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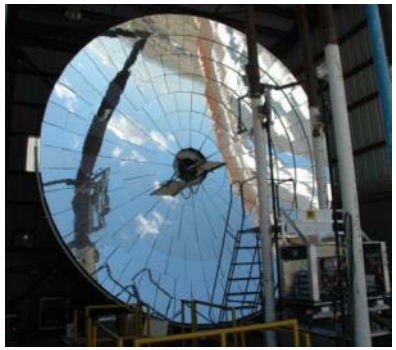


CSP Research and Development Activities at Sandia National Laboratories

June 27, 2013

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Presentation Outline

Sandia National Laboratories

I. NSTTF Capabilities

II. NSTTF Research Areas

III. What's Next

National Solar Testing Facility

Sandia National Laboratories

PV System Reliability

Dish Stirling R&D

Parabolic Trough R&D

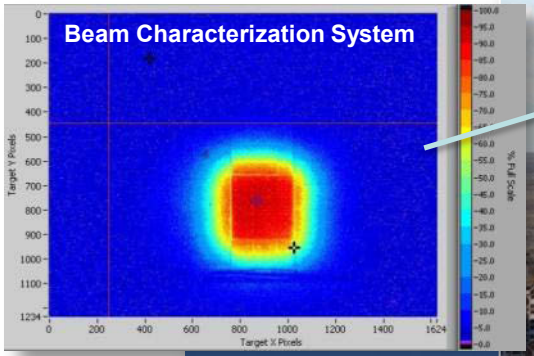
Solar Fuels and Selective Absorbers

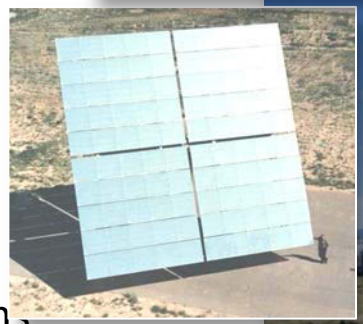
Thermal Energy Storage R&D

Receivers and Heliostats

Central Tower and Heliostat Field

- **Purpose:**
  - Test receivers, materials and systems under high solar flux conditions (6.2 MW_{th} incident power and 350 W/cm^2 peak irradiance)
- Heliostat field
  - 218 heliostats, each providing 37 m^2 reflective area
  - Completely re-mirrored with low-iron glass, > 95% solar-weighted reflectivity
- Central tower
  - 200 ft. tall with three test bays, including the rooftop
  - 100 ton capacity elevating module inside
  - Beam characterization system
- Heliostat test-bed
  - Full-scale heliostats
  - Novel designs
  - High performance reflective films





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Optics Lab

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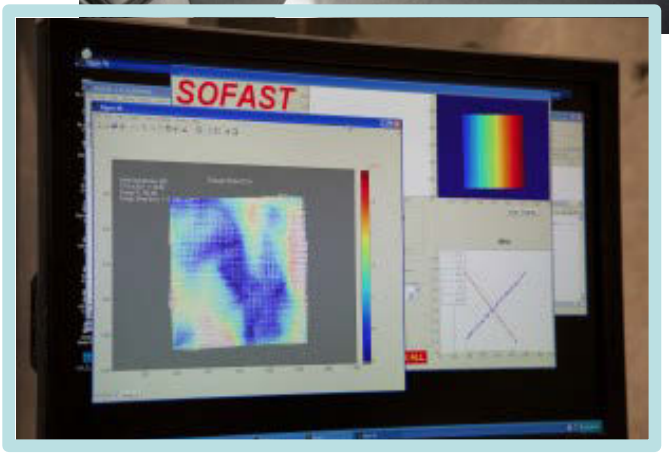
- **Purpose:**
  - Develop, demonstrate and deploy software & hardware tools that help maximize performance of CSP optical systems
- **Objectives:**
  - Provide a focused, cross-cutting effort in improving cost-effective optics for CSP systems
  - Develop and deploy advanced optical & system modeling tools that accurately and quickly aide in the evaluation of optical & opto/structural options
  - Develop and deploy advanced optical characterization & commissioning tools that enable and ensure high quality optics in a deployment environment
- **Research goals:**
  - Enable SunShot-capable optical technologies to be deployed cost effectively & measurably
  - Develop and extend optical tools for development & production environments, and assure quality optical system performance for all CSP technologies
  - Develop production ready and highly automated tools with specific emphasis on characterization & alignment tools
  - Develop modern systems analysis tools that incorporate real optical imperfections



