High Temperature Thermal Array for Next Generation Solar Thermal Power Production

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Presentation Outline

1. Los Alamos CSP Program Objectives
2. Technical Rationale
3. LANL Concentrated Solar ARRA Program
4. LDPD Project High Temperature Thermal Array
5. LDPD Project Goals and Technical Rationale
6. Technical Gaps for High Temperature Thermal Array
7. On-Going work and Technical Objectives

Los Alamos CSP Program Objectives

Development of technologies that maximize the thermodynamic availability of incident solar radiation delivered to power cycle.

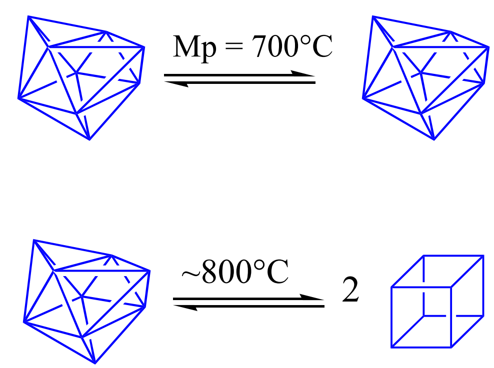
LCOE

Costs ↓ Capital / Operating / Installation

Power ↑ Net Power Output / System Efficiency

- Optimized Photon Capture
- Thermal Energy Storage (Latent/Thermochemical)
- Power Cycle Development (High Temperature Rankine)
- Thermal Energy Transport and Delivery

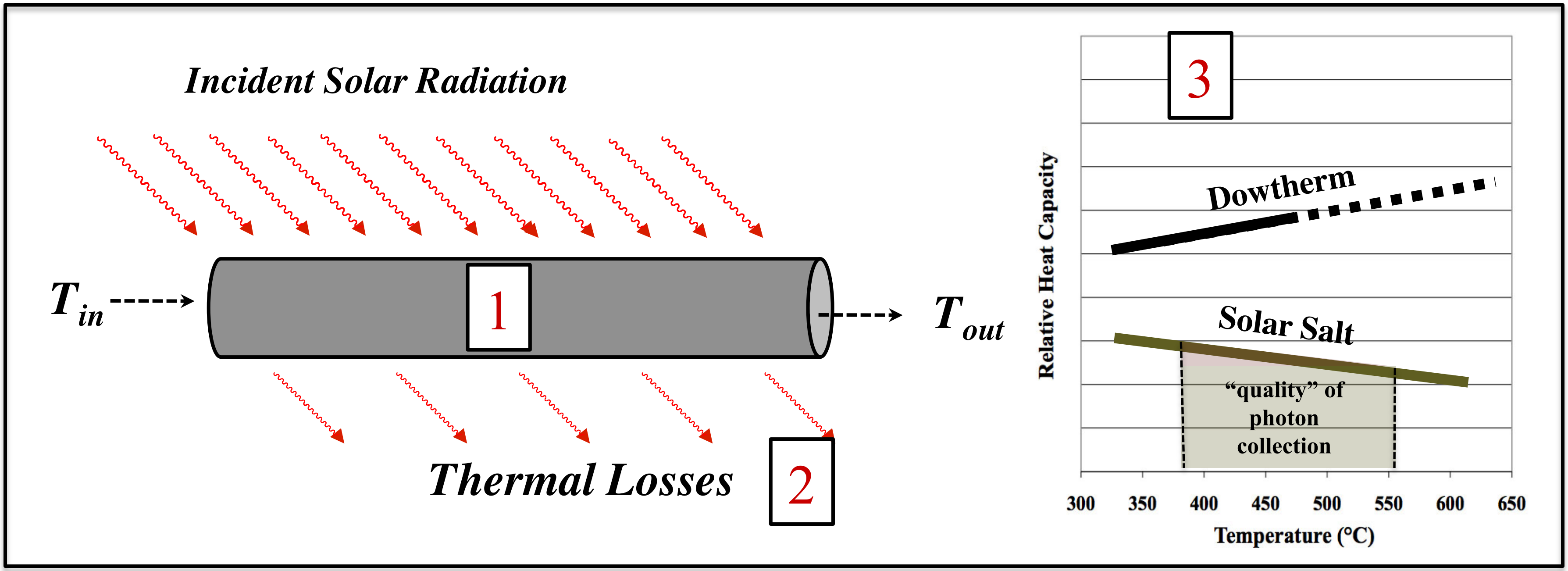
Combined Latent and Chemical Thermal Storage



