SunShot
U.S. Department of Energy

CSP Program Summit 2016

Los Alamos NATIONAL LABORATORY EST. 1943

NORWICH TECHNOLOGIES

High Temperature Heat Pipe Receiver for Parabolic Trough Collectors

Project Dates: October 1, 2015 to Sept 30, 2018

Project Budget: $3M

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energy.gov/sunshot

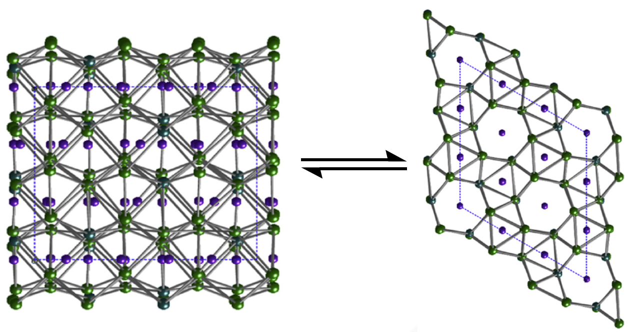
LA-UR-16-22615

LANL CSP Technology

Development of technologies to maximize system exergy and enable the use of high efficiency power cycles.

Thermochemical Storage

Low-cost solid state materials which undergo thermochemically-active thermal storage reaction



Heat Transfer Fluids

CX-500

- Clear colorless low-viscosity fluid
- -40°C gel point
- Thermally Stable to + 570°C

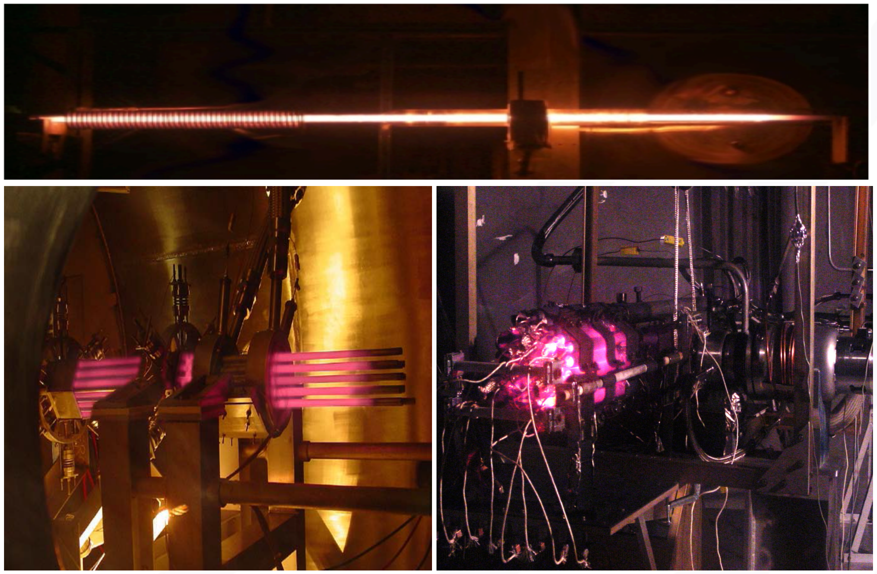
Conductivity, viscosity, specific heat comparable to DowTherm

Thermochemical Storage Technology

Heat Pipe Receiver Technology

Cooperative Partnership for New Trough Receiver Technology

Core Expertise in High Temperatures Heat Pipe Physics and Development

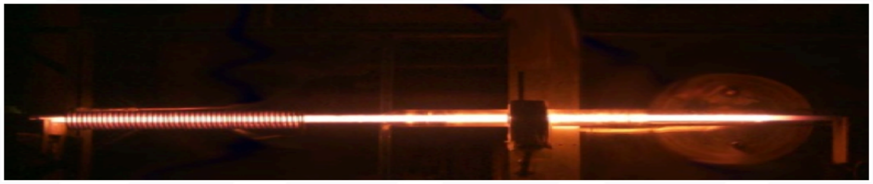


Core Expertise in Parabolic Trough Receiver Design

Project Goals

This work will

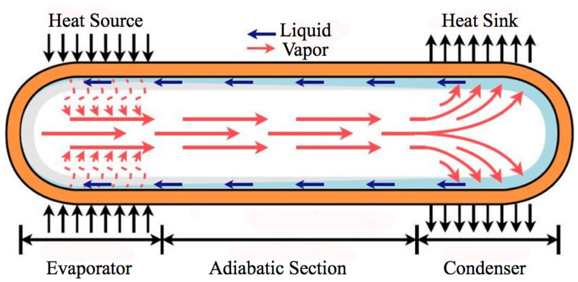
- Enable parabolic trough collector to operate at 750°C
- Reduce system complexity
- Mitigate unknowns associated with heat transfer fluid
- Maximize system exergy
- Enable the use of high efficiency power cycles
- Reduce the LCOE through
  - Elimination of unit operations
  - Net increase in power output
  - Expanded power output on diurnal and annual basis



