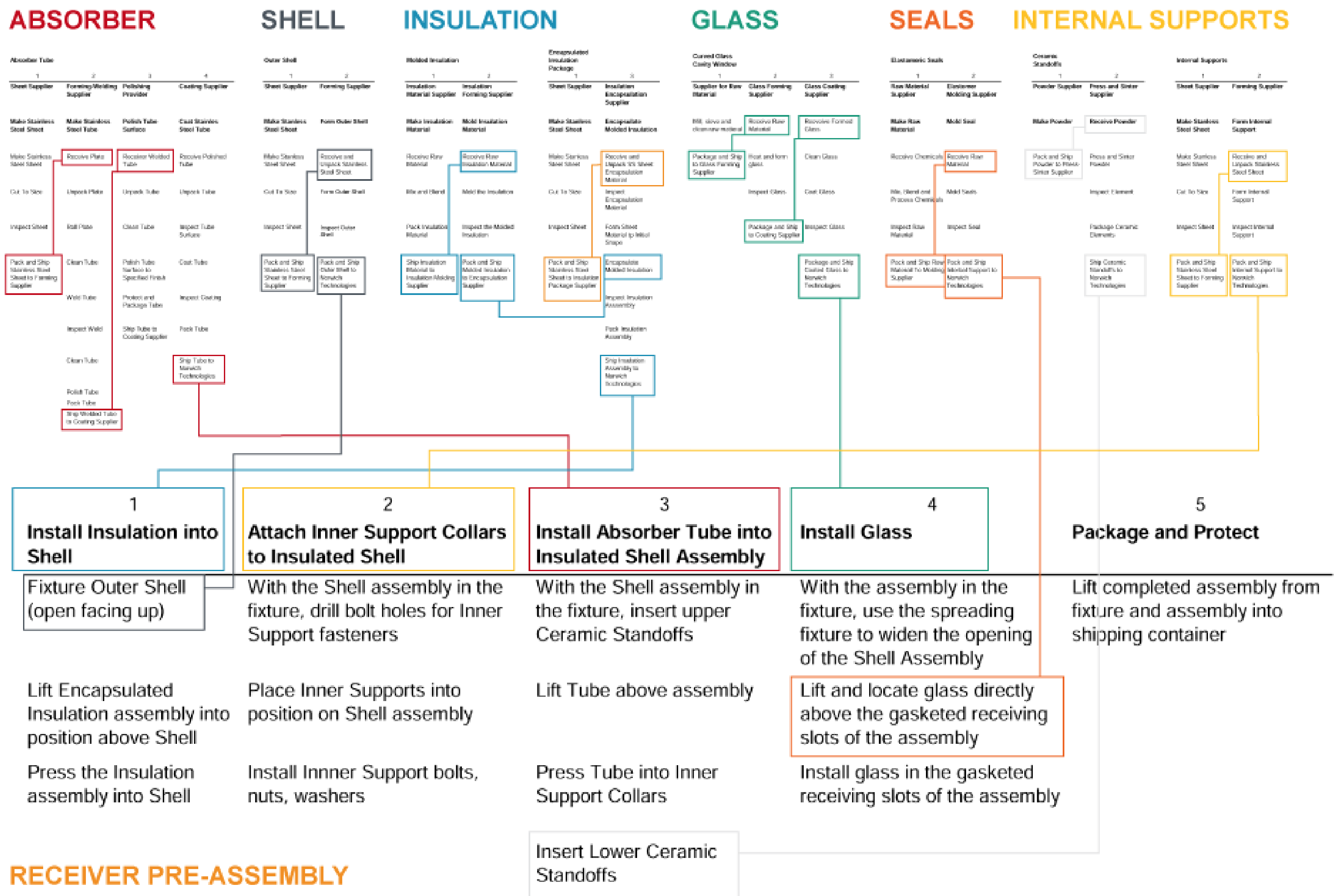
   Specialized fixtures to speed assembly

3. **Field assembly**

   Simpler than similar procedures used for SOA receivers

   Worksite process treated as a standardized, controlled assembly operation

Manufacturing Process Optimization



SunTrap Path to Market

- Field Demonstration of receiver string at conclusion of SolarMat2 award
- Pilot Project at increased scale with partner built on SolarMat2 work
- Commercial deployment with initial scale production

