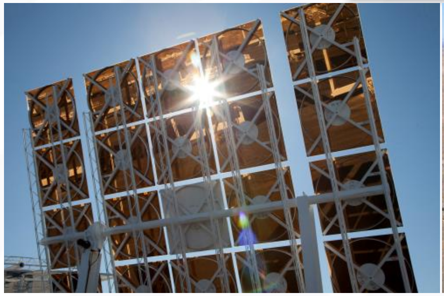
SunShot
U.S. Department of Energy

CSP Program Summit 2016



DOE’s National Solar Thermal Test Facility (NSTTF)

April 20, 2016

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energy.gov/sunshot

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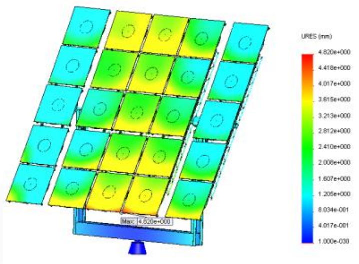
Sandia National Laboratories

Vision

- Develop the next-generation CSP technologies to provide dispatchable, clean solar-thermal generated electricity at higher conversion efficiencies
- Realize significant reductions in Levelized Cost of Energy (LCOE) by making fundamental advances in power cycles, receivers, thermal storage, and collectors to achieve the intent of the SunShot goals by 2020

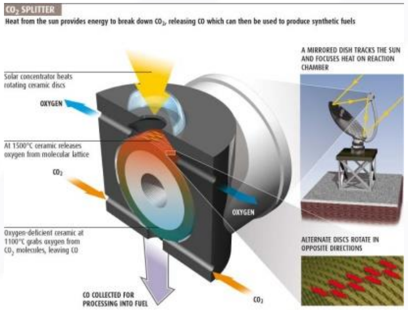
Development Areas

- Power Tower R&D – Reduce the cost and improve the performance of high-temperature receivers and novel heliostats
- Thermal Storage R&D - Lower the cost of thermal energy storage through analysis of HTF/material compatibility and performance evaluation of next-generation hardware
- Optical Materials and Tools - Address identified cost and performance impacts in the optical systems
- System Analysis - Develop models and analysis tools that will aid in the evaluation of CSP components and systems
- Dish R&D – Develop thermal storage systems for dish-engine system that use heat pipes and latent thermal storage
- SunShine-To-Petrol (S2P) – Development of a solar chemical process to convert CO_2 and H_2O into hydrocarbon fuels



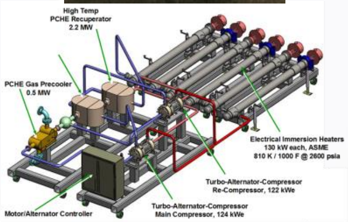
Full-scale heliostat modeling and testing at the NSTTF

Molten Salt Test Loop (MSTL)



Counter-Rotating-Ring Receiver/Reactor/Recuperator (CR5)

National Solar Thermal Test Facility at Sandia National Laboratories, Albuquerque, NM



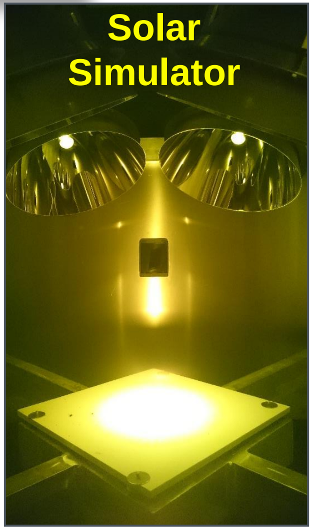
Development of supercritical CO_2 Brayton cycle