Technical Rationale

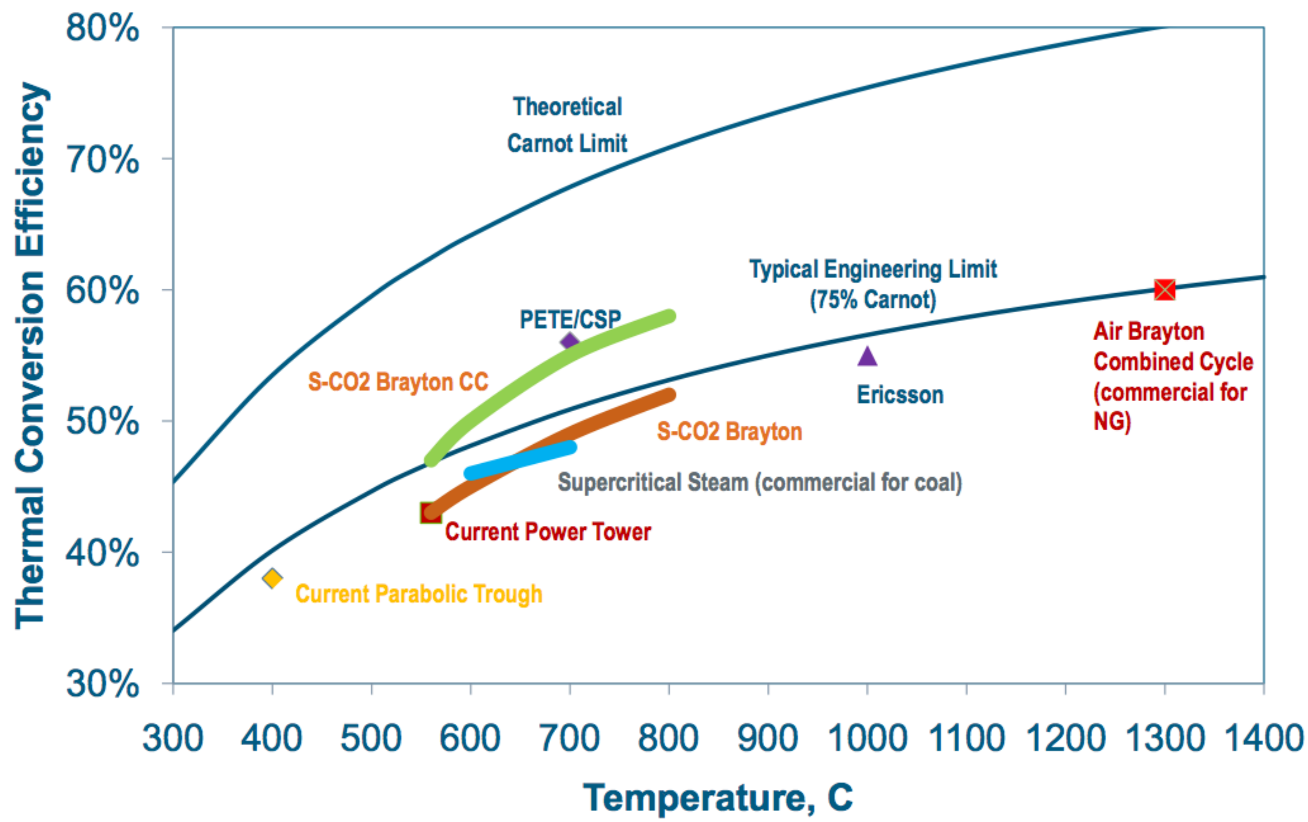
Photons don't care about temperature…

1. Photon energy assumes the thermodynamic state of the material impacted.
2. Energy capture (minus losses) results in incremental temperature changes.
3. Temperature change dictated by the thermal state of material impacted.