- IP Development
  file provisionals, US utility and international PCT patent applications

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Novel Low-Cost Parabolic Trough Collector Structures – initial development and next steps

SunShot Incubator award DE-EE0006687

1 Year ($700k DoE SunShot Funding)

Joel Stettenheim, President & Principal Investigator

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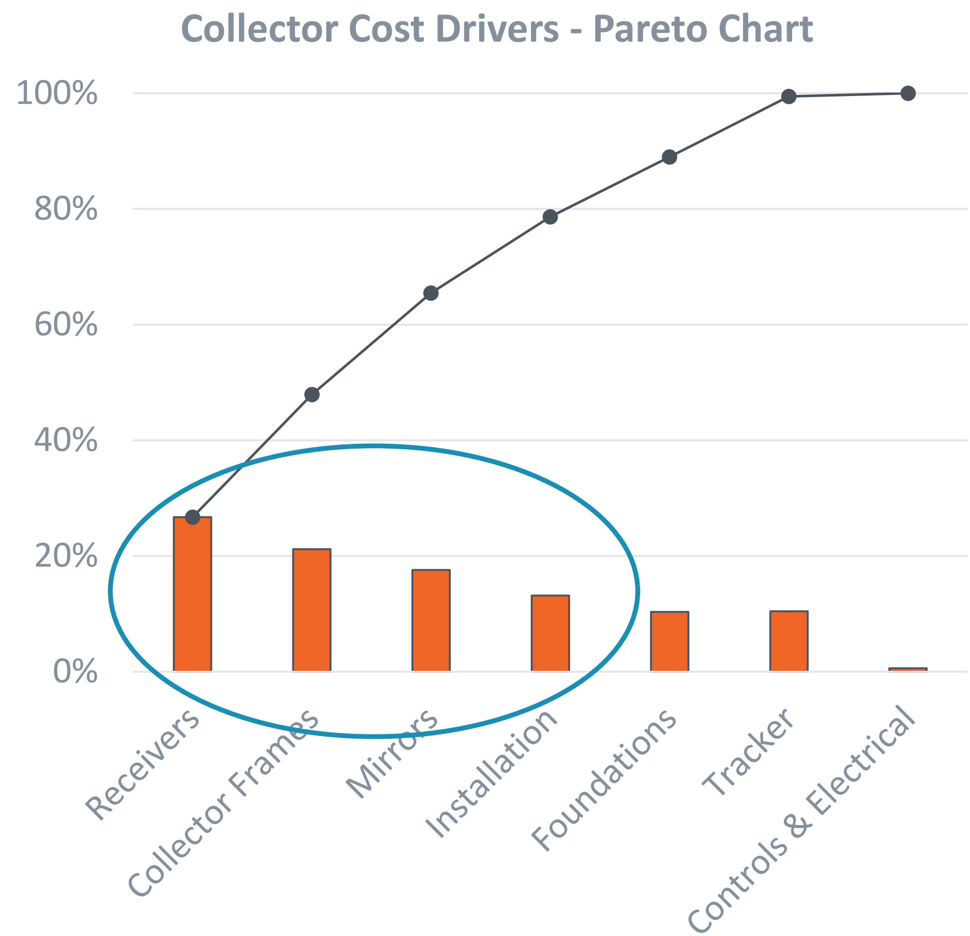
Parabolic Trough Solar Field – Cost Drivers

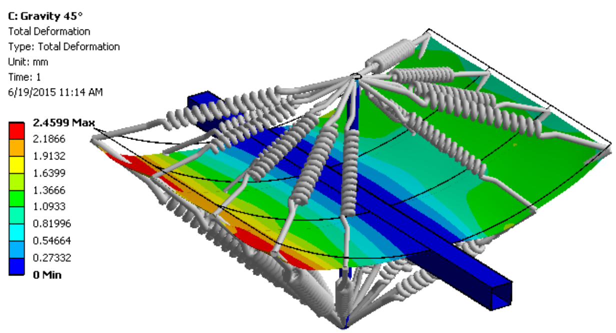
- SunTrap receiver
  - Incubator demonstration
- Novel collector structures
  - Reduce framing
  - Simplify assembly
  - Highly accurate mirrors at competitive cost