National Solar Thermal Test Facility

PV System Reliability

Dish Stirling R&D

Parabolic Trough R&D



Materials R&D

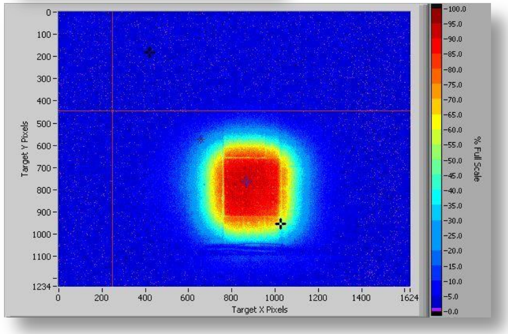
Thermal Energy Storage R&D

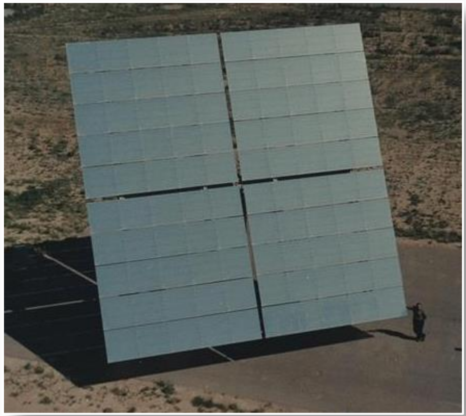
Solar Fuels and Selective Absorbers

Power Tower & Heliostat Field

- **Capability**
  - Testing receivers, materials and systems under high solar flux conditions (6.2 MW_{th} incident power and 350 W/cm^2 peak irradiance)
- Heliostat Field
  - 214 heliostats.
  - 37 m2
  - Completely re-mirrored
  - Low-iron, >95% solar-weighted reflectivity
- Tower
  - 200 ft tall tower
  - 100-ton capacity elevating module
  - Three test bays
  - Beam Characterization Target
- Heliostat Test Bed
  - Full-scale heliostats
  - Novel designs
  - High performance reflective film evaluation

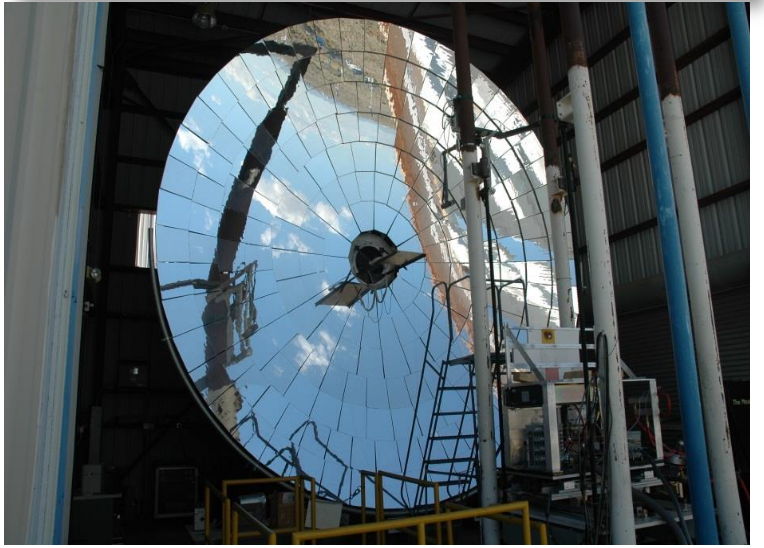
Shuttle Tile Testing on top of Solar Tower





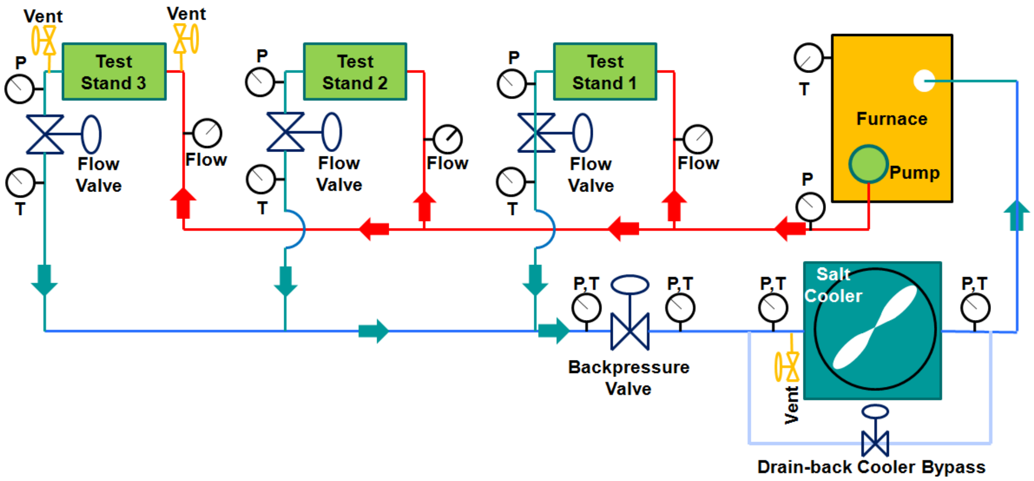
Solar Furnace

- The 16 kW solar furnace comprises:
  - Primary heliostat
  - A secondary concentrator
  - Test table where experiments or calibrations are performed.
- The peak flux provided is greater than 600W/cm2.
- Furnace used to demonstrate the feasibility of the Sunshine-to-Petrol initiative.
- Furnace used for selective absorber testing and material screening.
- The solar furnace is the only place in the US that can provide a solar calibration for flux gages.