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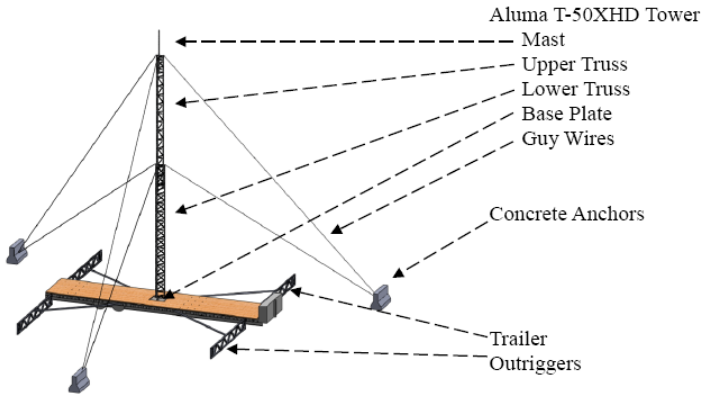
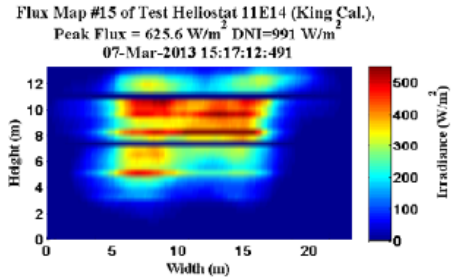
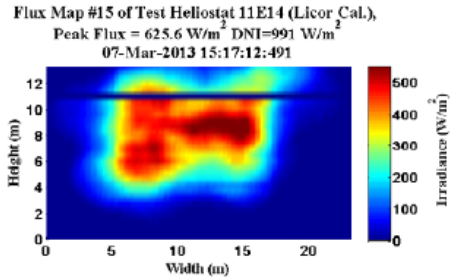
Long Range Flux Mapping

- **Purpose:**
  - Evaluate the performance of long-range developmental and deployed heliostats
- **Features and benefits:**
  - Large target stand equipped with an array of collimated pyranometers
  - Maps the flux profiles from long-range (up to 1 mile) heliostats
  - Evaluates beam shapes, peak flux, and facet alignments
  - Deployable test stand uses mostly COTS components and designed for rapid deployment a CSP installation site