Technology Development Protocol

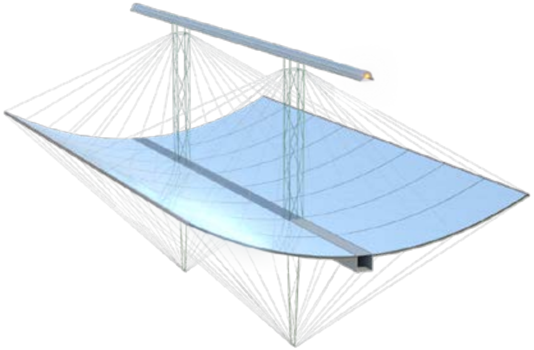
Modeling

Mechanical and optical performance



Analysis and Design

Vary configurations & component (mast, panels, tube,..)

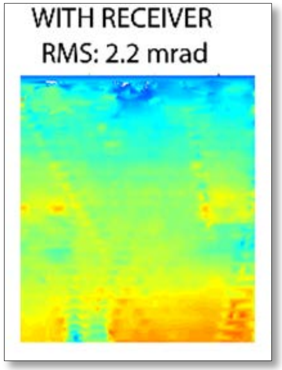


Prototype Build

Assemble cable suspension & panel structure

Testing and Validation

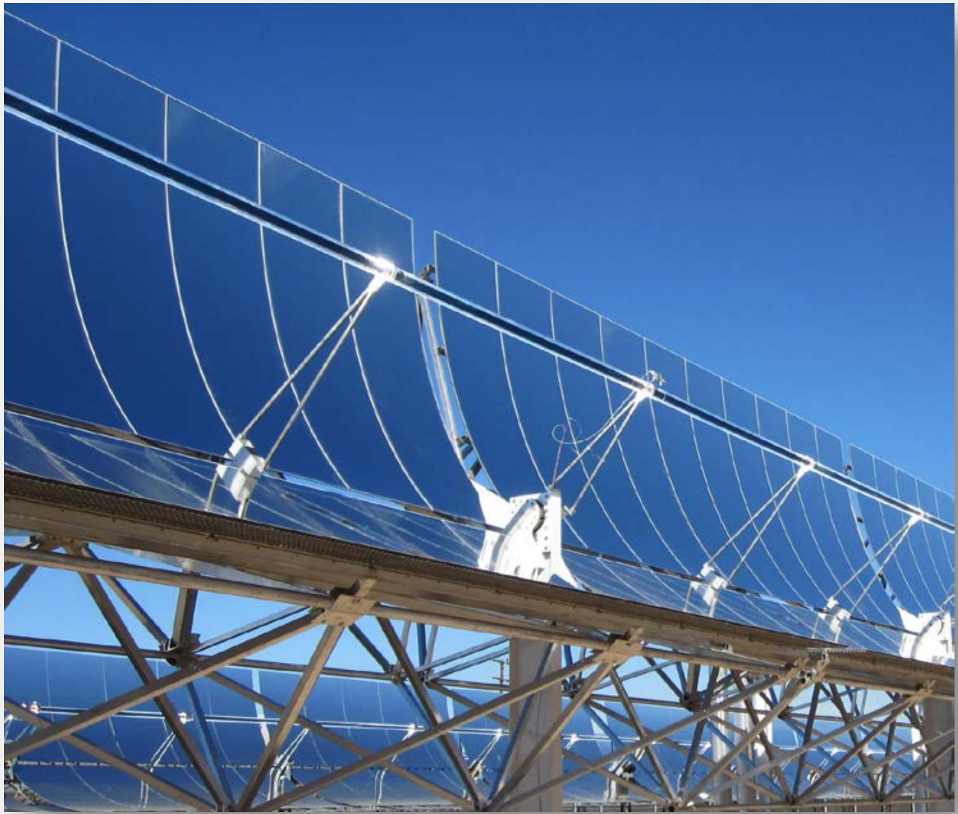
Test optical performance photogrammetry



Trough Structure Overview

- Survival:
  - Wind load torsion on long drive string – mirror breakage
- Operation:
  - Stable tracking orientation
  - Accurate shape and surface
- Space frame structures highly optimized
  - Gossamer LAT™ 7.3m, 8m

GOSSAMER INNOVATIONS



http://news.3m.com/press-release/company/3m-and-gossamer-space-frames-inaugurate-worlds-largest-aperture-parabolic-trou