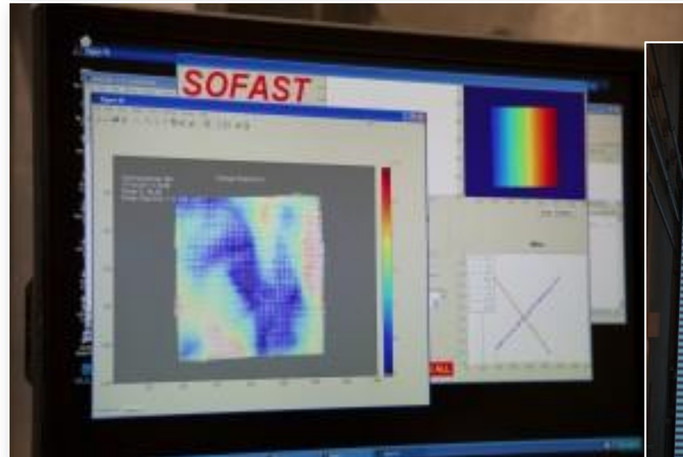
Molten Salt Test Loop

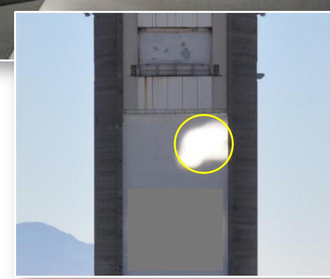
- Purpose:
  - Enables testing of molten salt hardware at high-flow and high-pressure, over a range of temperatures
- Features & Capabilities
  - 3 Test Stands
  - 60% $NaNO_3$ / 40% KNO_3
  - Flow rate: 1.5 m^3/min (400 gal/min)
  - Salt temperature range: 300-585^{o}C (572-1085^{o}F)
  - Maximum salt pressure: 40 bar (580 psi)
  - Remove up to 1.4MW solar thermal input



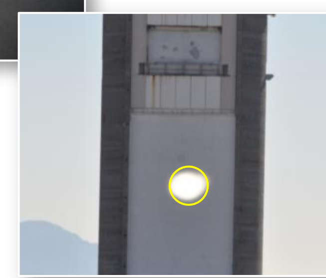
Test Capabilities: Optical Lab and Systems

- Optical characterization
  - Millimeter resolution surface normal characterization
  - Full dish or facet metrology
  - Licensable software tools
- Optical alignment
- Opto-structural interaction evaluation
- Beam characterization
- Tracking evaluation
- Soiling studies
- Reflectivity evaluation





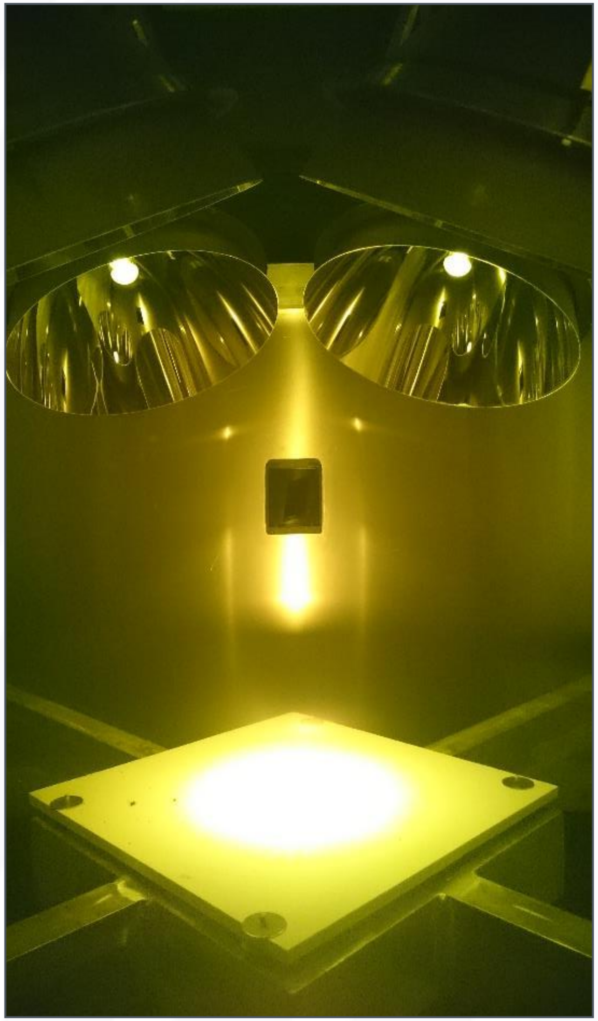
Before



After

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

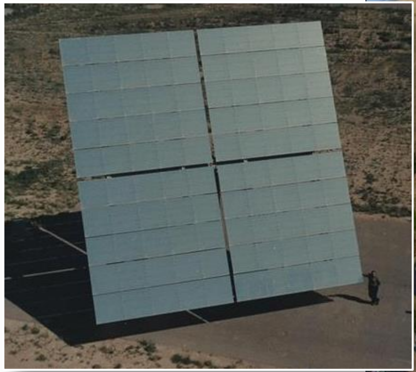
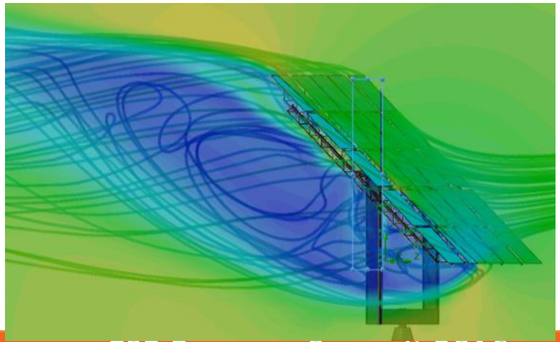
- Purpose:
  - Solar Simulator provides accelerated aging tests for materials under high flux conditions
- Features & Capabilities
- Peak Irradiance:1.3 MW/m^2
- Average Irradiance: 0.9 MW/m^2
- Spot size: 2.54 cm
- Operational: 24/7
- Programmable, robotic sample holder, for multi-sample testing



