Low-Cost Dispatchable Heat for Small-Scale Solar-Thermal Desalination Systems

SETO SUMMIT 2019

March 18,19, 2019

UNIVERSITY OF CALIFORNIA
UCMERCED

Contents

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Nonimaging solar optics

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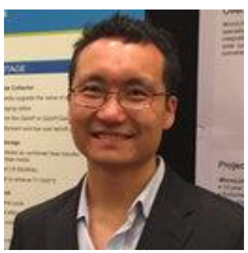
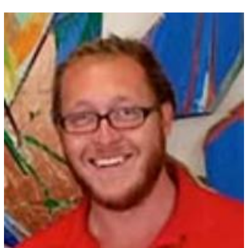


Lun Jiang
Project Scientist
ICPC Manufacturing



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Thermal Energy Storage

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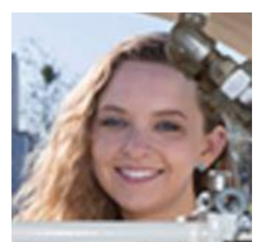
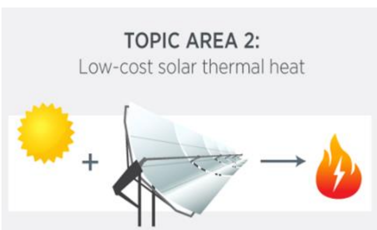


Jordyn Brinkley
PhD Student
ICPC Design, Simulation

Solar Desalination Program

<table>
<tr><th>Topic Area</th><th>Description</th><th>Metric</th><th>UC Merced</th></tr>
<tr><td rowspan="4">2. Low-cost solar thermal heat
- small scale

</td><td>1. Levelized cost of heat (LCOH)</td><td>< $0.015</td><td>$0.015</td></tr>
<tr><td>2. Temperature of delivered heat</td><td>120 °C</td><td>120 °C</td></tr>
<tr><td>3. Mobility</td><td>Transport to multiple locations</td><td>Transport to multiple locations</td></tr>
<tr><td>4. System Lifetime</td><td>> 25 years</td><td>25 years</td></tr>
</table>

Based on our modelling and system design to date, we expect our ICPC + TES solar system will meet the FOA targets.

Project Objectives

Develop, prototype, test

- Low-cost non-tracking solar thermal collector with ≥64% solar-to-thermal efficiency @ 150 °C
- Low-cost phase change thermal energy storage (TES) with ≥ 120 °C extracted heat