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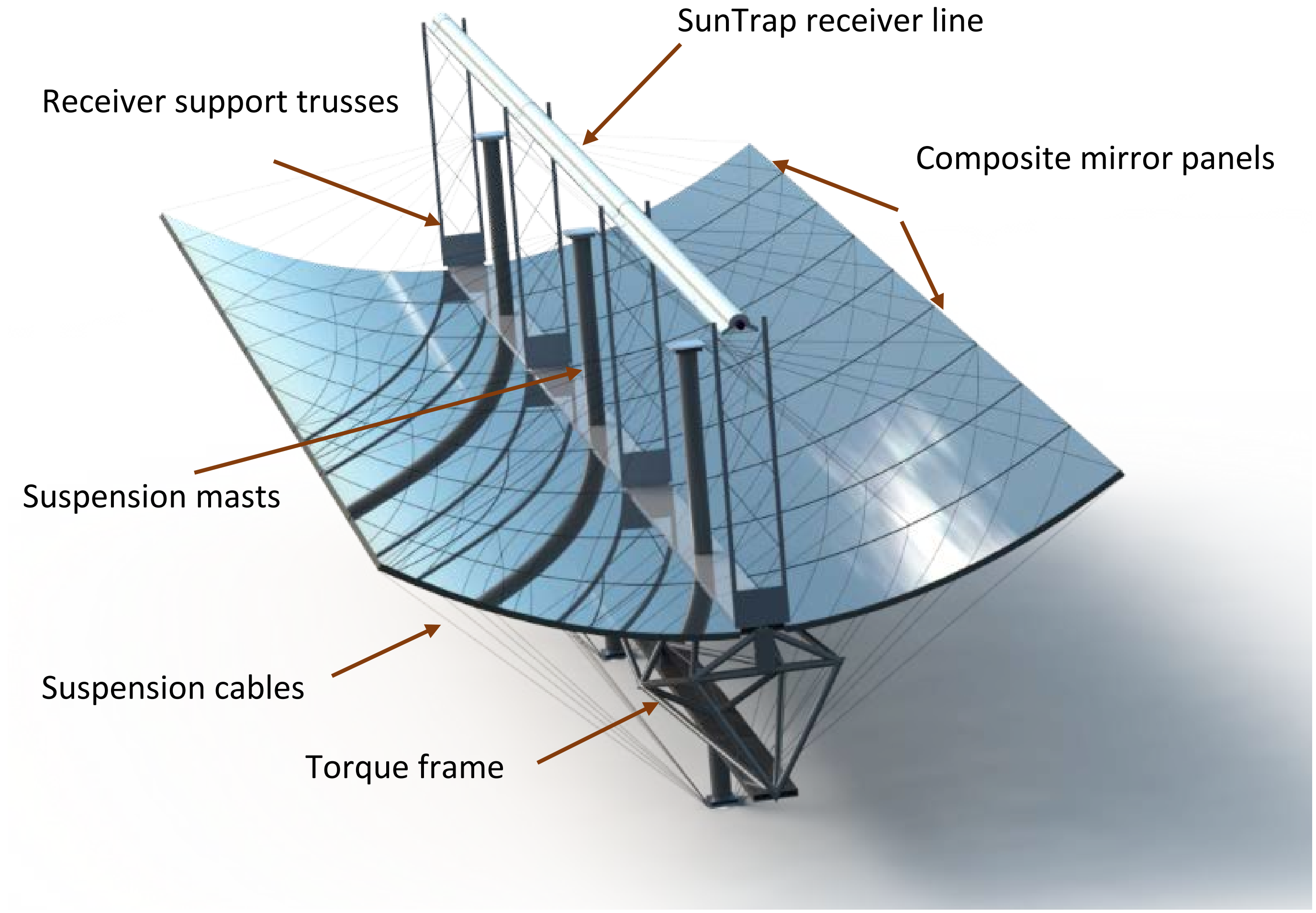