Sandia's Current CSP Related R&D

- Next Gen Receivers
- Dish Storage
- Thermochemical Energy Storage
- Solar Selective Materials
- Novel Reflectors
- Solar Hydrogen



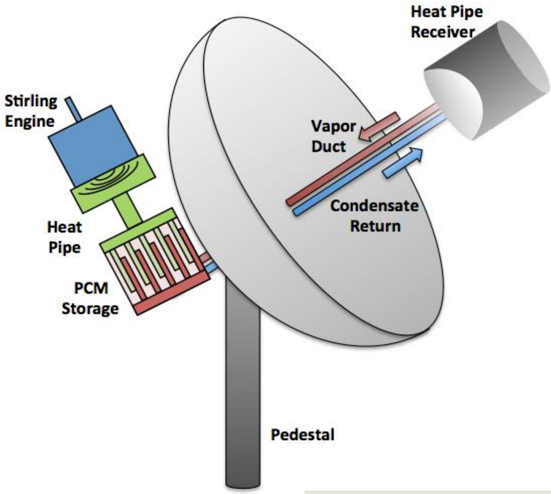
Falling Particle Receiver

- Falling Particle Receivers
  - Benefits
    - High temperatures (T > 700 °C)
    - Direct energy storage of particles
    - Increased fluxes
  - Challenges
    - Particle attrition / wear / conveyance
    - Particle solar absorption
    - Particle/fluid heat exchange
    - Need to increase thermal efficiency (from 50% to 90%)

Dish Stirling High Performance Thermal Storage

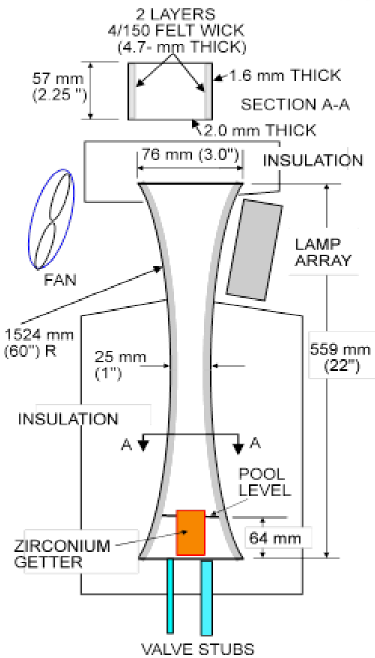
Goal:

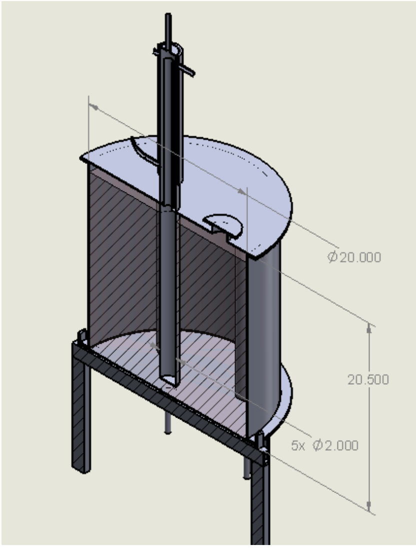
- Demonstrate the feasibility of thermal storage for dish Stirling systems
- Demonstrate key components of a latent storage and transport system
- Provide a technology path to a $25kW_e$ system with 6 hours of storage at reduced costs



Innovation:

- Develop and validate high temperature, high performance PCM storage
- High performance heat pipes for latent transport
- Latent storage *and* transport matching Stirling cycle isothermal input





High-Temperature Solar Selective Coatings

Selective absorber coatings for receivers with high absorptance in the solar spectrum & lower emittance in the infrared, stable in air, easily applied at large scale, cost effective, and survives thousands of heating and cooling cycles