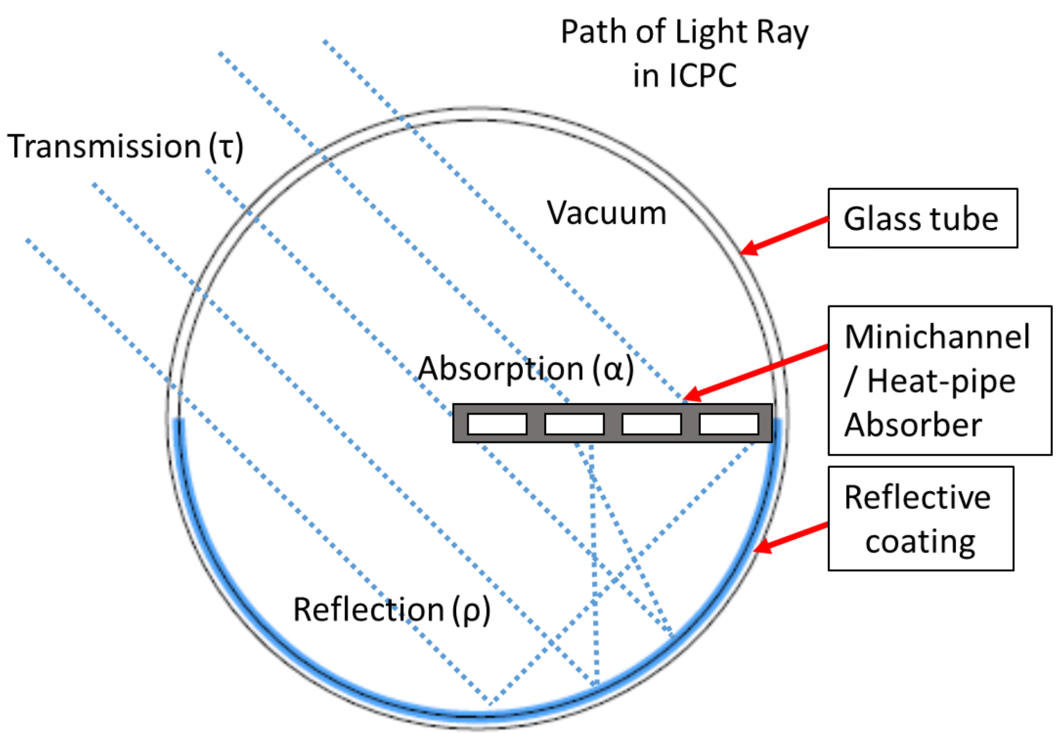
Demonstrate at pilot scale

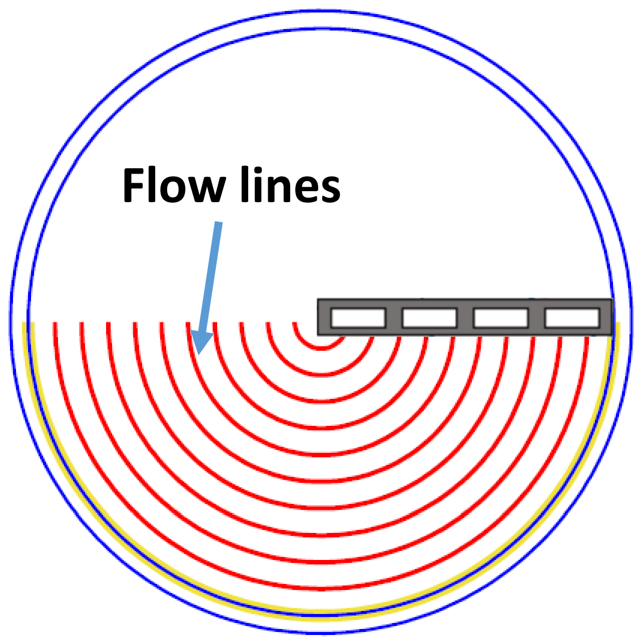
- Integrated (solar thermal + TES) system on track to provide LCOH < $0.015

Budget period 1: Bench-scale ICPC & TES performance testing

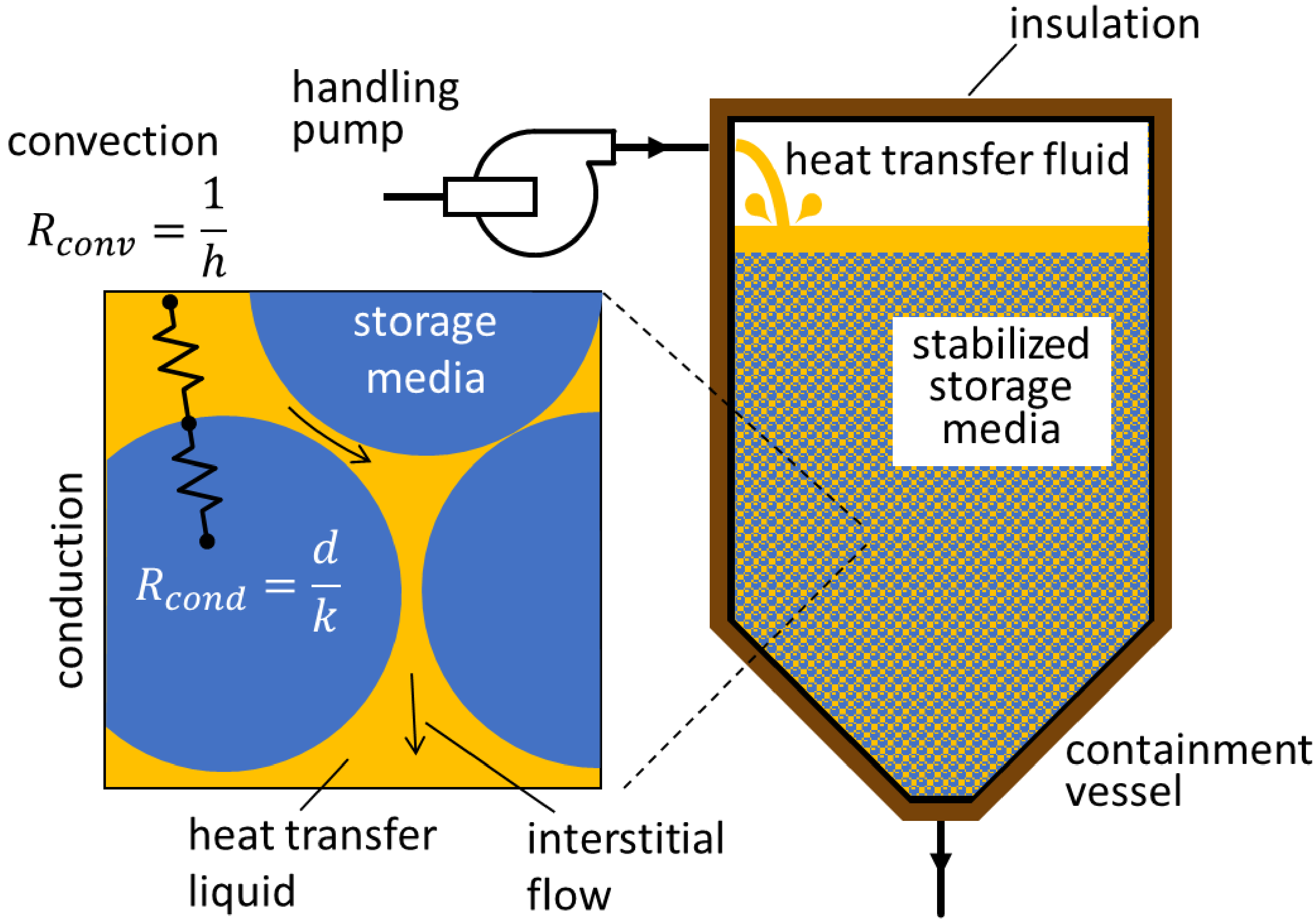
Budget period 2: Integrated 20 kW_{th} ICPC solar array + 90 kWh_{th} TES storage