Conceptual Technology Integration

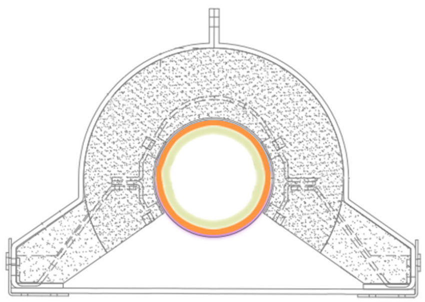
Proposed Heat Pipe Receiver

High L/D Heat Pipe System



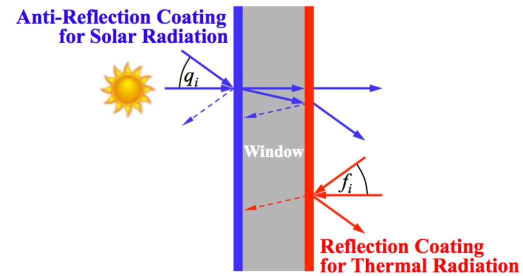
Sodium-stainless steel heat pipes with very high L/D used to produce an extended array. These heat pipes act as the prime solar capture and thermal transport medium

Norwich Technology Trough Receiver



Norwich Technologies' SunTrap™ receiver is an insulated, recessed solar radiation-collection designed to operate at high temperatures. This system will be optimized to enable operation at 750°C.

Solar Selective Window



A solar selective window maximizes the optical and thermal efficiency of the receiver. An AR-coating maximizes transmission of intermediate and low incidence angles. A wavelength selective coating transmits the solar spectrum and reflect blackbody radiation.

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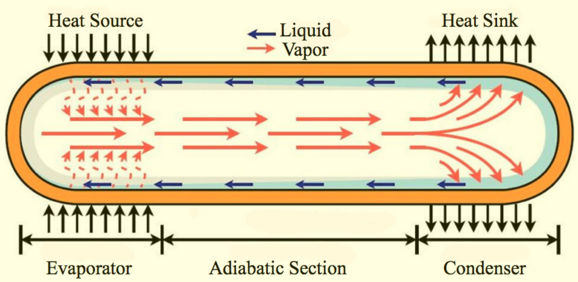
High Temperature Heat Pipe Receiver System

Proposed Heat Pipe Receiver

High L/D Heat Pipe System



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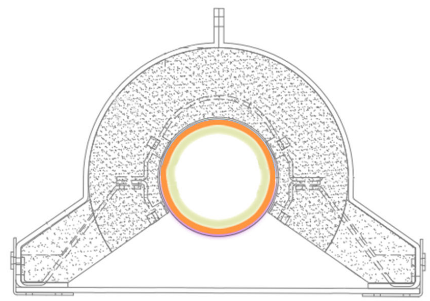
Norwich Technology Optical Cavity



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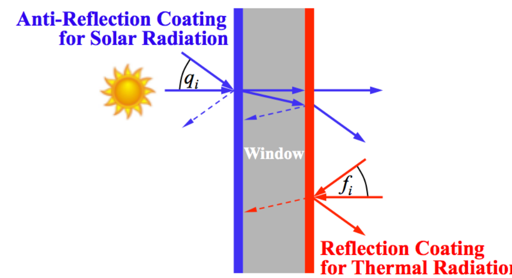