Transition Metal oxides

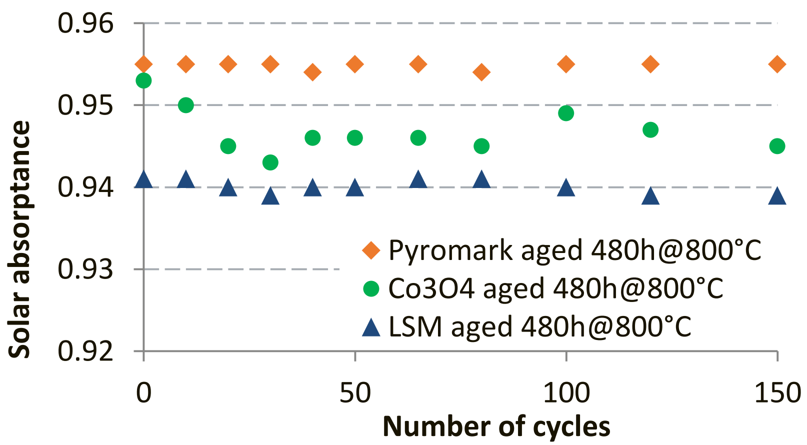
- Inherently stable at high temperature and in air
- Amenable to doping and substitution to chemically tailor their properties
- Ease of application (thermal spray, paint, dip-coat…)

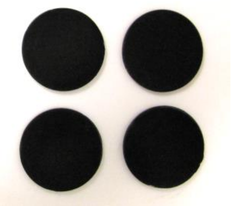
Solar furnace: 150 automatic heating/cooling cycles on already-aged samples

600 kW m^{-2} / 0 kW m^{-2}

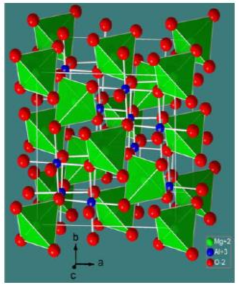
850˚C / 100˚C

substrate: Inconel 625

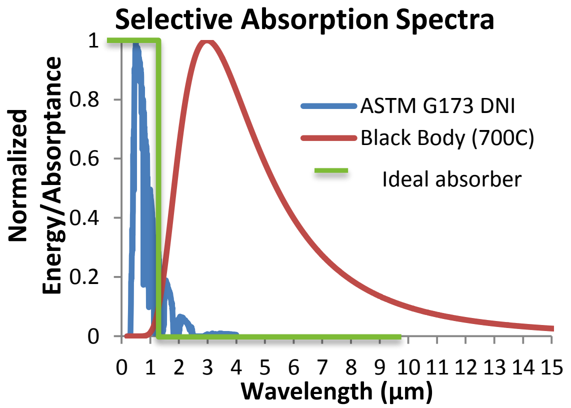


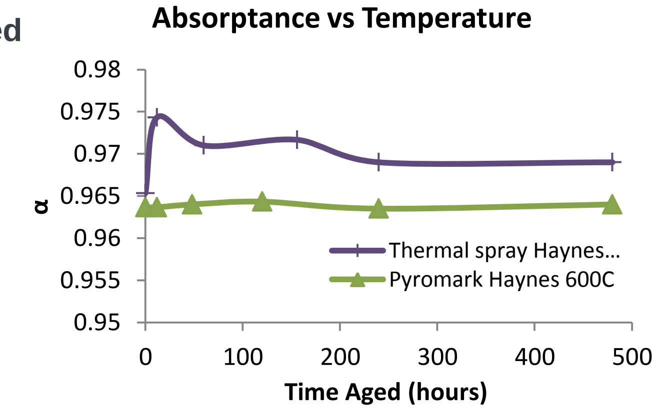


Thermal-sprayed oxide coating, aged 240 h



Spinel structure

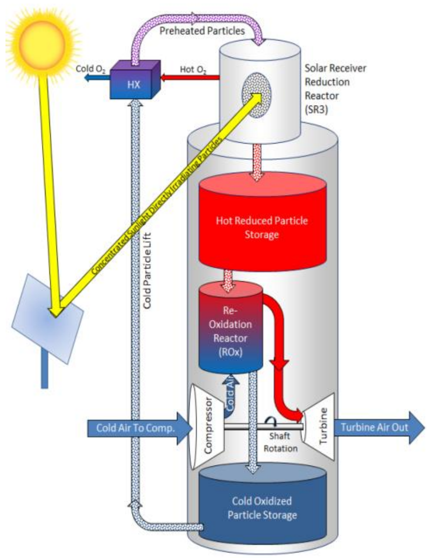




Thermal-sprayed oxide maintains > 96% absorptivity after 480 h at 600 °C (isothermal)

High Performance Reduction/Oxidation Metal Oxides for Thermochemical Energy Storage (PROMOTES)

The PROMOTES effort seeks to advance both materials and systems for TCES through the development and demonstration of an innovative storage approach for solarized Air-Brayton power cycles.