Internal Compound Parabolic Concentrator (ICPC)

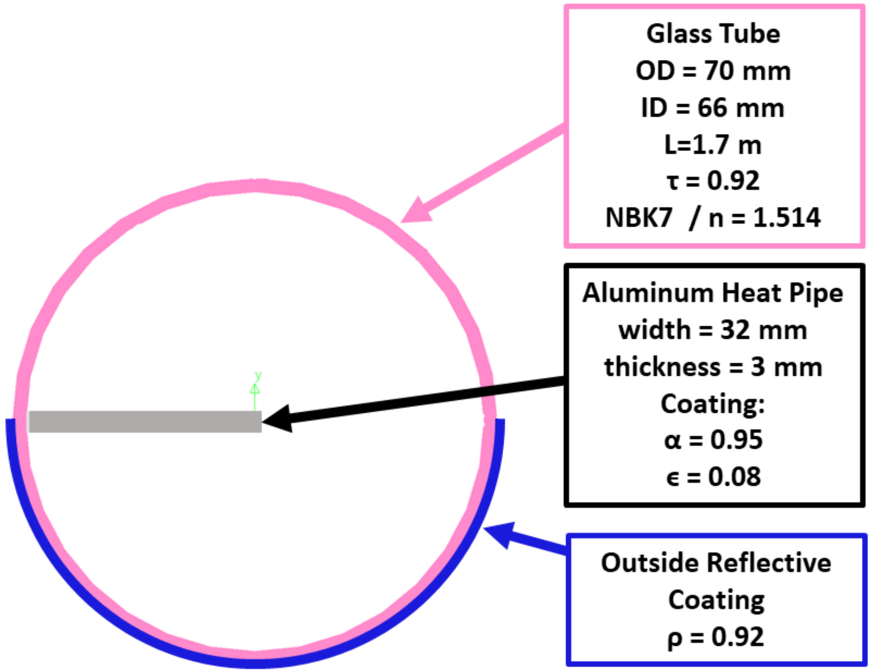


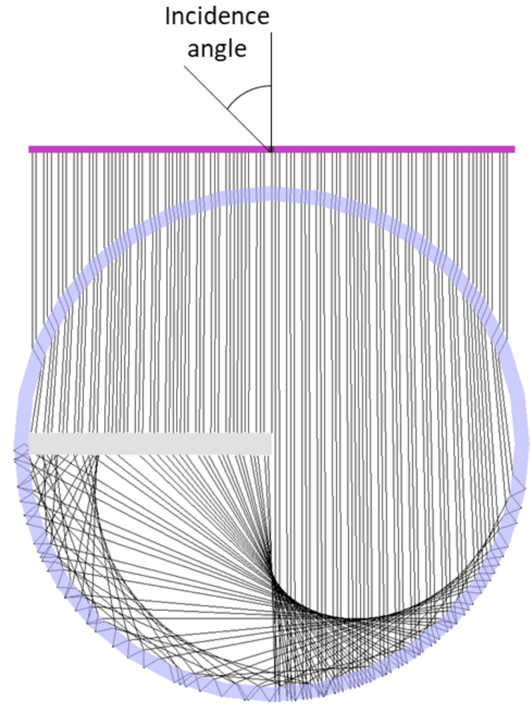


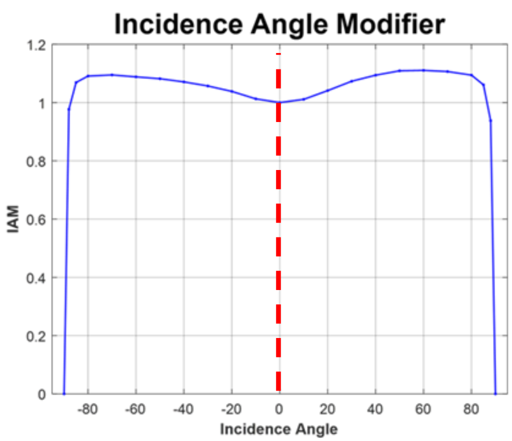
Thermal Energy Storage (TES)