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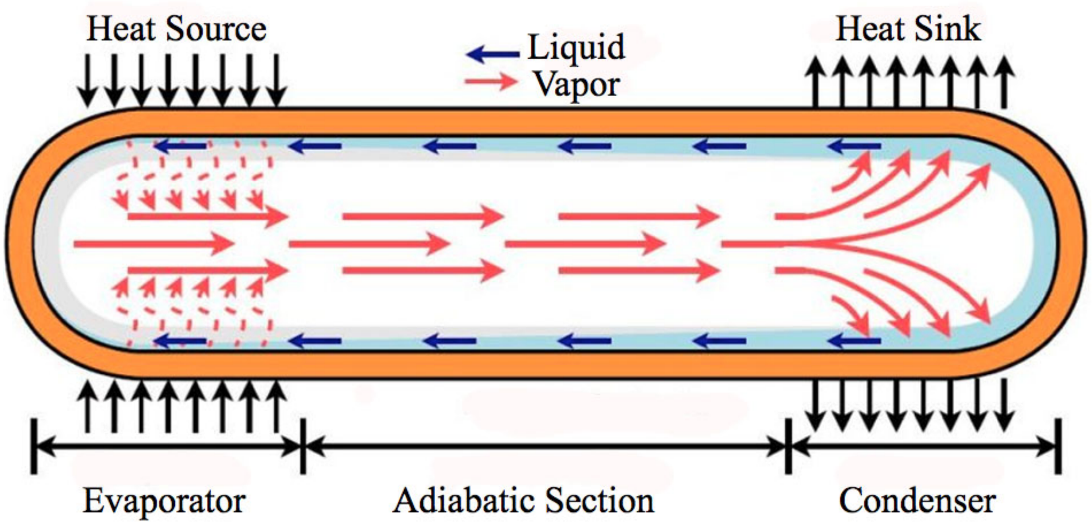
Heat Pipes



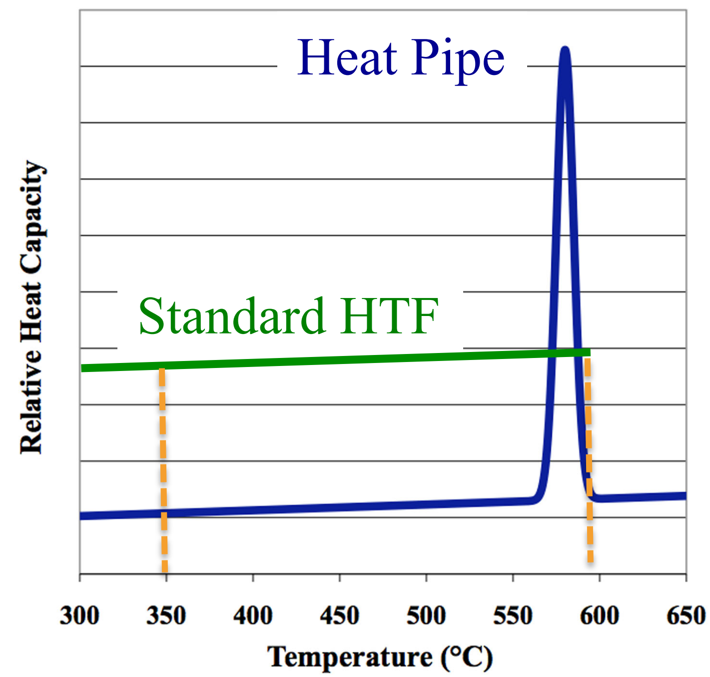
- Operates on principle of metal vaporization and vapor transport
- Capillary action draws condensate to evaporator
- Thermal energy captured as latent heat
- Very high concentrations lead to high receiver efficiency

Heat Pipes Systems Impacts

Key Properties of Heat Pipes

- TRL-10 with decades of operational history
- Low-maintenance
- Safety envelope:
  - Self extinguishing
  - non-propogation
- Maximizes system exergy
- Reduced heat exchanger size
- Myths
  - Heat Pipes are small.
  - Heat Pipes are expensive

Heat pipes maximize thermodynamic availability.



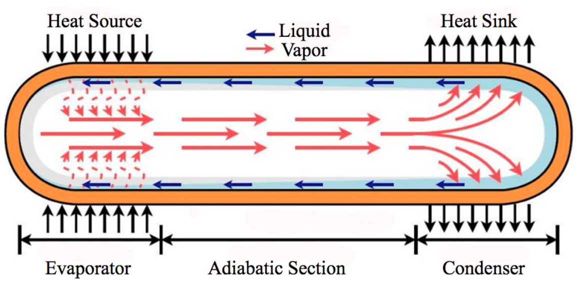
Heat Pipes-System Losses, Materials, and Unit Operations