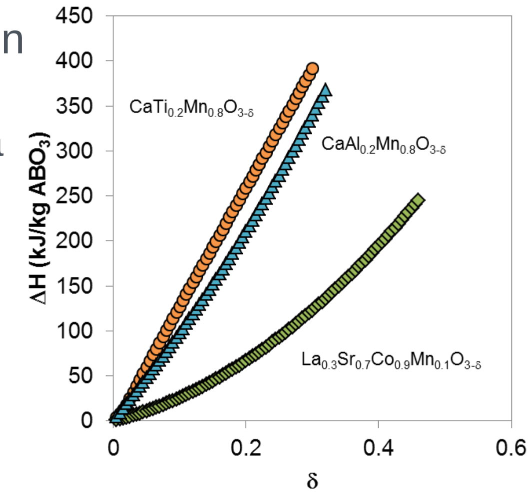


- Challenge: Current heat storage methods are limited for next-generation CSP towers, which are expected to operate at temperatures > 600 °C, in order to maximize efficiency and economic competitiveness
- Solution: Thermochemical energy storage (TCES)
  - Heat stored as chemical bonds can be stored indefinitely and accessed on-demand
  - Sensible and latent heat recovery results in high storage densities
  - Direct irradiation of thermal storage media

- Result: Newly developed redox-active $CaMnO_{3-\delta}$ -based materials display total mass specific enthalpies of > 1200 kJ/kg (T_H = 1200 °C, T_L = 200 °C)

$$\Delta H_{tot} = \Delta H_{rxn} + C_p \Delta T$$

Material	Max δ	ΔH_{rxn} (kJ/kg) (at δ_{max})	Est'd C_p (kJ/kg-K)	ΔH_{tot} (kJ/kg)
$CaTi_{0.2}Mn_{0.8}O_{3-\delta}$	0.293	393	0.881	1243
$CaAl_{0.2}Mn_{0.8}O_{3-\delta}$	0.322	371	0.918	1269

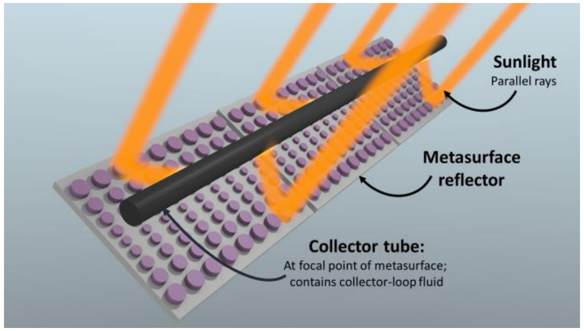


KEY PARTNERS: Georgia Institute of Technology, King Saud University, Arizona State University

Dielectric Metasurface Concentrators

Problem Statement

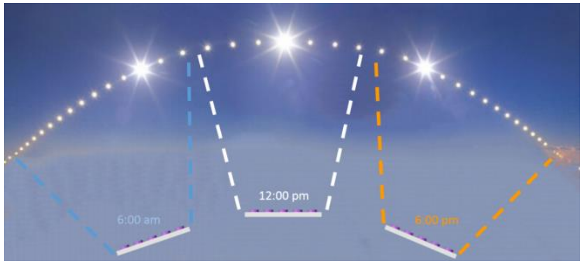
- The largest expense (~50%) in CSP installation cost is the collector field, which includes the mirror and tracking costs
- Reducing the tracking requirement can alleviate collector field cost



Hypothesis

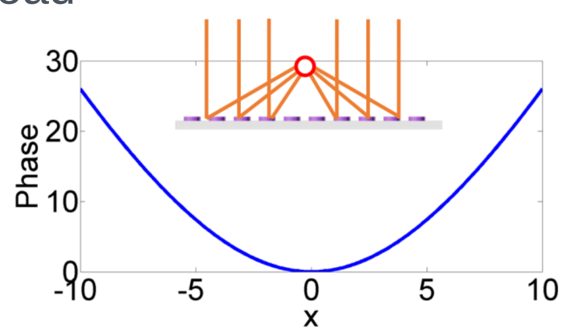
- Metasurfaces can be engineered to focus sunlight over a broad acceptance angle and broad spectrum, thus minimizing the tracking requirements
- With large acceptance angle, diffuse light can be collected for improved efficiencies

Minimized Tracking

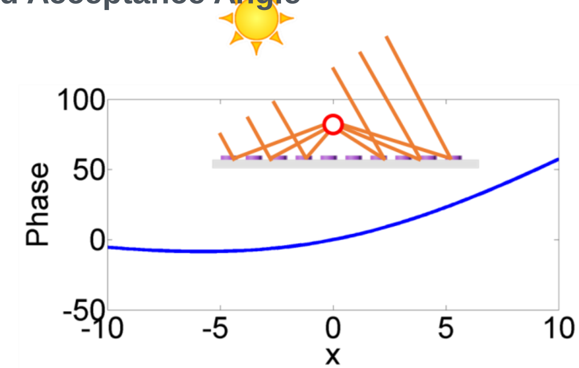


Scientific Approach

- Tune the metasurfaces for broad acceptance angle and reflection of broad spectrum
- Use Sandia's nano-fab capabilities