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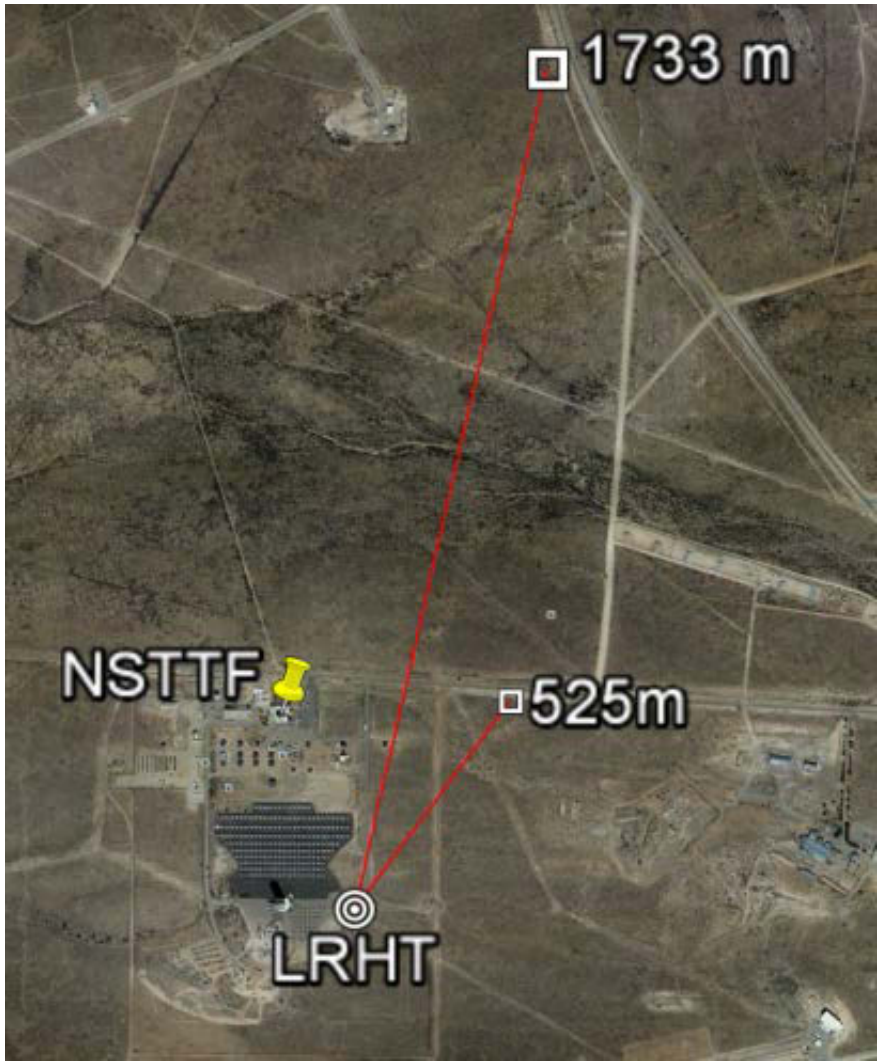
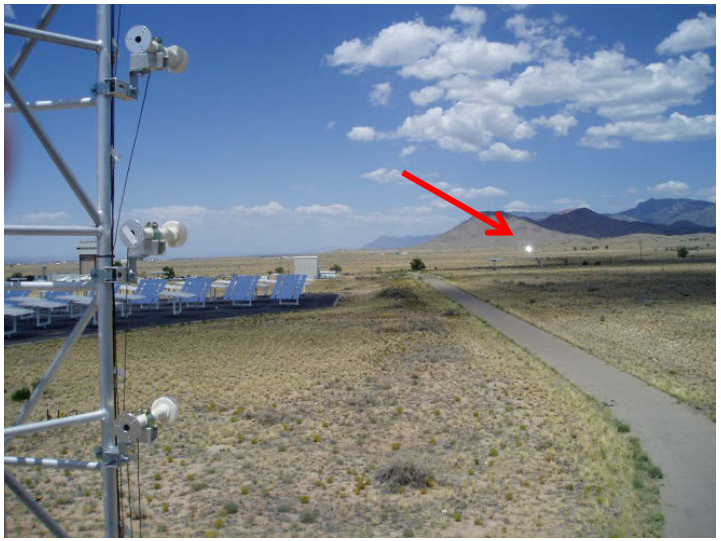
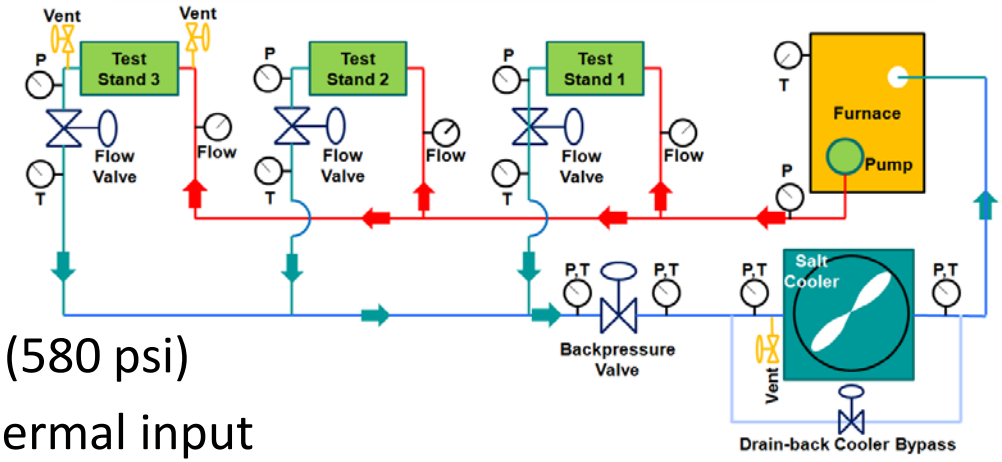
Long Distance Single Facet Tests