Parasitic Losses		Heat Transfer Fluid	Heat Pipe
Fluid Pumping		5-10% of Net Power Plant Output	None-passive Operation
Heat Transfer Working Fluid		**Heat Transfer Fluid**	**Heat Pipe**
Chemical Composition	600°C	Unknown composition. Ionic Salts Molten metals, inert gas components	Potassium metal
	750°C		Sodium metal
	900°C		Sodium metal
Working Fluid Quantity		Tons	kilograms
Materials of Construction		**Heat Transfer Fluid**	**Heat Pipe**
Fluid Containment Alloy	600°C	Stainless Steel	Stainless Steel
	750°C	Super Alloy	Stainless Steel
	900°C	Super Alloy	Stainless Steel
Wall Thickness		mm	mm
Corrosion Rates		Microns per year	Microns per decade
Ancillary Systems and Equipment		**Heat Transfer Fluid**	**Heat Pipe**
Fluid Expansion Tanks		Required	Not Required
HTF Fluid Tanks		Required	Not Required
Pumps		Required – Unknown Composition	Not Required
Gaskets			Not Required
Seals			Not Required
Freeze Protection/Heat Tracing			Not Required
Safety		Major fire hazard	Heat pipe rupture self extinguishing

Key Innovation-Heat Pipes

Proposed Heat Pipe Receiver

High L/D Heat Pipe System



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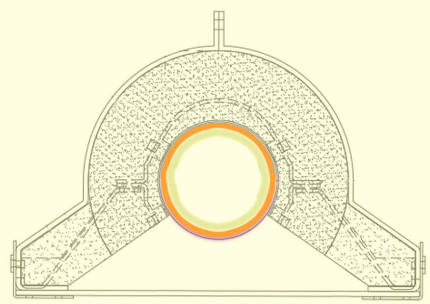

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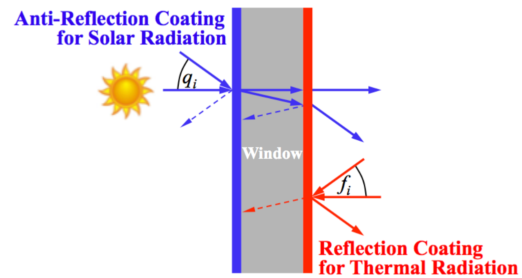
Solar Selective Window



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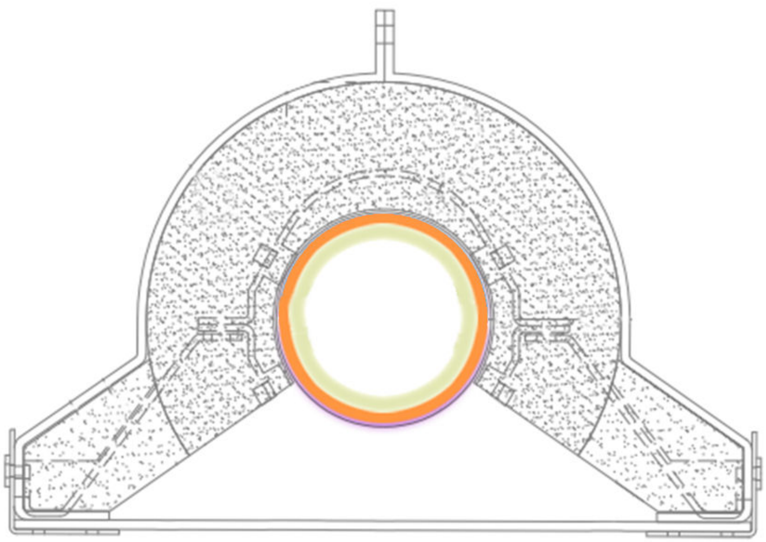
Key Innovation - SunTrap™ Cavity Receiver

- Flexible **receiver** geometry for parabolic-trough concentrating solar power (CSP)
- **Improved performance** at higher temperatures while **reducing** acquisition and operation & maintenance **costs**.