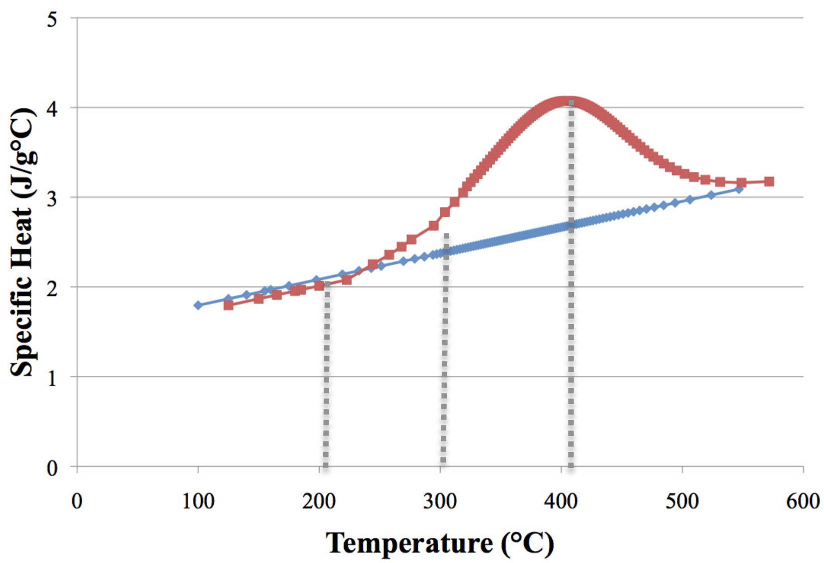
Technical Rationale

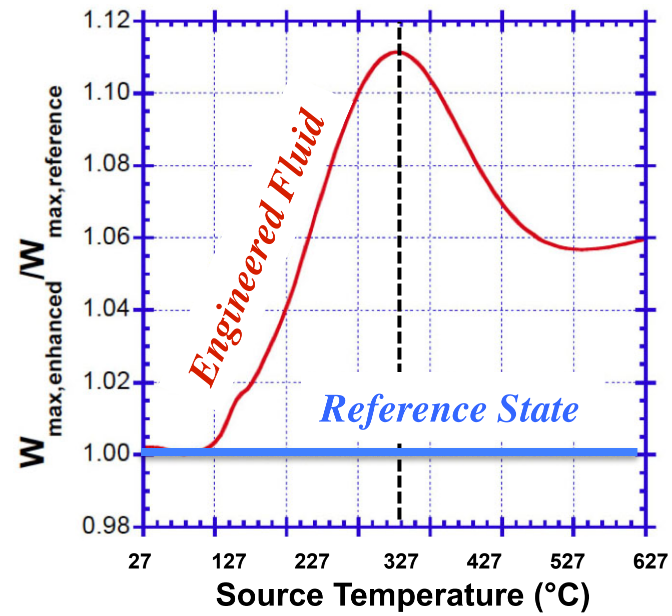
…but power cycles do.



LANL Concentrated Solar ARRA Program

Engineering HTF Specific heat yields modified power output.





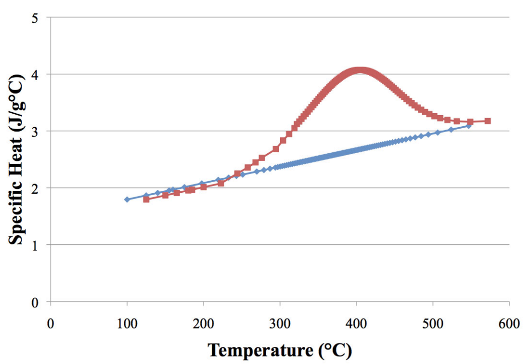
A 10% increase in shaft work is directly attributable to modified thermal heat capacity

ARRA Program Metrics and Program Goals

- **Development of High Thermal Stability HTF**

Fluid Property	DOE Program Metrics
Thermal Stability	> 500 °C
Vapor Pressure at 500°C	< 5 atm
Freezing Point	> 80 °C
Specific Gravity	0.7 – 1.7 g/cm^3
Heat Capacity to 500°C	2 – 5 J/g·°C
Viscosity to 500°C	~ 1 cP

- **Chemically Engineer HTF Heat Capacity**



- **Validate Fluid and Performance Characteristics**

LANL CX500 fluid developed under ARRA

Fluid Properties

- Clear colorless low-viscosity fluid
- -40°C gel point
- Thermally Stable to + 550°C.