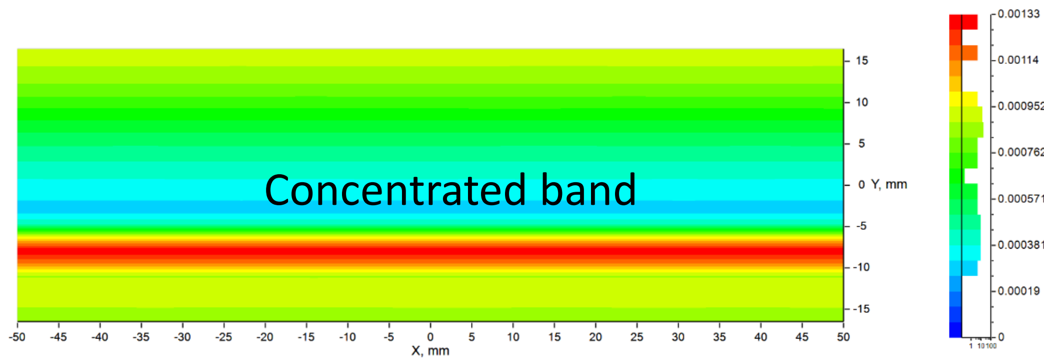


Optical Simulation



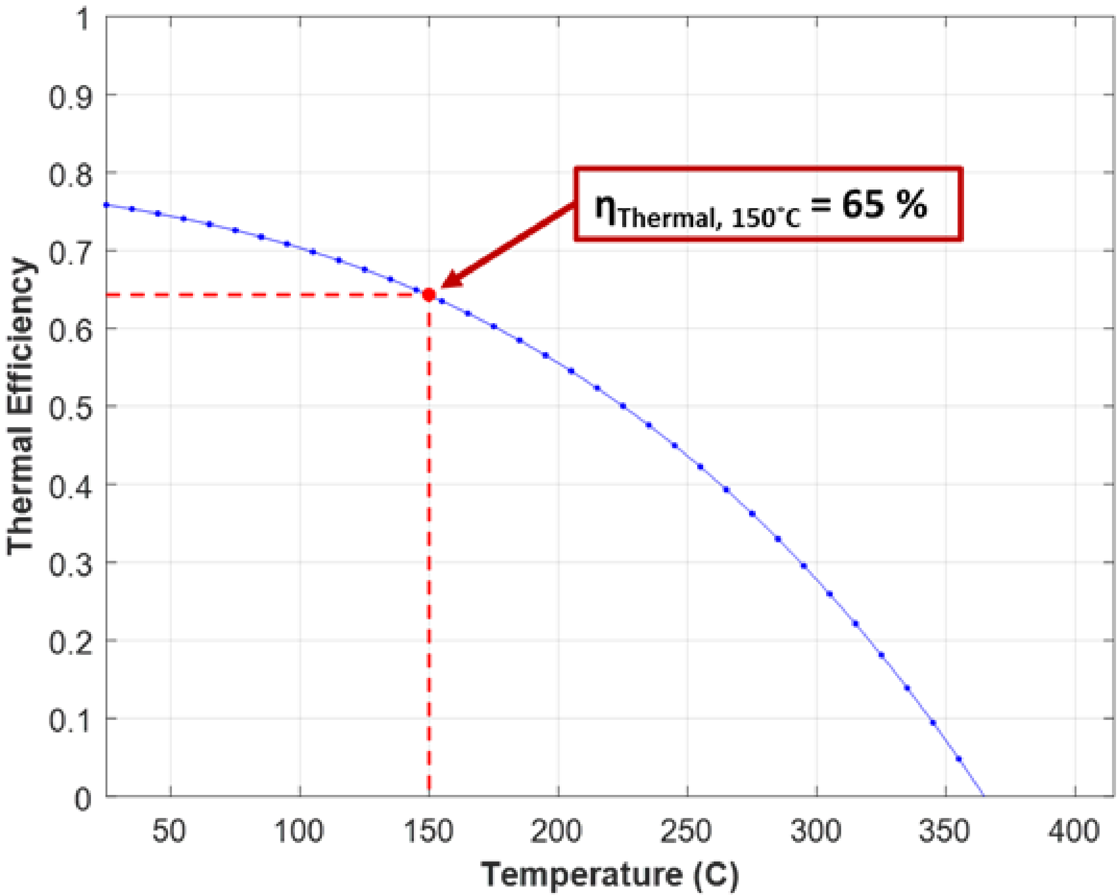






76% optical efficiency @ normal incidence

Thermal Simulation



$$\eta_{thermal} = \underbrace{\rho\tau\alpha}_{\eta_0} - \underbrace{\frac{\epsilon\sigma(T_{abs}^4 - T_{amb}^4)}{C_x G}}_{radiative\ loss}$$

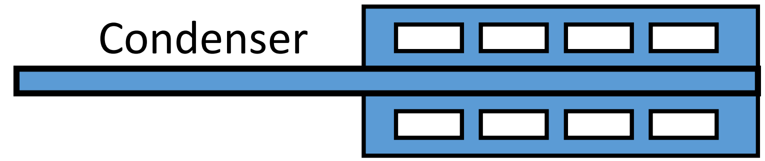
$$C_x = \frac{A_{aperture}}{A_{absorber}} = 1$$