Molten Salt Test Loop

- **Purpose:**
  - Enable testing of molten salt hardware at high flow and high pressure over a range of temperatures
- **Features and capabilities:**
  - Three test stands
  - 60% $NaNO_3$ / 40% KNO_3 salt mixture
  - Flow rate: 1.5 m^3/min (400 gal/min)
  - Salt temperature range: 300 – 585°C (572 – 1085°F)
  - Maximum salt pressure: 40 bar (580 psi)
  - Removes up to 1.4 MW solar thermal input



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The Rotating Platform, or Aztrak, Precision Measurement System

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It has the following capabilities:

- **Ability to track sun in azimuth at 0 degrees incidence angle (eliminate off-axis cosine affects)**
- **Ability to track sun in azimuth at any constant incident angle (measure off-axis cosine affects)**

Azimuth tracking: resolution of 0.09 deg., accuracy of 0.30 deg.

Elevation tracking: Resolution of 0.04 deg.; accuracy of 0.08 deg.

- **Heat transfer fluid thermal stability at the test device of $\pm$ 0.2°C at temperatures up to 350°C at a flow rate of 55 $\pm$ 0.2 l/min for a 15 to 20 minute test window**

System is highly stable and adjustable to meet test requirements

Platform dimensions are 16.2 m long, 4.6 m wide, therefore capable of supporting collector modules with three receivers

Only one other facility in the world can test trough efficiencies up to 350°C

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Dish Test Area

- **Purpose:**
  - Allows industry partners to install full-scale solar dishes for long-term reliability testing and evaluation
- **Features and capabilities:**
  - Currently NSTTF site has ~~ten~~ two 30-kW dishes and six 3-kW Infinia dishes
  - NSTTF site also includes two Sandia-developed solar dishes that are available for research
  - Fully characterize short- and long-term performance

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Solar Furnace

- **Purpose:**
  - Perform materials and proof-of-concept testing, and calibrations
- **Features and capabilities:**
  - Furnace comprises of a primary heliostat, secondary concentrator, Louver for solar irradiance input control, and test table for experimentations and calibrations
  - 16 kW_t power, 600 W/cm^2 peak irradiance, and 3 cm spot at focus
  - Demonstrated the feasibility of the Sunshine-to-Petrol (S2P) initiative
  - Performed selective absorber testing and material screening
  - **The only place in the US that can provide solar calibrations for flux gauges**

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Software Analysis Tools

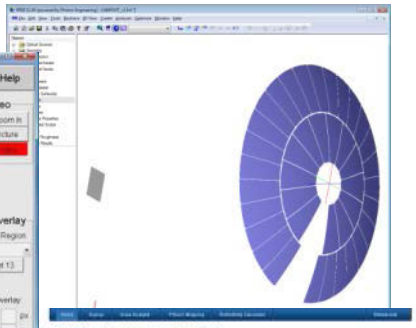
- Modeling and Analysis Tools
  - ASAP
  - FRED

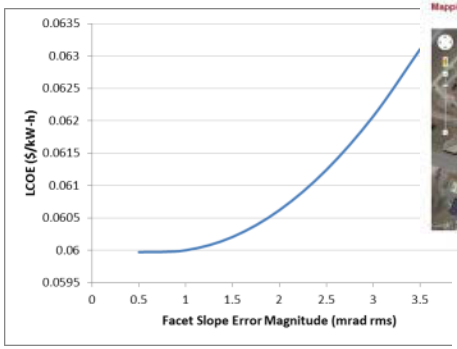
  Commercial optical ray tracing tools
  - HELIOS
  - DELSOL
  - CIRCE

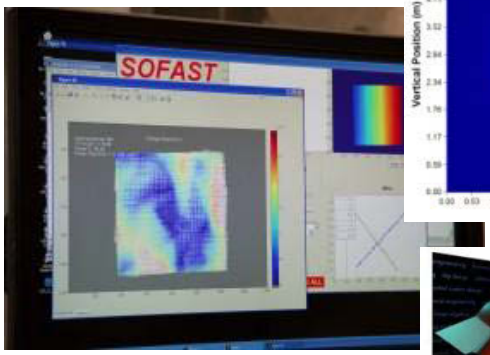
  Sandia developed CSP systems modeling and analysis code that use 'cone optics' techniques
  - SOFAST
  - HFACET
  - PHLUX
  - SGHAT