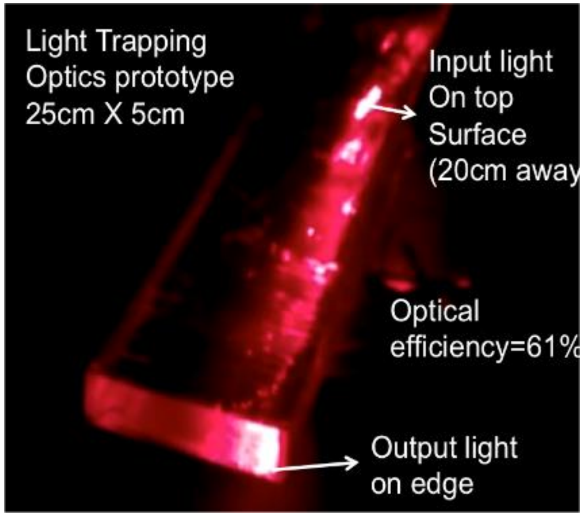
Broad Acceptance Angle



Single-Axis Tracking Waveguide Collector

Problem Statement

- The largest expense (~50%) in CSP installation cost is the collector field, which includes the mirror and tracking costs
- Relaxing the tracking requirement and using low-cost materials can alleviate collector field cost

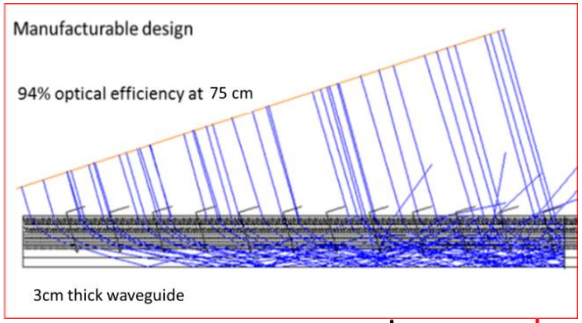


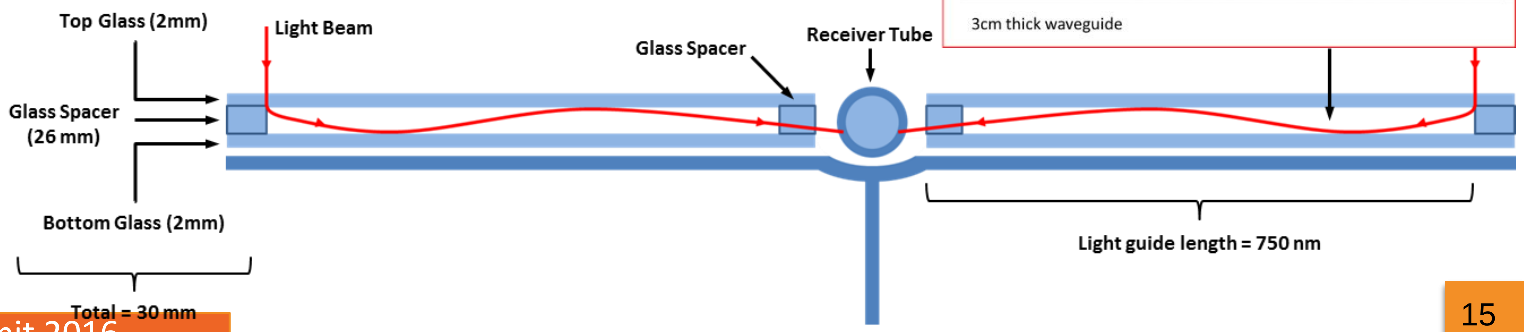
Hypothesis

- Sunlight can be efficiently collected and prorogated within the waveguide panel using total internal reflection to one edge of the panel where the thermal energy will be collected

Scientific Approach

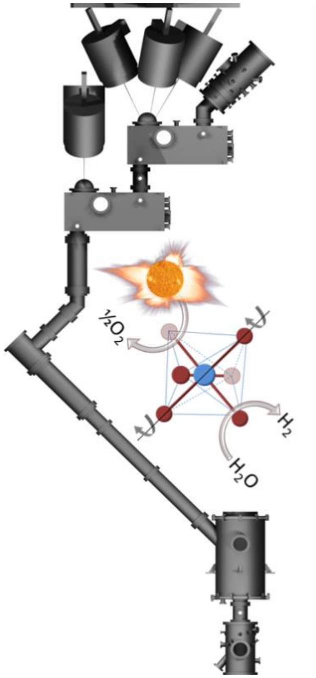
- Waveguide collected will be designed to have broad acceptance angle to relax the tracking requirements
- Manufacturing will be optimized for low-cost assembly of the waveguide panels