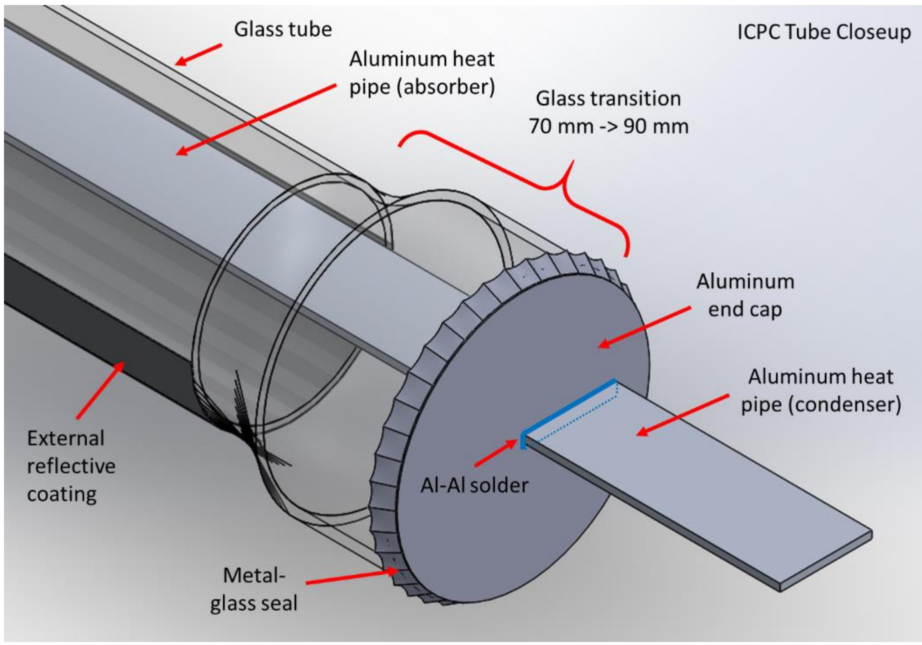
Simulation Parameters

- η_o = 76%
- ϵ = 0.08
- T_{amb} = 37 °C
- G = 1000 W/m^2

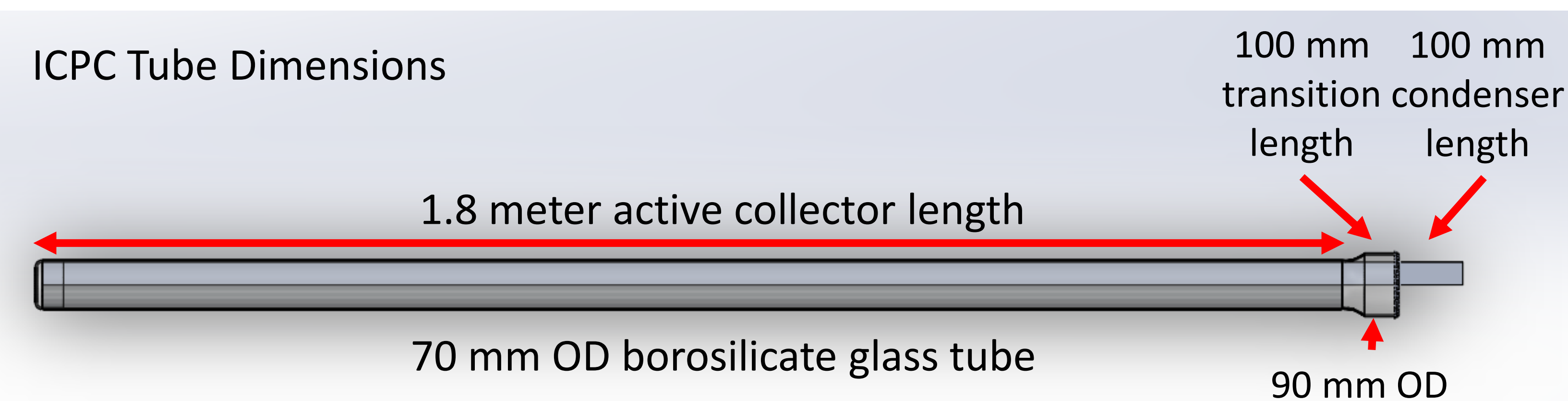
65% thermal efficiency @ 150 °C

ICPC Tube Design

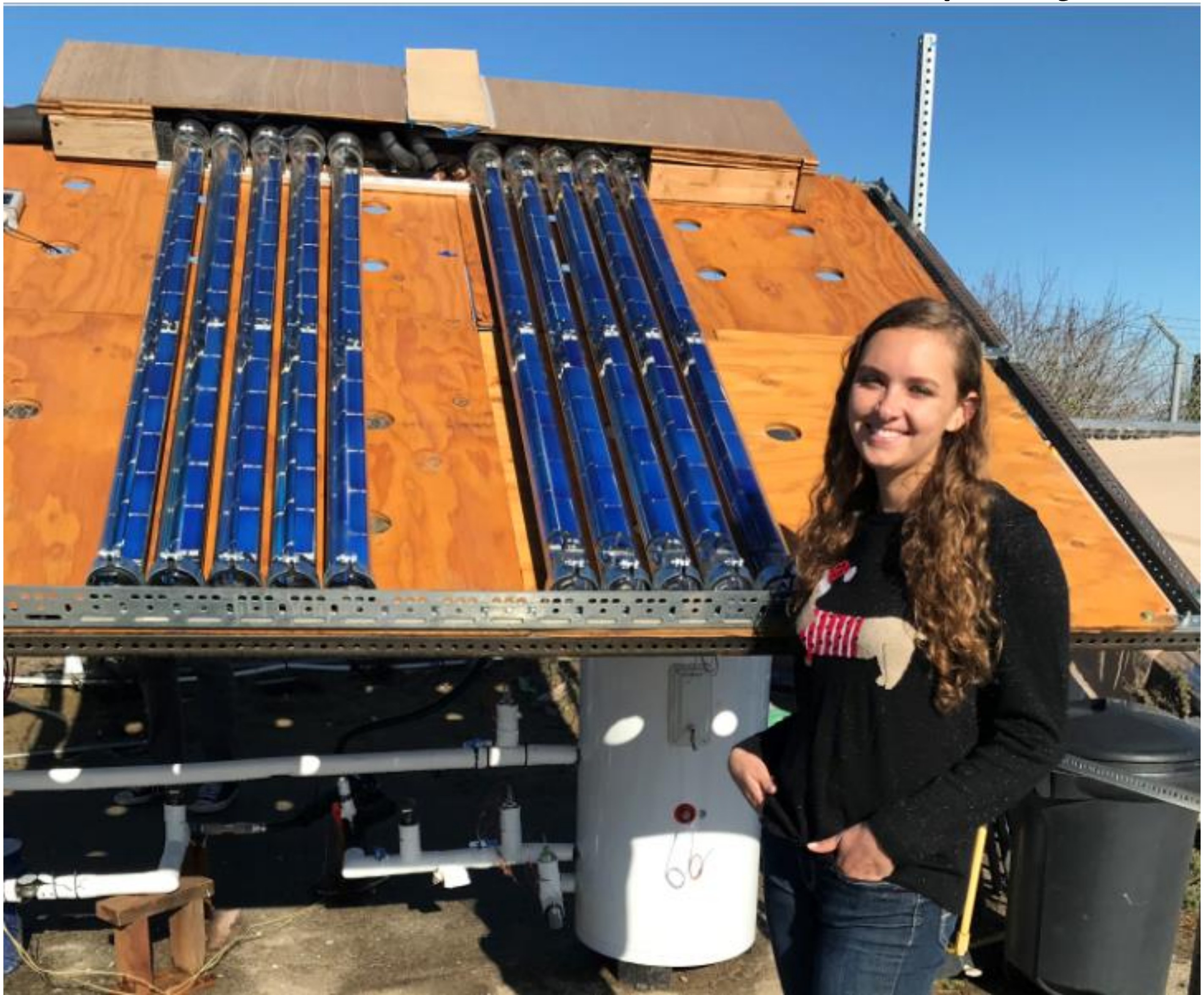




Tube Performance	
Optical Efficiency	75%
Thermal Efficiency (150 °C)	64%
Aperture Length	1.8 m
Aperture Width	66 mm
Aperture Area per tube	0.12 m^2
Gross Length	2 m
Gross Width	90 mm
Gross Area per tube	0.18 m^2