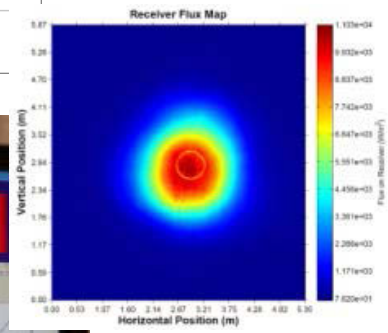
  Sandia developed code for optical characterization & analysis of CSP components
  - SolidWorks/APEX
  - ANSYS
  - MATLAB®

  Additional commercial software









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NSTTF Research Areas

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- Optical modeling, measurement and characterization
  - Gravity & wind impacts, alignment & solar tracking
- Low-cost, high efficiency collector design and characterization
- Advanced reflective materials and coatings
  - e.g. selective absorbers, high temperature & anti-soiling coatings
- Receiver design and analysis
  - High temperature receivers, gas- & liquid-based central receivers, solid particle receivers
- Thermal energy storage
  - Sensible storage, phase-change materials, thermochemical storage
- Solar fuels (e.g. hydrogen)
- System and component modeling and analysis
  - e.g. finite element analysis, computational fluid dynamics
  - Levelized cost of electricity (LCOE) estimation & optimization

Thermal Energy Storage

- **Benefits:**
  - Energy storage for increased capacity factors and dispatchability to meet demand curves
- **Challenges/Opportunities:**
  - Containment materials and interaction mechanisms
  - Material properties and corrosion
  - System design, modeling, and optimization
  - System interfaces
  - Subsystem concerns
    - Instrumentation
    - Flow management
    - Insulation
    - Containment
    - Pre-heating

Molten Salt Test Loop at Sandia

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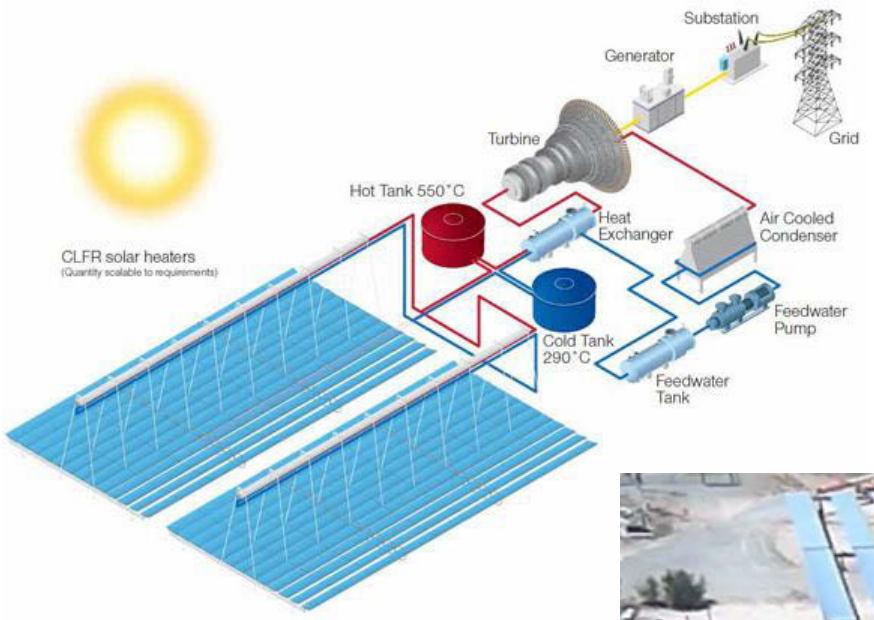
Areva Compact Linear Fresnel Test

- Areva will test a Compact Linear Fresnel system on the Molten Salt Test Loop (MSTL)
- This is the first-ever test of a CLF flowing molten salt
- MSTL will give realistic efficiency measurements, critical to Areva's ability to finance future power projects