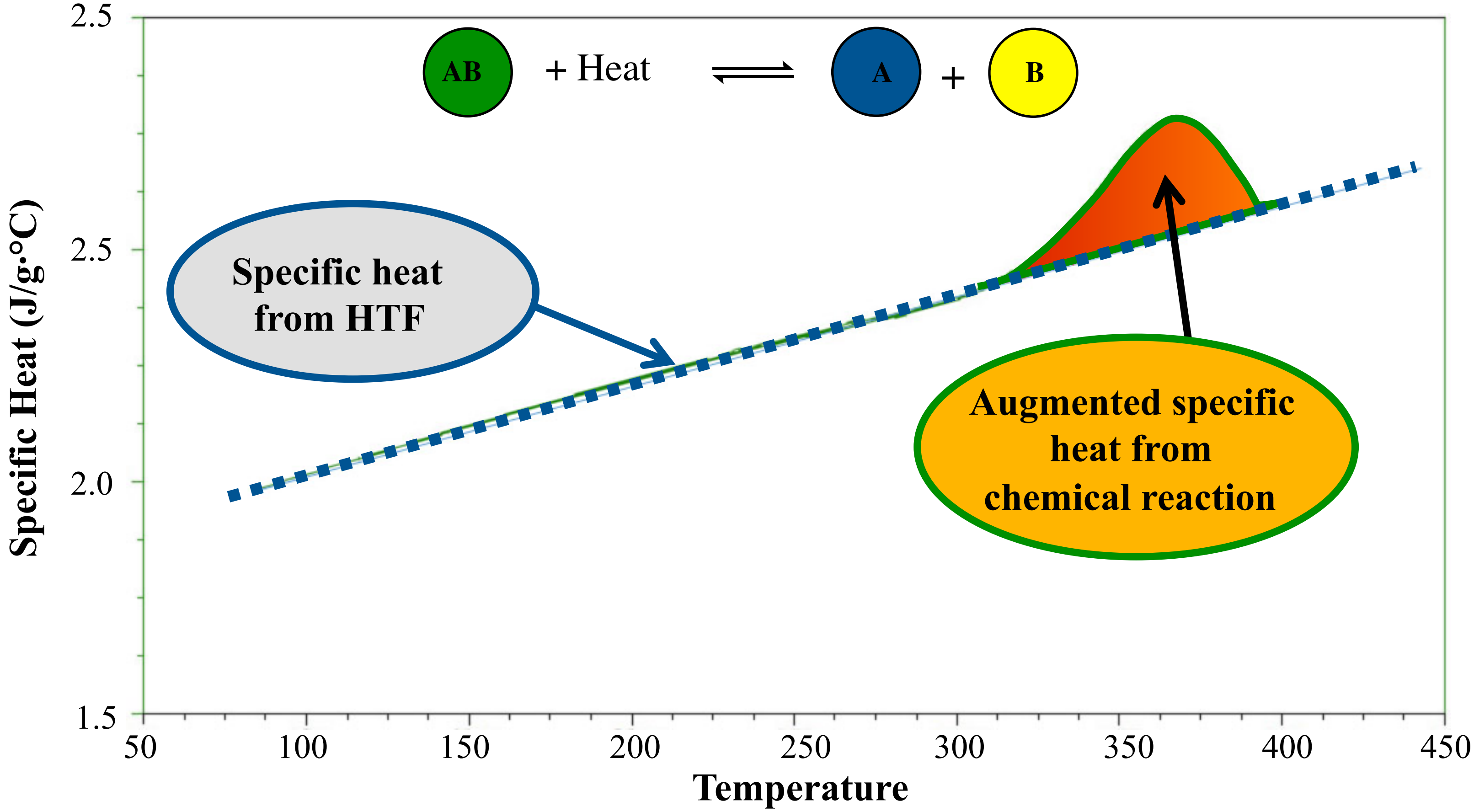
Thermal and Processing Properties

- Thermally cycled 4000 times from 300 to 550°C over a period of 52 weeks
- Prolonged exposure at 530°C for 180 days
- No hydrogen evolution observed during thermal processing.
- Corrosion properties comparable to Dowtherm and Syltherm through ASTM D 1384
  - 304SS, 316SS, 321SS, Hastelloy, Haynes Inconel
- Conductivity, viscosity, specific heat comparable to DowTherm

Environmental and Availability

- Exempt from Federal VOC regulations and California (CARB)
- Starting material produced in megaton quantities.
- Price point comparable to Syltherm 800.