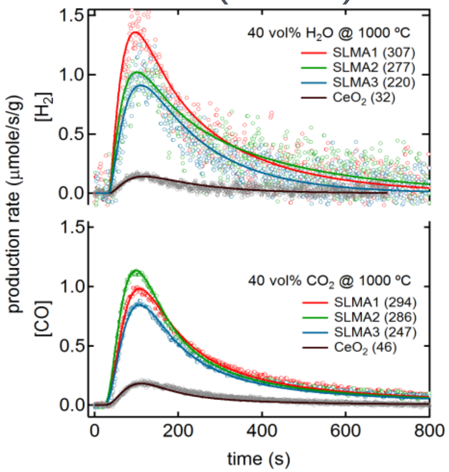


High Efficiency Solar Thermochemical Reactor for Hydrogen Production (STCH)

The STCH effort seeks to advance concentrated solar thermochemical hydrogen production technology through materials and engineering innovation.



- Challenge: Demonstrate that a high temperature, two-step thermochemical cycle to split water using concentrated solar energy can meet DOE targets for H_2 production cost and process efficiency
- Solution: Innovative reactor design coupled to novel redox materials
  - Achieve unprecedented solar-to-H_2 conversion efficiency using our particle-based cascading pressure receiver/reactor (CPR2)
  - Formulate high redox capacity, low cost active materials that meet H_2 production cost targets

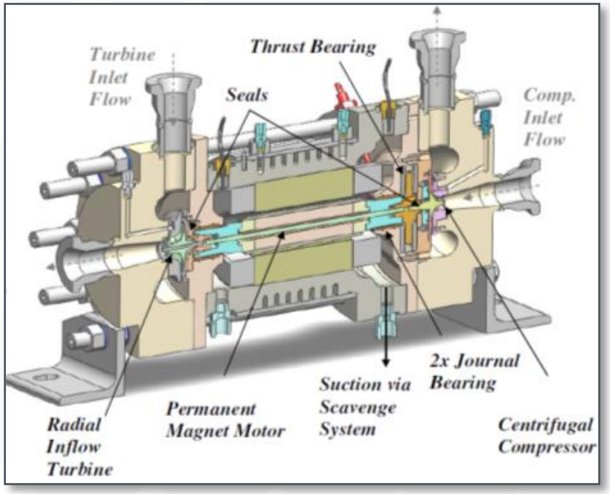


- Result: Designed a 3kW CPR2 prototype that when fabricated will demonstrate Sandia's *novel* and *scalable* reactor concept
- Result: Developed $SrLaMnAlO_{3-\delta}$ -based materials that have a fuel capacity one order of magnitude > CeO_2 (T_H = 1350 °C, T_L = 1000 °C)

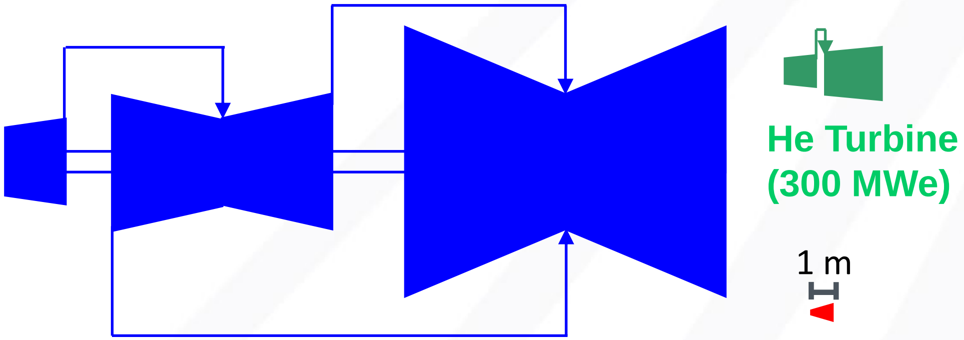
KEY PARTNERS: German Aerospace Center, Arizona State Univ., Bucknell Univ., Colorado School of Mines, Stanford

Supercritical CO_2 Brayton Cycle

- High efficiency
  - 50% thermal-to-electric
- Compact power conversion
  - Liquid-like densities with CO_2

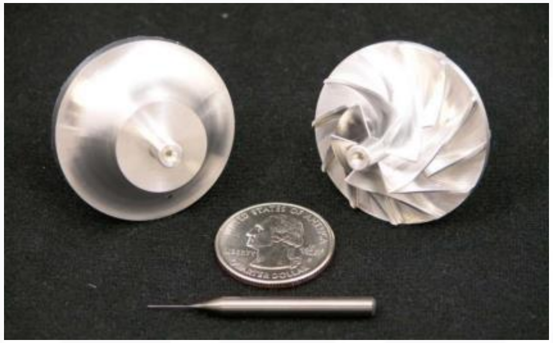


Sandia sCO_2 turbo-alternator-compressor (Conboy et al., 2013)



Steam Turbine (250 MWe)

S-CO_2
(300 MWe)



Compressor wheel for 150 kW_e sCO_2 Brayton cycle (SAND2010-0172)

Thank You