Customer's CLF System

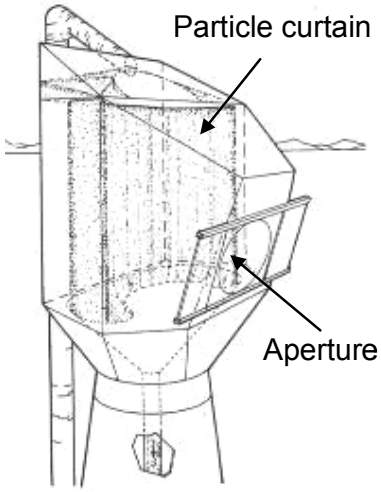
East Reflector Field

Foundations for Receiver Towers

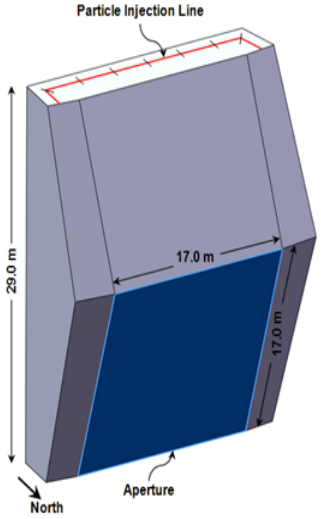
MSTL

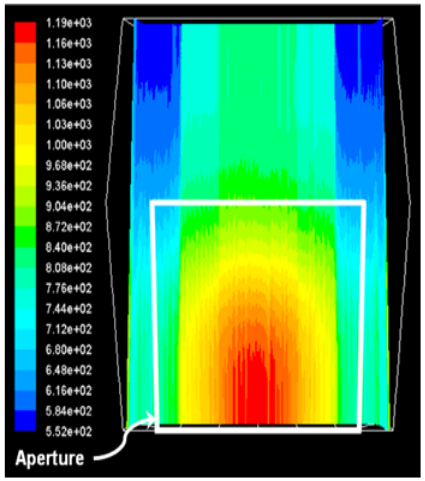
Falling Particle Receiver

- **Benefits:**
  - High temperatures (T > 700 °C) possible
  - Direct energy storage in the particles
  - Increased incident fluxes
- **Challenges/Opportunities:**
  - Particle attrition, wear, and conveyance
  - Particle solar absorption and emissivity
  - Particle/fluid heat exchange
  - Need to increase thermal efficiency (from 50% to 90%)



Falling particle receiver (Falcone et al., 1985)





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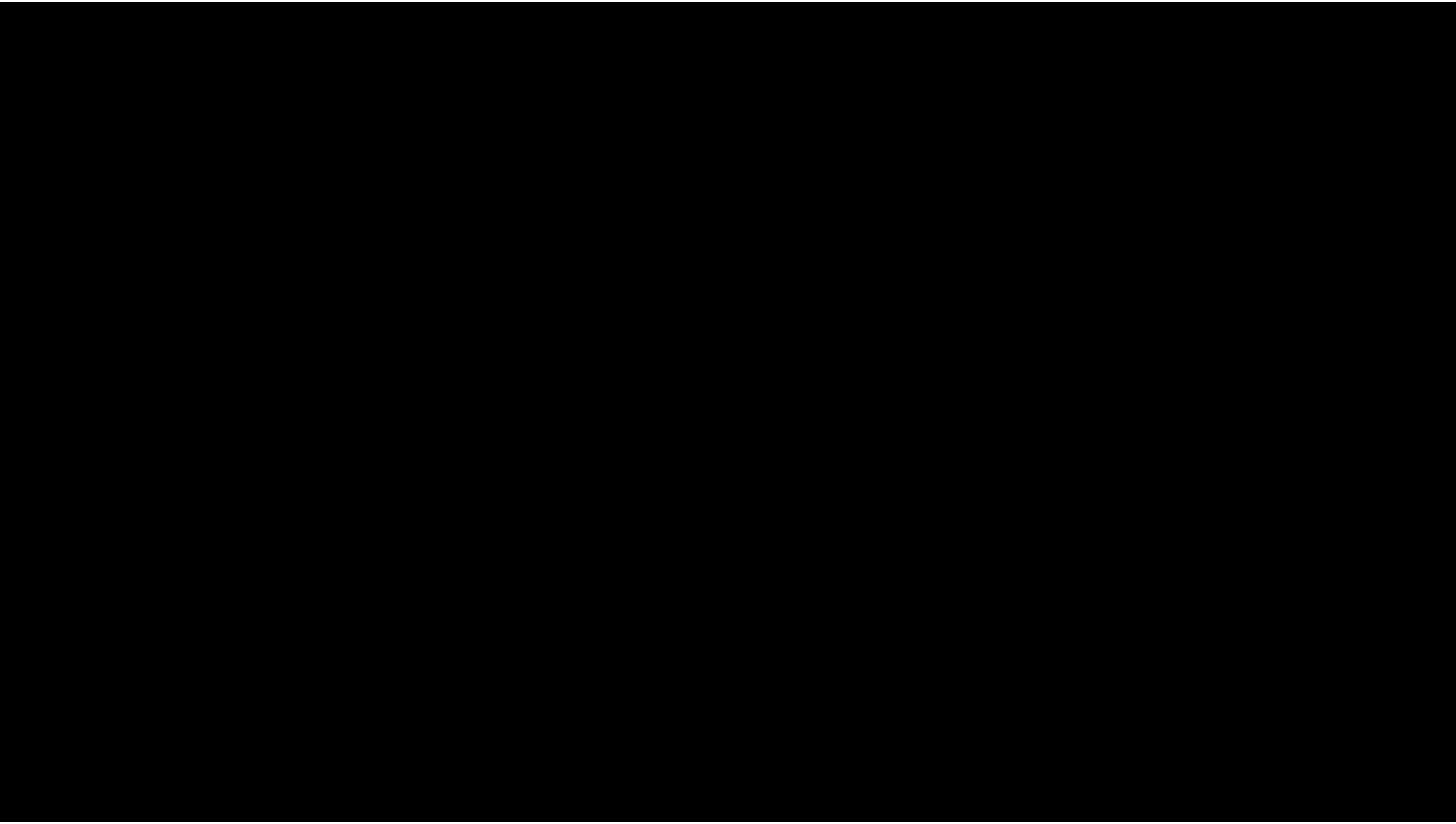
Prototype Receiver