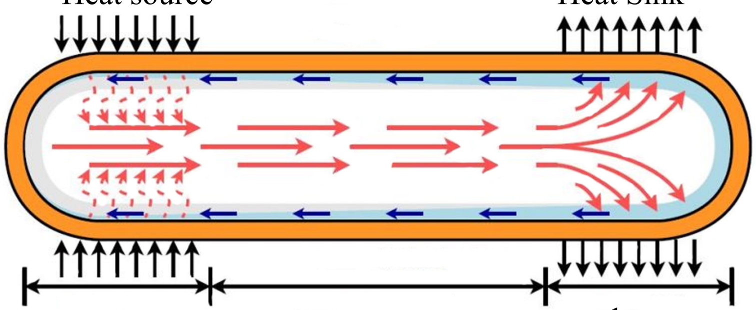
Augmentation of HTF Specific Heat



Chemical reaction reversible but decomposition noted after 50 cycles

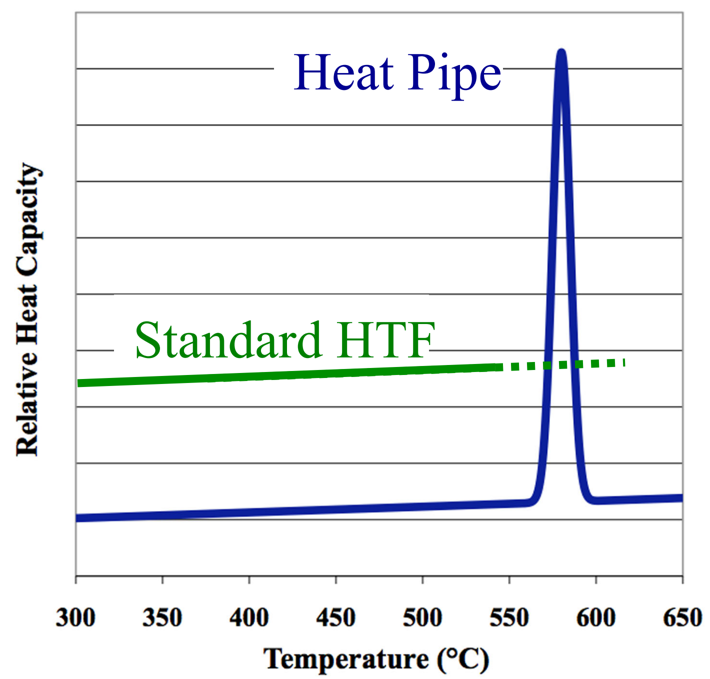
High Temperature Thermal Array

Heat Pipe



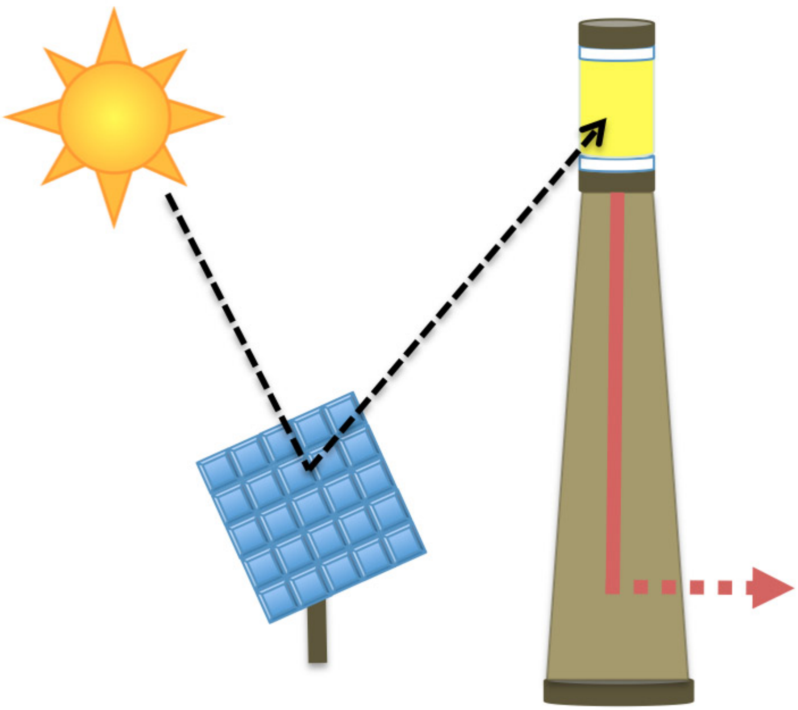
- Operates on principle of metal vaporization.
- Capillary action draws condensate to evaporator.
- Thermal energy captured as latent heat.
- Fastest method to transport thermal energy.
- Traditionally small and subject to gravity limitations.

Heat pipes maximize thermodynamic availability.



LDPD Project Objectives

LANL has developed a method to overcome traditional countergravity limitations which enables the construction of a heat pipe-based system suitable for megawatt-scale CSP tower system.



Project Goal: Development of technical knowledge gaps for heat pipe operation, heat pipe design and material science gaps to enable the cost-effective fabrication of a 300 ft CSP heat pipe-based tower operating at 1200°C.

Advantages of Thermal Array

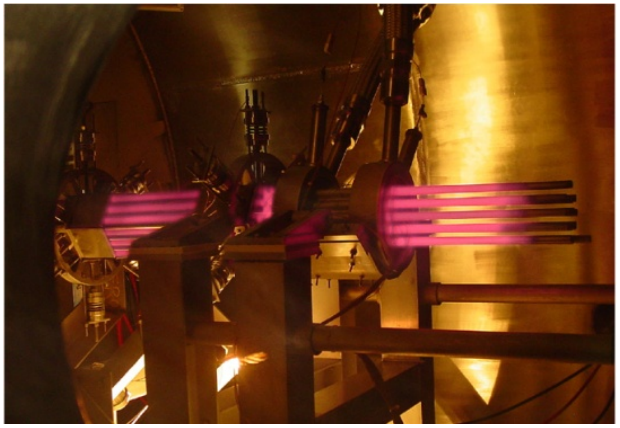
		Heat Transfer Fluid	Heat Pipe
Fluid expansion tanks		Yes	None
Current Temperature Limits		600°C	1350°C
Heat Tracing		Yes	None
HTF Storage Tanks		Yes	None
Pumps, gaskets, seals		Yes	None
Thermal Storage Compatibility	Sensible	Yes	-
	Latent	Yes	Yes
	Chemical	Yes	Yes