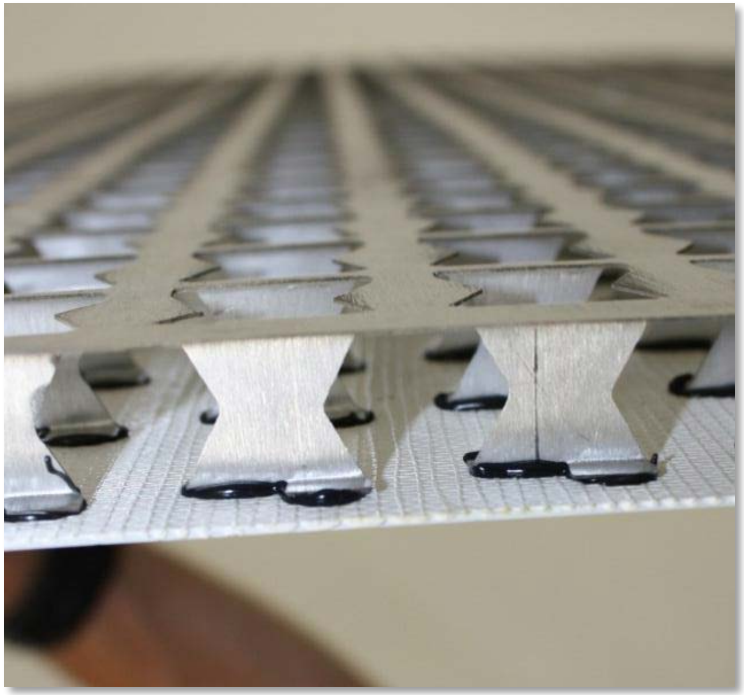
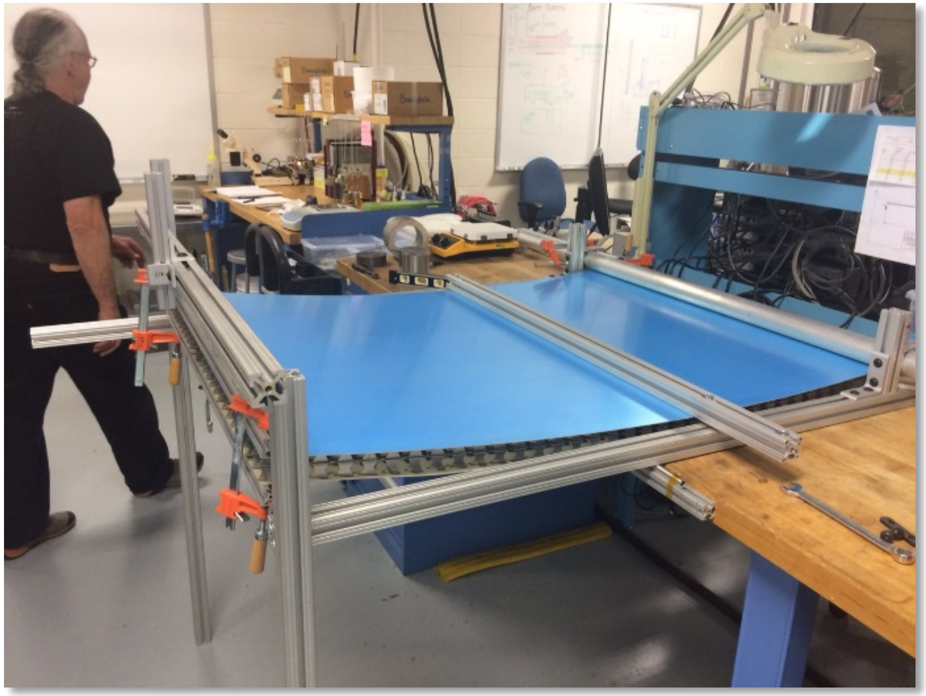
Collector Design & Analysis