Innovation:

- **Encapsulated with insulation**

  state-of-the art insulation with thermal conductivity < 20 mW/m·K
- **Smaller radiating surface**

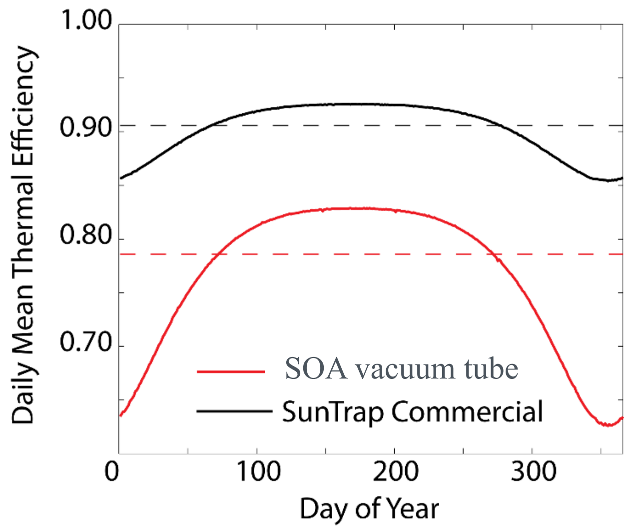
  reduces radiation losses at high T
- **Simplify structure**

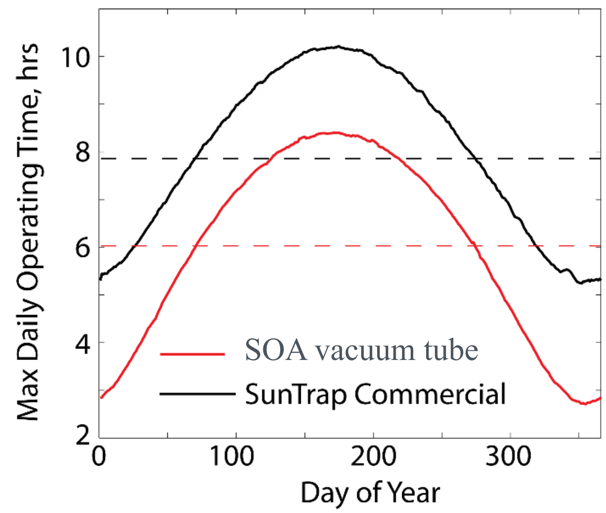
  increases reliability and reduces costs
- **Flexible design**

  accommodates a variety of absorber tube geometries including heat pipe

Key Innovation - SunTrap™ Cavity Receiver

SunTrap™ Cavity Receiver shows high efficiency and expands operating hours.





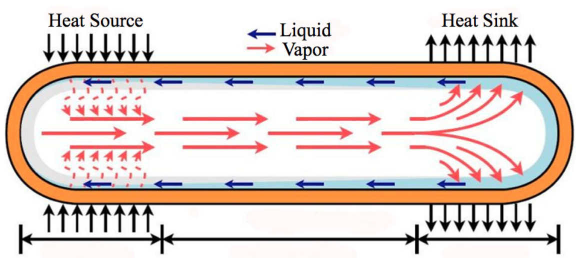
Suntrap 2nd Gen. prototype achieves >10% better overall performance than SOA vacuum tube at 650℃

- **Dramatic improvements in thermal efficiency** enables cost effective operation of troughs at higher temperatures
- Allows troughs to **compete with Power Towers** at higher temperatures

High Temperature Heat Pipe Receiver System

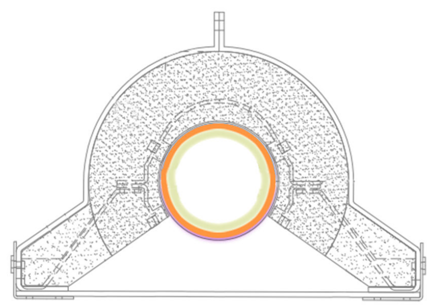
Proposed Heat Pipe Receiver

High L/D Heat Pipe System



Sodium-stainless steel heat pipes with very high L/D are interlaced producing an extended array. These heat pipes act as the prime solar capture and thermal transport medium

Norwich Technology Optical Cavity



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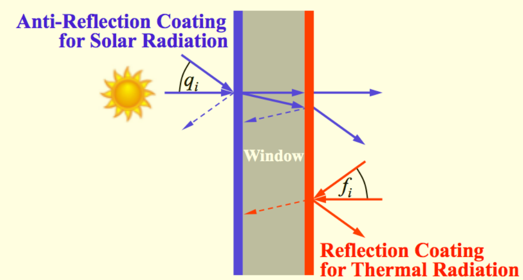