Advantages of Thermal Array

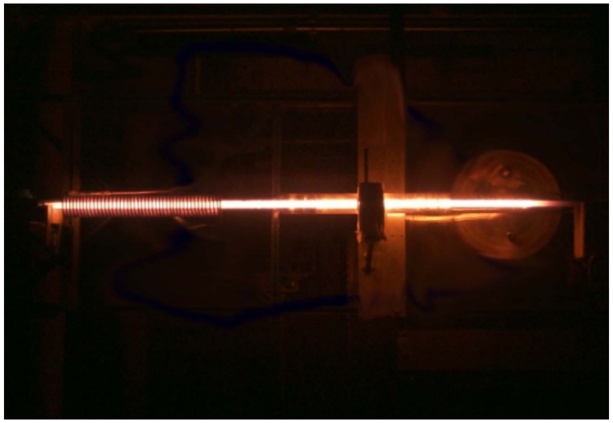
		Heat Transfer Fluid	Heat Pipe
Operational Temperature		-30 to 550°C	-220 to 2500°C
Working Fluid Composition	650°C	Unknown composition. Ionic salts, molten metals, inert gas compositions	Potassium
	800°C		Sodium
	1000 C		Sodium/Lithium
	1200 °C		Lithium
Working Fluid Quantities		Tons	Kilograms
Materials of Construction	650°C	Stainless Steel	Stainless Steel
	800°C	Superalloy	Stainless Steel
	1000 C	Refractory Metal	Superalloy
	1200 °C	Refractory Metal	Refractory Metal
Typical Wall Thickness		mm	µm
Corrosion Rates		Microns per year	Nanometers per year

Major Technical Gaps and Challenges

- Heat Pipe Wick
- Counter-gravity Physics and Operations.
- Heat Pipe Start-Up and Thermal Cycling
- Thermal Array Construction Methods
- Field Scale System Design
- Field Deployment and Construction Method



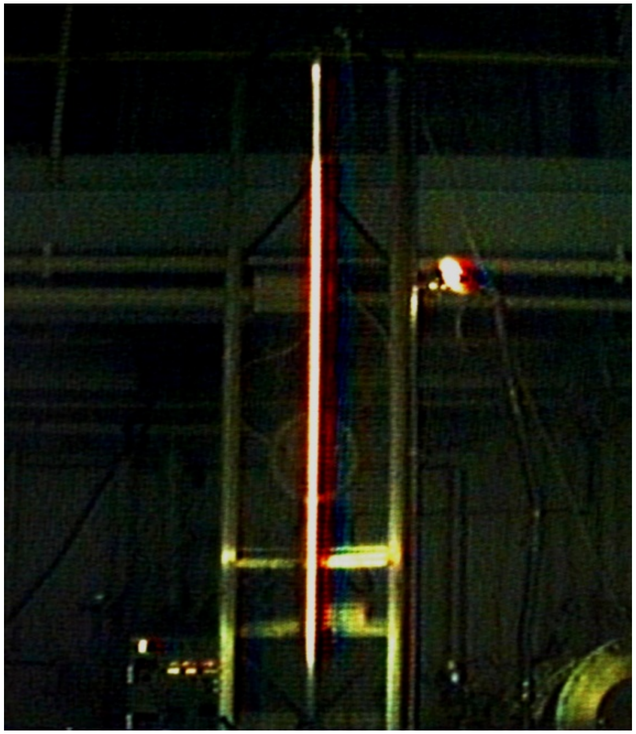
Heat pipe array operating at 800°C



Thermal cycling studies operating at 1200°C.

Phase 1: Counter-gravity Physics and Operations.

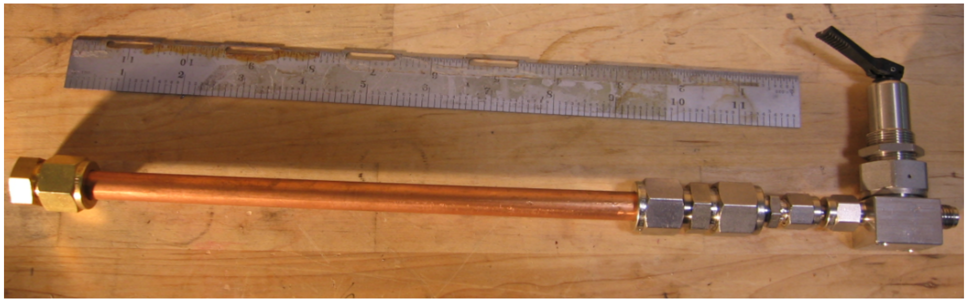
- **Vertical counter-gravity heat transport is the most difficult orientation**
  - Requires a wick structure with small pore size and free of defects
  - Capillary limit is reached at a lower power than in horizontal operation
- **Counter-gravity operation is required for heat pipe use in CSP towers**
  - Full characterization of counter-gravity physics and operation is essential for program success



Lithium heat pipe operating at 1373 K with evaporator above condenser.

Phase 1: Counter-gravity Physics and Operations.

- **Scaling heat pipe in development utilizing well understood with system design parameters**



- **Counter-gravity operation is required for heat pipe use in CSP towers**
  - A test bed is developed to allow detailed performance analysis of heat pipes and heat pipe modules.
  - Instrumented heat pipes (both scaling and refractory) to be tested at various angles and thermal cycling.
  - Resistive and induction heating coupled with gas calorimetry.