Gossamer X-Perf™ Structural Mirror Panels

- High accuracy, lightweight structural composite mirror panels with thin glass or 3M mirror film
- Gossamer LAT™ 7.3m trough with 104x concentration
- Tunable for very high stiffness





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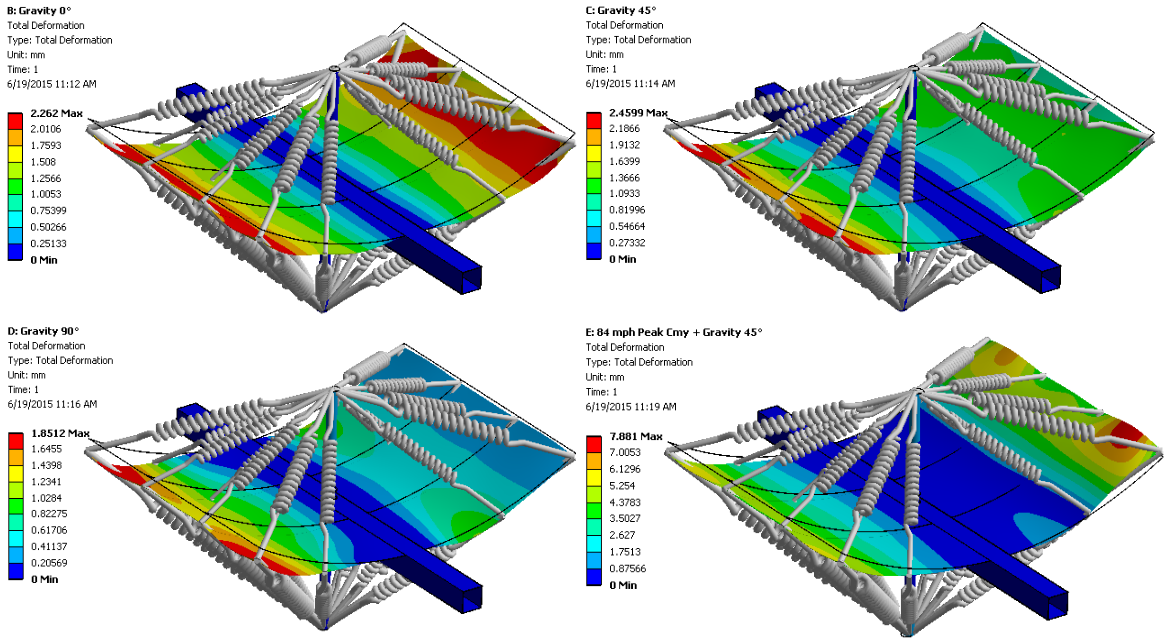
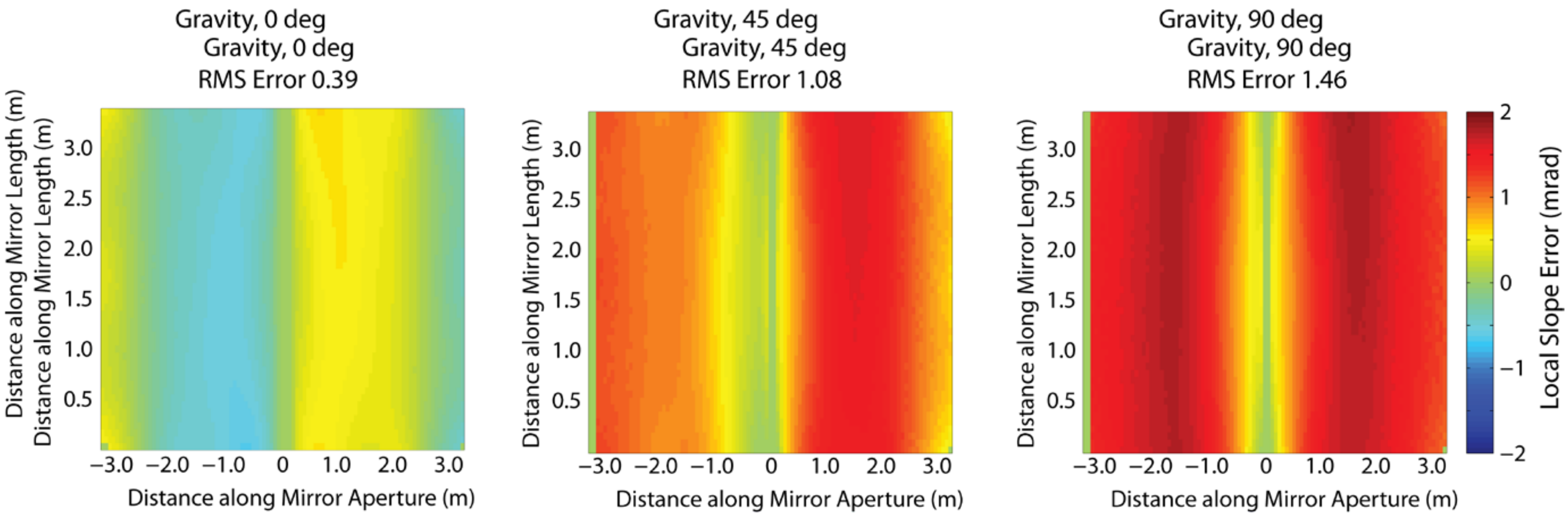
Collector Physical Modeling