∴ Current results show good particle stability with air curtain

Prototype Receiver



Dish-Engine with Energy Storage

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- Dish-Engines: High performance systems
  - Over 31% sunlight to grid efficiency
  - High temperature, concentration
- Needs storage
  - Match demand curves
  - Utilities/PUC's need to "value" evening generation
- Research Innovations at NSTTF
  - Isothermal storage and transport minimize exergy losses
  - Liquid sodium transferred between heat pipe and PCM storage
- Advantages
  - Balanced concentrator reduces cost
  - Spherical receiver optimizes cavity performance
  - Heat pipe input to engine demonstrated performance enhancement

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Sandia's R&D Projects Involvement

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- Cost reductions (by 75%) & improving efficiencies to reach **SunShot** goal of **$0.06/kW-h** with no tax credits**.** 15-18% of electricity from solar by 2030.
  - Cost reductions:
    - Solar collection field (e.g. heliostats, wiring/communication, reduce weight/materials)
    - Components (e.g. receivers, coatings, etc.)
    - Manufacturing, assembly, and installation
  - Improving efficiencies:
    - Optical collectors (also reduce soiling & water usage for O&M)
    - Higher operating temperatures -> materials studies, corrosion studies
    - Receivers (>650°C, >90% efficiency), heat exchangers
    - Power cycles (e.g. s-$C0_2$ & Brayton, >50% efficiency, dry cooling, hybrids)
- Thermal energy storage to increase capacity factors and meet demand curves (>95% exergetic efficiency)
  - Storage media (e.g. fluids, solid particles, chemical), material degradation, corrosion, storage methods, system design & modeling, subsystem design
- Systems analysis
  - Evaluate and validate the cost, performance, and durability of CSP technologies

Sandia is involved in areas that are circled in red.

Path Forward

Sandia National Laboratories

- Sandia's CSP capabilities span a wide spectrum
  - Existing infrastructure and skills
  - Upgraded heliostat field, beam characterization targets, MSTL, Rotating platform and Solar Furnace
  - Key additions to capabilities
    - Strategic additions to staff
    - New hardware: Falling particle receiver, long range heliostat testing etc.
    - Revamped modeling capabilities
- We welcome industry engagement
  - Visit our website www.energy.sandia.gov/?page_id=2445
  - or call (505) 284-2965