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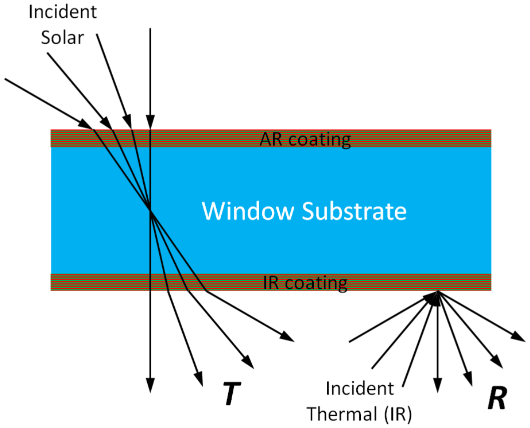
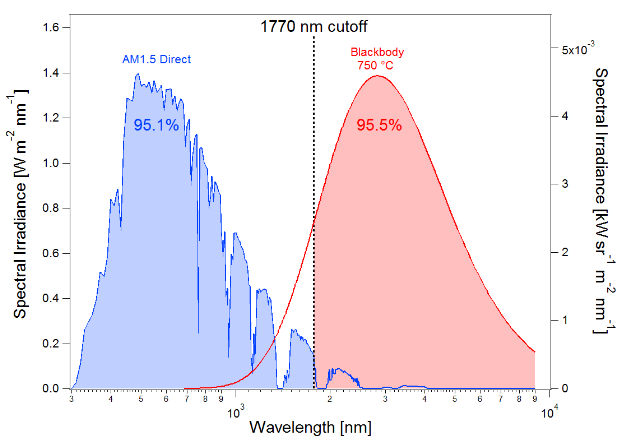
Proposed Work- Solar Selective Window

Parabolic trough solar selective window

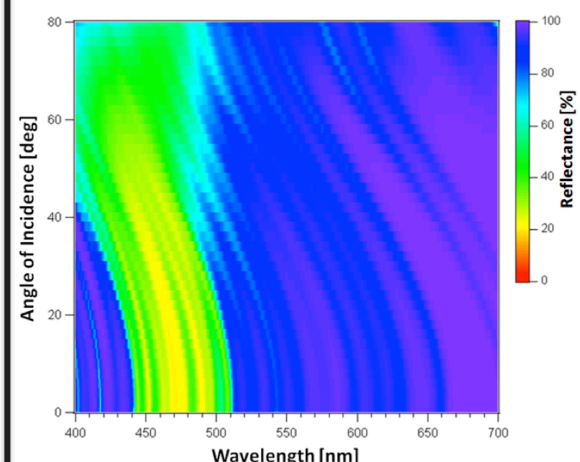
- Traditional AR coatings designed for normal incidence.
- Flat window strains the AR coating performance parameters
- Parabolic trough collectors experience the ±23.5º seasonal variation
- Parabolic trough receivers experience ~60°

New AR and NIR control at high incident angles



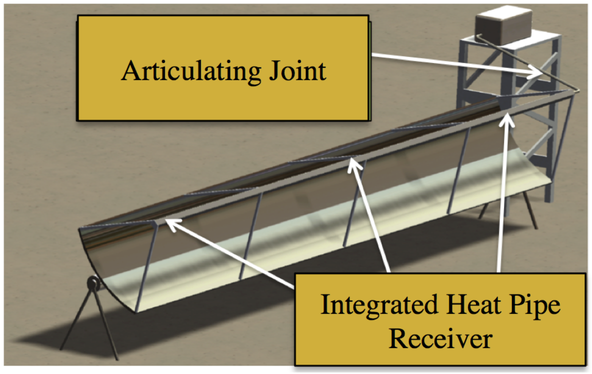


Leverage LANL expertise in highly constrained dielectric coatings



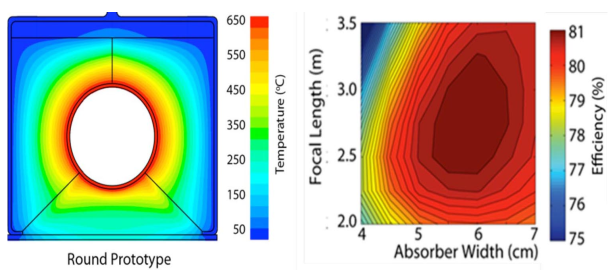
Phase 1 Technical Challenges

Heat Pipe System



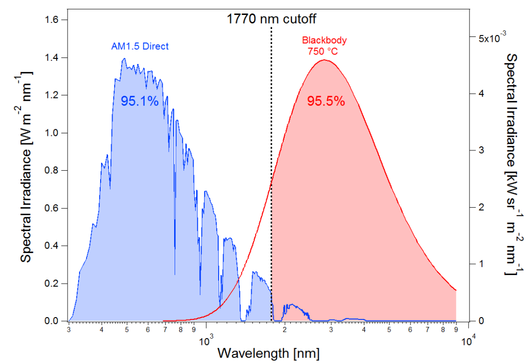
- High L/D Trough Heat Pipe
- Articulating Heat Pipe
- Thermal array connectivity