Output per tube	61 watts



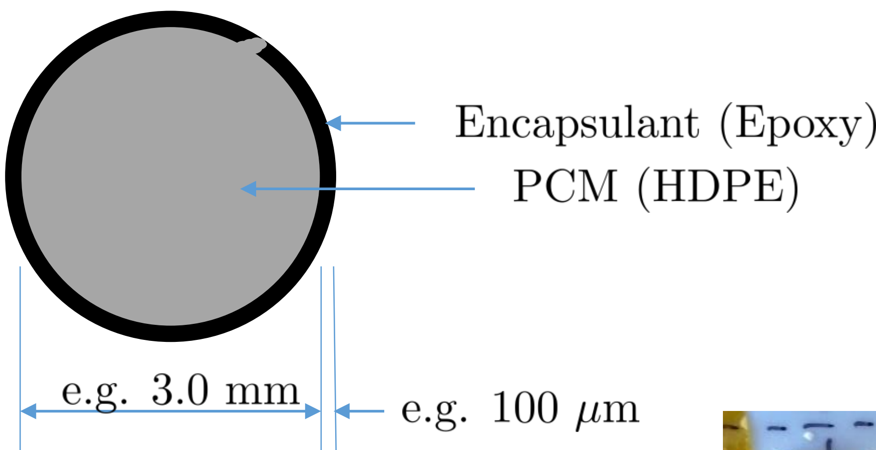
Combined Heat and Power project

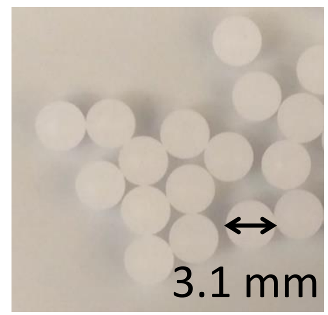


Our tube expert, Dr. Lun Jiang we hire them young

Media candidate 2: Encapsulated polymer

- Stabilized encapsulated thermoplastic storage media synthesized
- High density polyethylene phase change material (PCM)
- Encapsulated in thin thermoset (epoxy) polymer shell
- Encapsulant contains polymer on melting