- Model with SolidWorks, ANSYS, and custom analytical
  - Deformations of panels and mast structures
  - Vary structural elements (e.g., torque tube, panel, mast, cables)
- Wind & Gravity load analysis



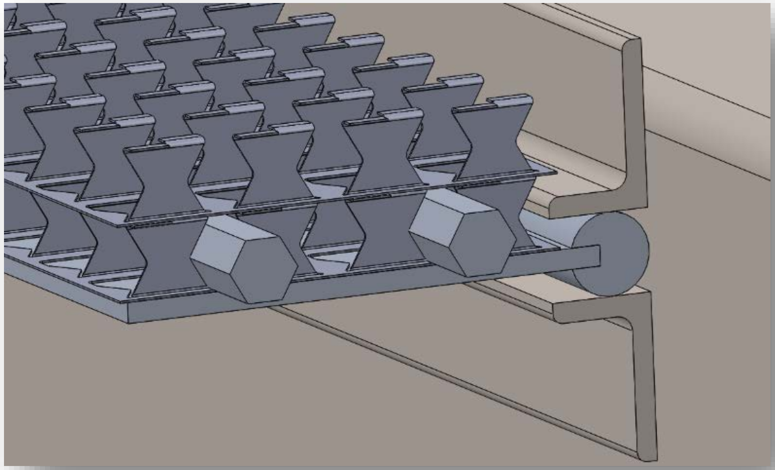
Collector Optical Analysis from Mechanical Results

- Coupling of structural and optical models
  - Geometric Slope and Operational Effects
    - Displacement – panel, gravity & support structure
    - Scatter: Sun shape, tracking, specularity