Norwich Technology Optical Cavity



- Optical model development.
- Thermal model development.
- Mechanical and structural model development.

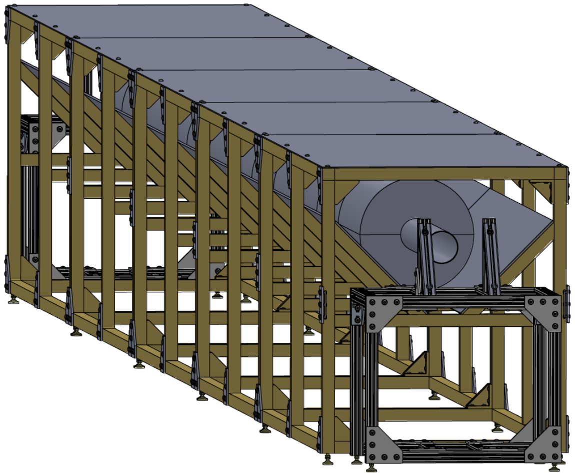
Solar Selective Window



- High incidence angle from mirror and solar altitude
- Matching target spectrum over wide angular range
- Coating design for short-pass filter

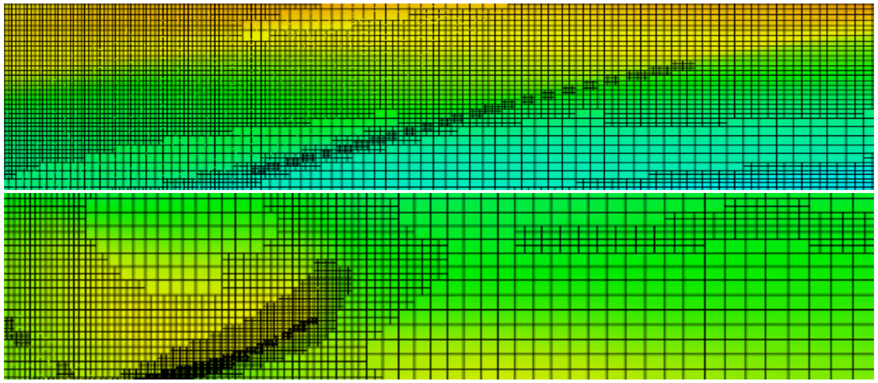
Technical Challenges for Systems Development and Integration