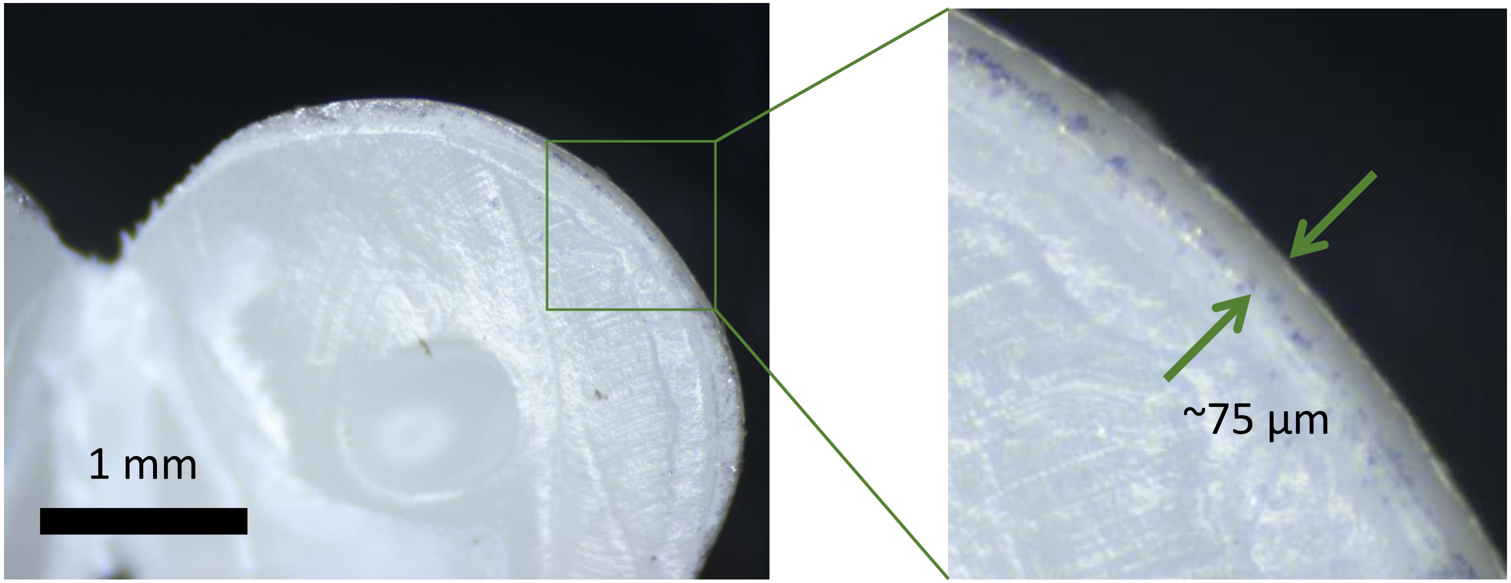


HDPE beads

Individual coated beads

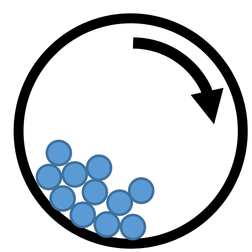
bulk encapsulated media

Encapsulant structure



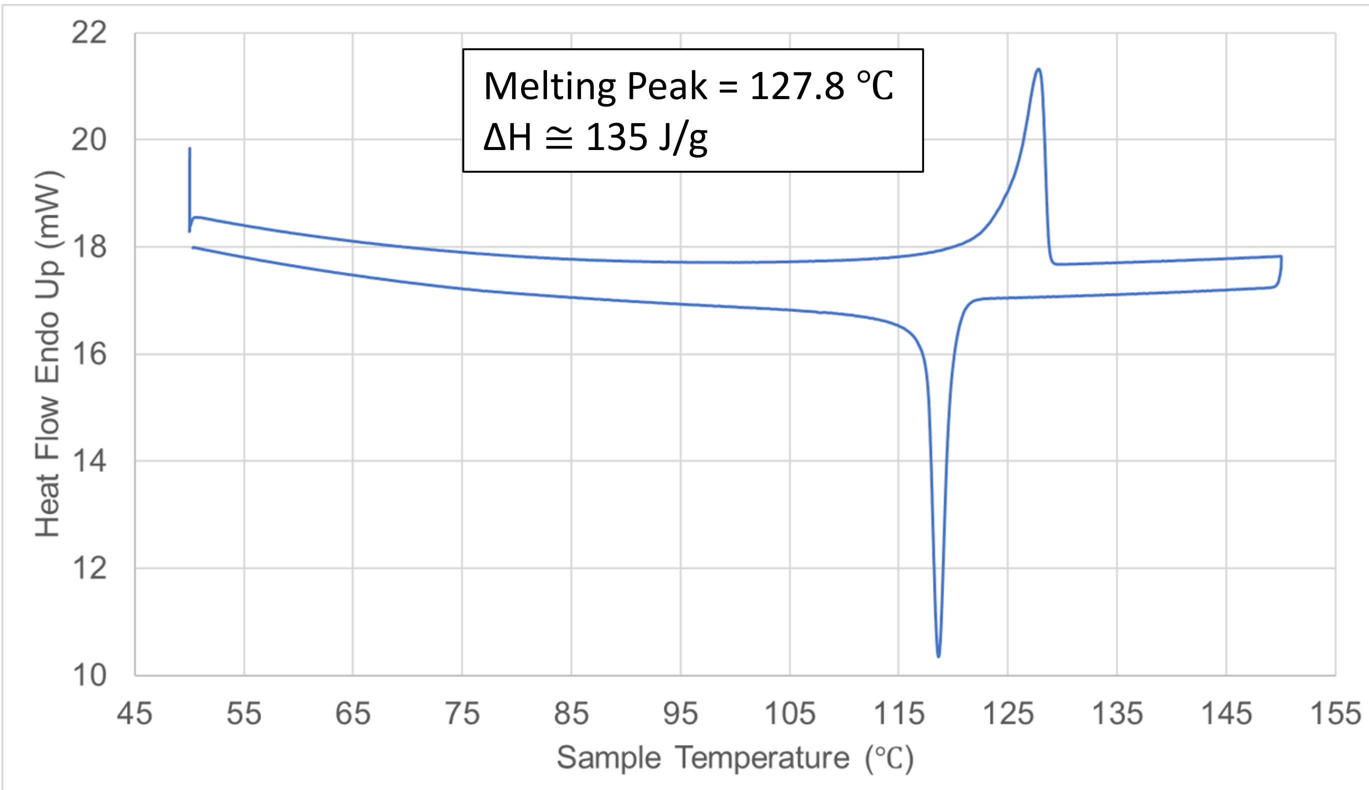
- Minimizing encapsulant thickness is important to:
  - Reduce cost
  - Maximize effective latent heat
- Approach for minimizing encapsulant thickness
  - Minimize uncured encapsulant viscosity
  - Maximize resin coating uniformity before introduction of hardener