Phase 1: Start-up and Thermal Cycling

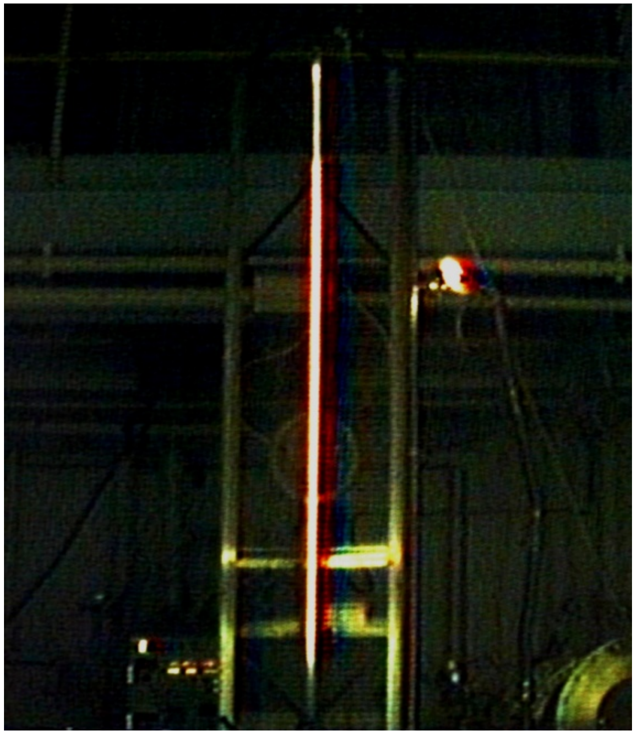
Demonstration of counter-gravity start

- On shut-down, wick structure de-wets and metal solidifies.

- Repriming Technical Paths
  - passive fluid dynamic techniques
  - electromagentic priming

- Room-temperature prototype for passive start-up is being assembled for test

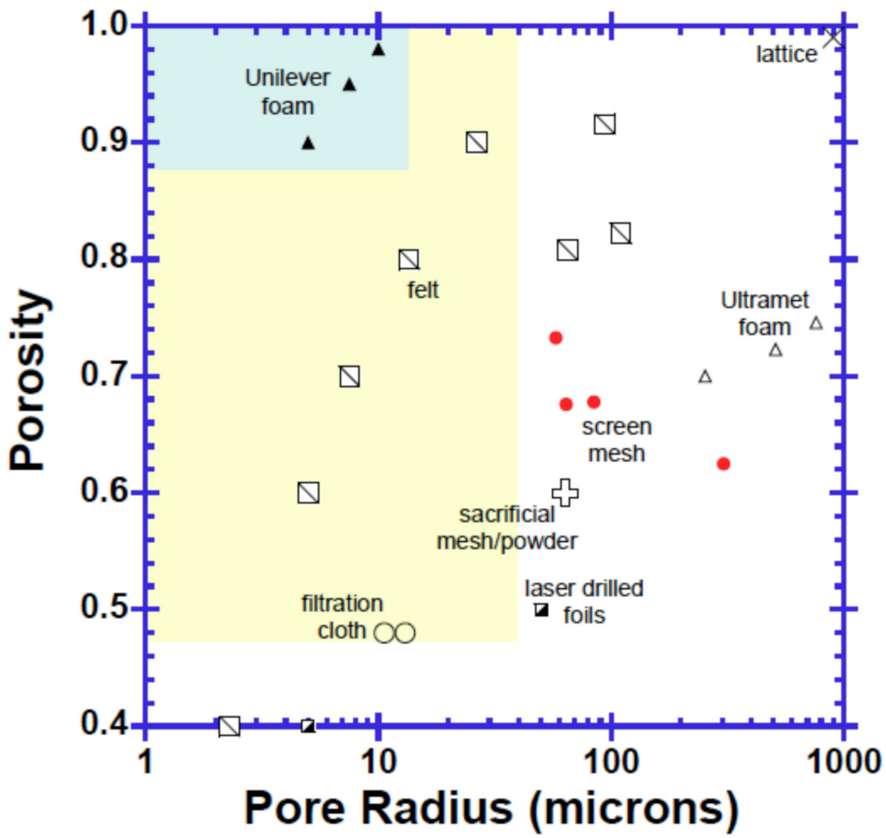
- Unique artery system passively primes the wick structure



Lithium heat pipe operating at 1373 K with evaporator above condenser.

Phase 1: Heat Pipe Wick Development.