High L/D Heat Pipe



New Wick Designs

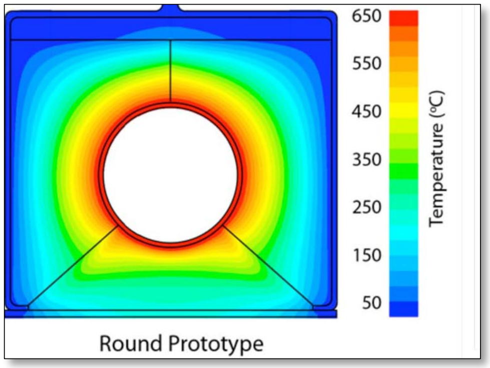
Heat Pipe Physics



Proposed Work-Receiver Development

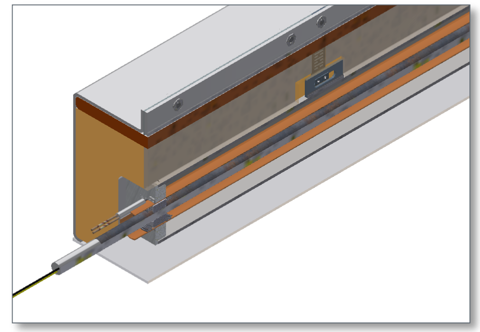
Modeling

developed SOA optical and thermal models



Analysis and Design

optimized design based on efficient analysis of 1000's of permutations

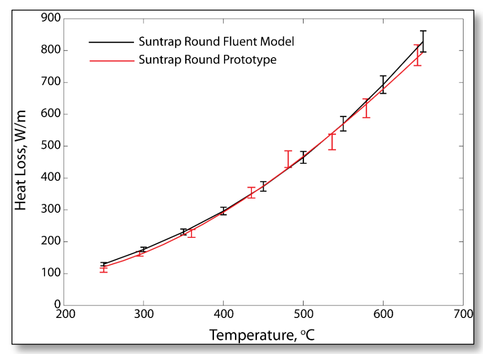


Assembly

built optical and thermal prototypes and test facilities and developed novel testing protocols

Testing and Validation

optical and thermal models rigorously validate high performance and models



Economic Analysis and LCOE Impact – Theoretical Maximum

- **Power cycle efficiency**
  - 38% for steam Rankine at 400°C
  - 46% for a $SCCO_2$ power cycle at 750°C.
- **Parasitic pumping costs are 5 to 10% of net power.**

Model Heat Transfer Medium Receiver Temperature	PTR70 Eutectic Oil 400°C	Heat pipe receiver Sodium Heat Pipe 700°C
η_{pump}	0.95	1.0
$\eta_{Receiver}$	0.71	0.71
η_{cycle}	0.38	0.46
η_{Total}	**0.257**	**.328**

Efficiency Improvement
5.2%
0%
21%
27%

Ignoring all thermodynamic losses, the maximum theoretical improvement over traditional parabolic trough CSP using a SC-CO_2 power cycle at 700°C is roughly 27%.

Strategic & Development Partners

Phase 1. System Design and Integration

Phase 2. Hardware Development

Key Milestone: Downselection of Field Demonstration Partners

Phase 3. System Testing and Field Deployment

Questions

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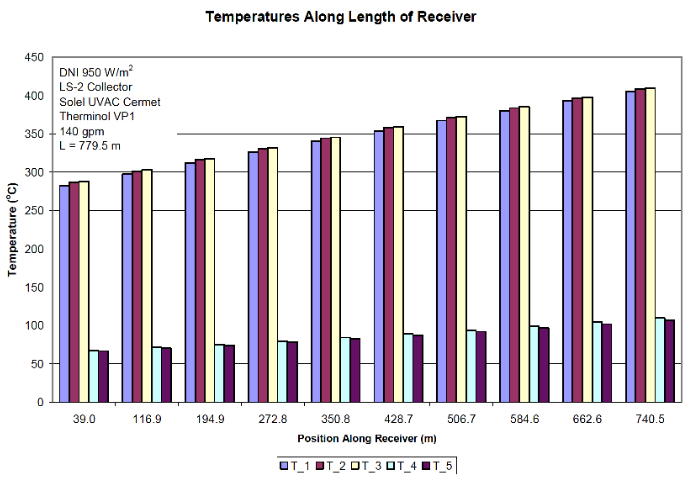
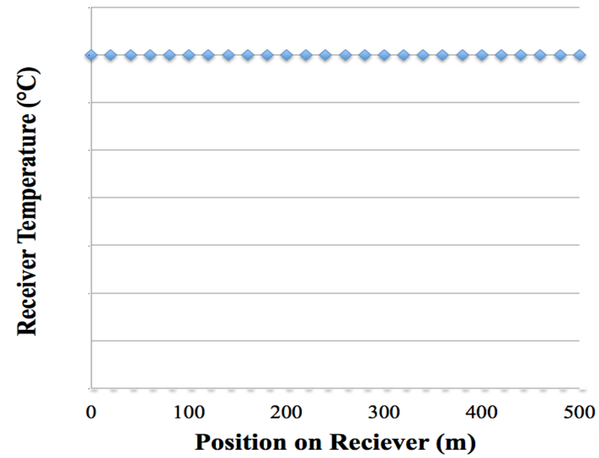
Differences in Thermal Capture and Loss

Traditional Thermal Capture Profile



R. Forristall "Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver" 2003 NREL/TP-550-34169

Heat Pipe Thermal Capture Profiles



- Heat Pipes show isothermal capture and release characteristics.
- Heat pipe systems length is not dictated by the length necessary to take HTF to temperature
- Temperature drop in a sensible heat HTF system results in a loss of energy and exergy.
- Temperature drop in a latent heat system results only in loss of exergy.