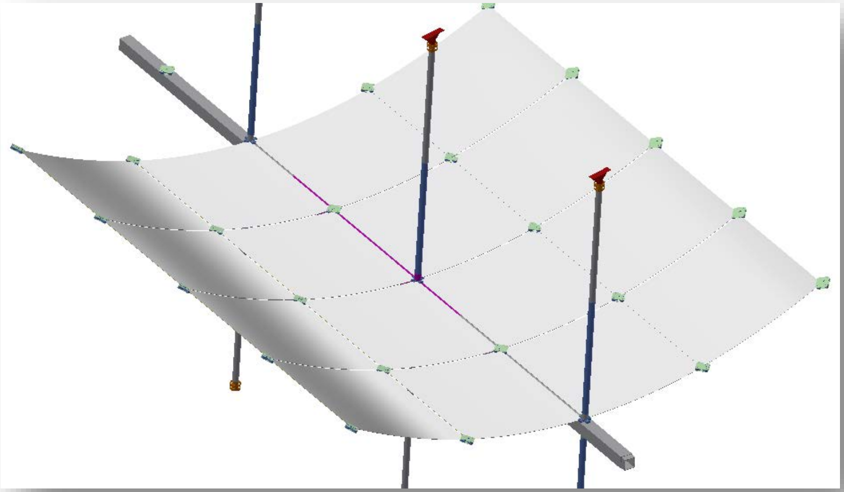


Design Iterations

- Iterative panel and support structural analysis and refinement



Gossamer X-Perf™ panel backing structure



Mast, cable and receiver structure

NORWICH TECHNOLOGIES

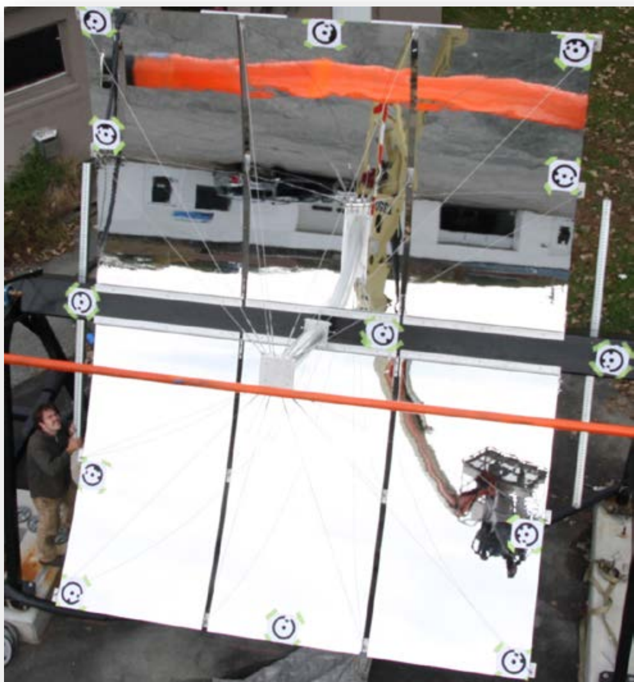
Prototype Build – Suspension Trough

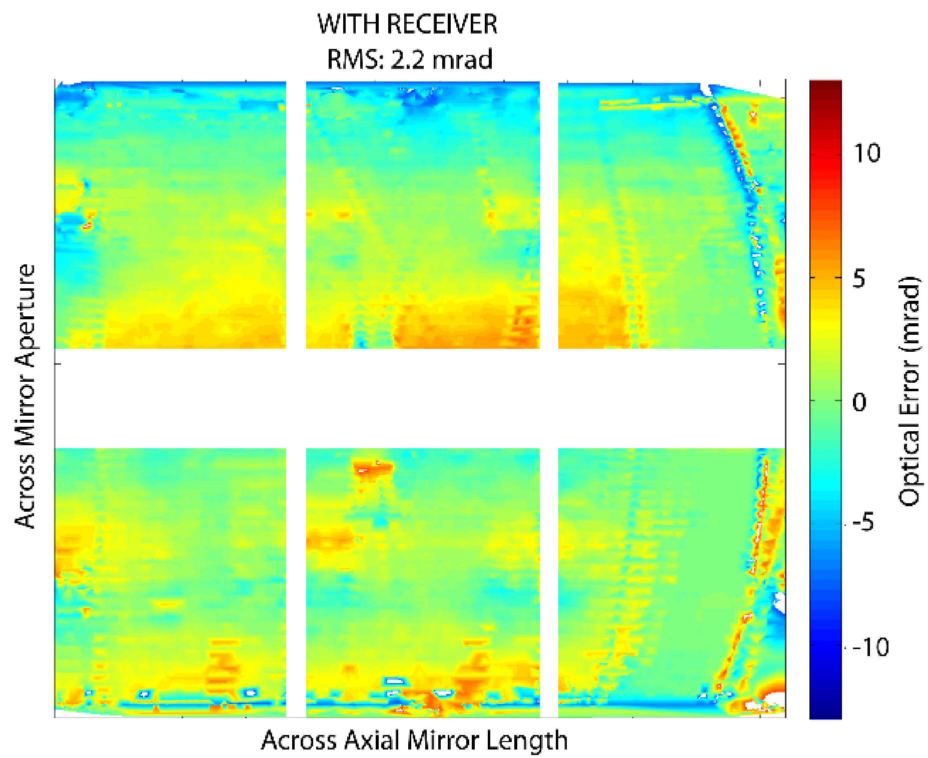
- Use cables to define parabola, highly stiff X-Perf^{TM} mirror panels to hold shape between mounting points

- High accuracy (2.2 mrad slope error for system)

Testing – Development of Photogrammetry Tools

- NREL Observer method – rapid mirror error mapping
  - Reflected image of absorber on mirror surface
  - Measured as slope error





Next-Stage Development

- Optimized X-Perf™ mirror panels enable cantilever beyond supports, minimal framing to define parabola
- Torsional stiffness required to withstand wind, maintain tracking accuracy
  - Torque ~ aperture^2, drive string length
  - Large aperture dilutes costs per mirror area, long drive string dilutes tracker cost but requires large, expensive drive
    - Increasing drive count allows less expensive drives and reduces governing torsional loads on collector frame
      - Unlock opportunities to simplify structure and assembly

Path to Market

- Pending Incubator grant for follow-on refinement
- Field Demonstration
- Pilot Project with development partner
- Commercial Deployment

Project Team

GOSSAMER INNOVATIONS

Creare

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Powered by SunShot
U.S. Department of Energy

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