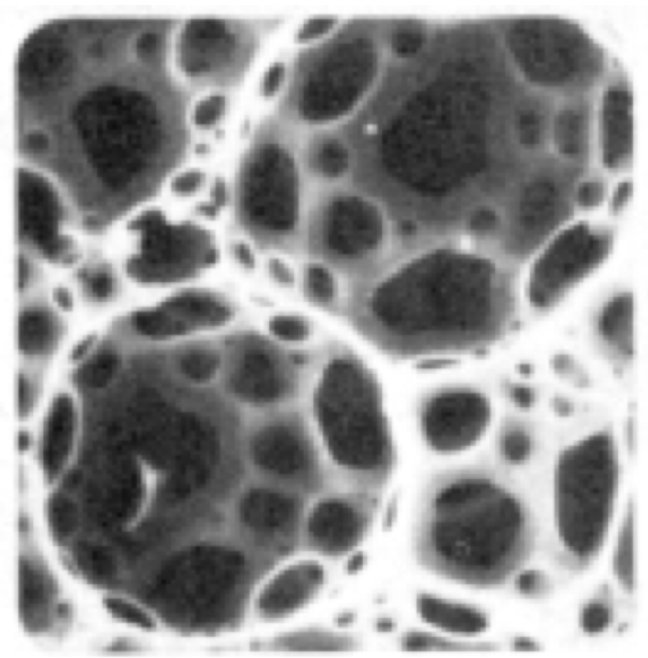
Current wick structures are not optimized for cost effective Thermal Array.



- Wick porosity and pore radius are intimately tied to system performance and cost effective system design
- Small pore radius increases wick performance.
- High porosity increases liquid metal flow rates
- High porosity and small pore radius ensures low Thermal Array system cost.

Phase 1: Heat Pipe Wick Development.

Current wick structures are not optimized for cost effective Thermal Array.



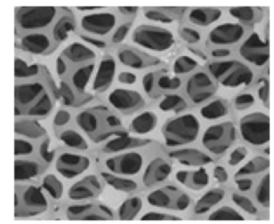
Impregnate polyurethane foam of desired pore size with resin

↓

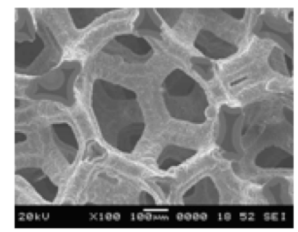
Pyrolize to form reticulated vitreous carbon foam

↓

Infiltrate reticulated vitreous carbon foam with structural ceramic or metal material to desired density to form refractory open-cell foam (70–90% open porosity)



Reticulated vitreous carbon foam



Refractory open-cell foam

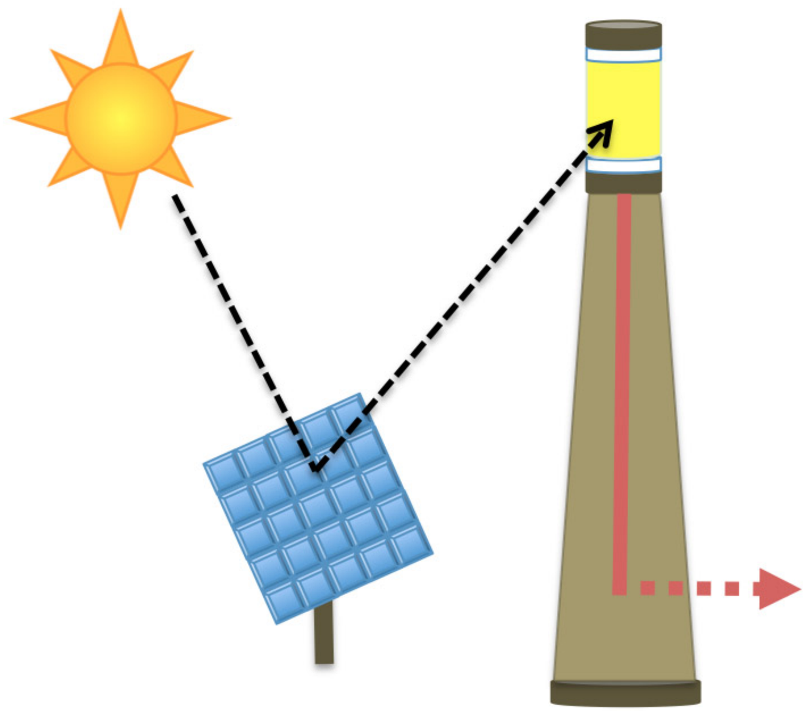
Recent advancements in deposition of refractory metal on sacrificial polymeric substrates enables a host of new wick compositions to be developed.

LA-UR 13-22800

Phase 2 and 3.

Phase 2

Wick development
Countergravity Physics and Operation
Heat Pipe Start-Up and Thermal Cycling
Field Assembly Technique Development



Phase 3.

Bench-scaled Thermal Array Fabrication
Performance testing
Field-scale system design and deployment

Questions?

Photo taken of Los Alamos National Laboratory from Pajarito Mountain.