encapsulant roll coating



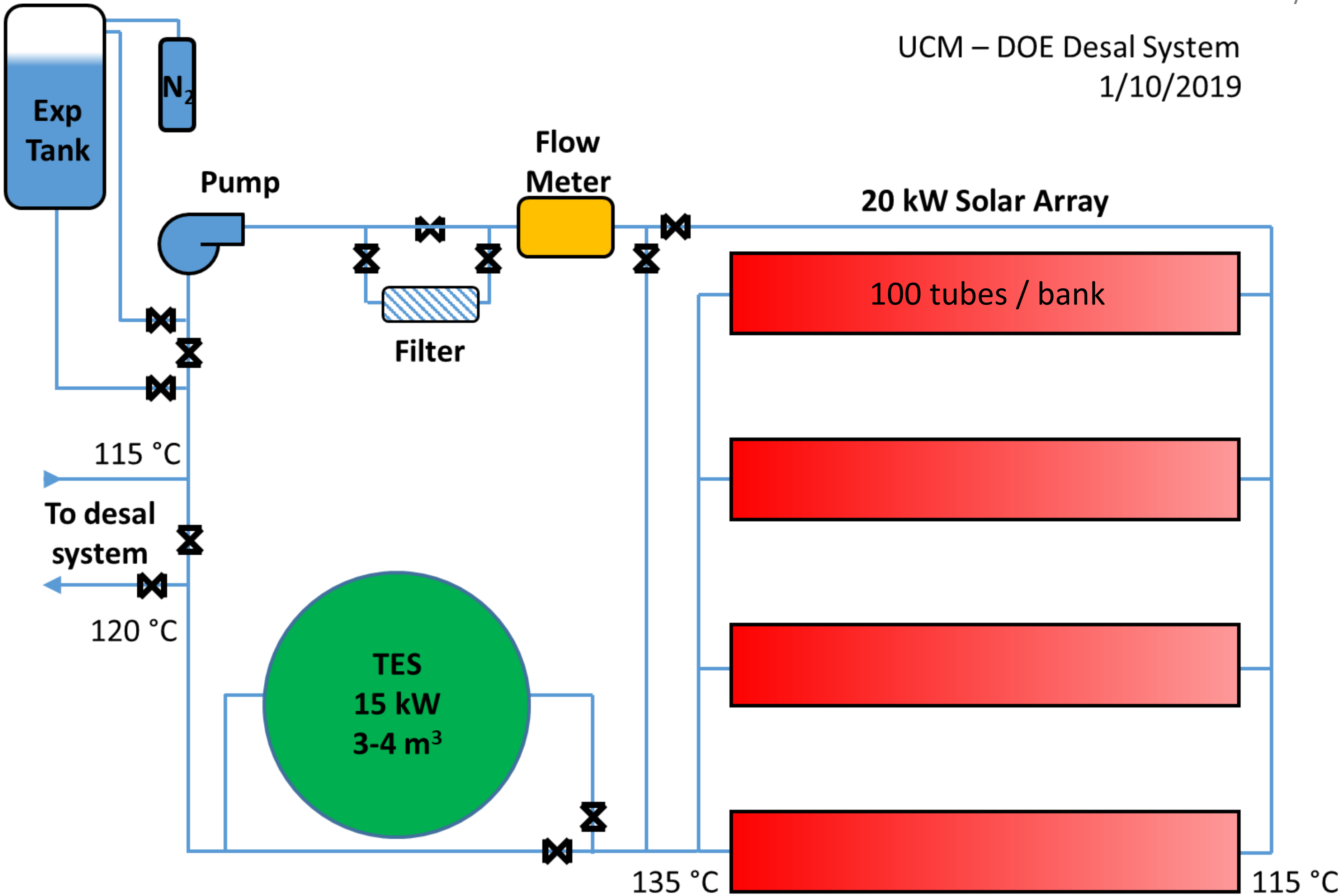
Ex. 75 µm coating, 5 mm bead: 10% volume encapsulant

Latent heat of HDPE PCM

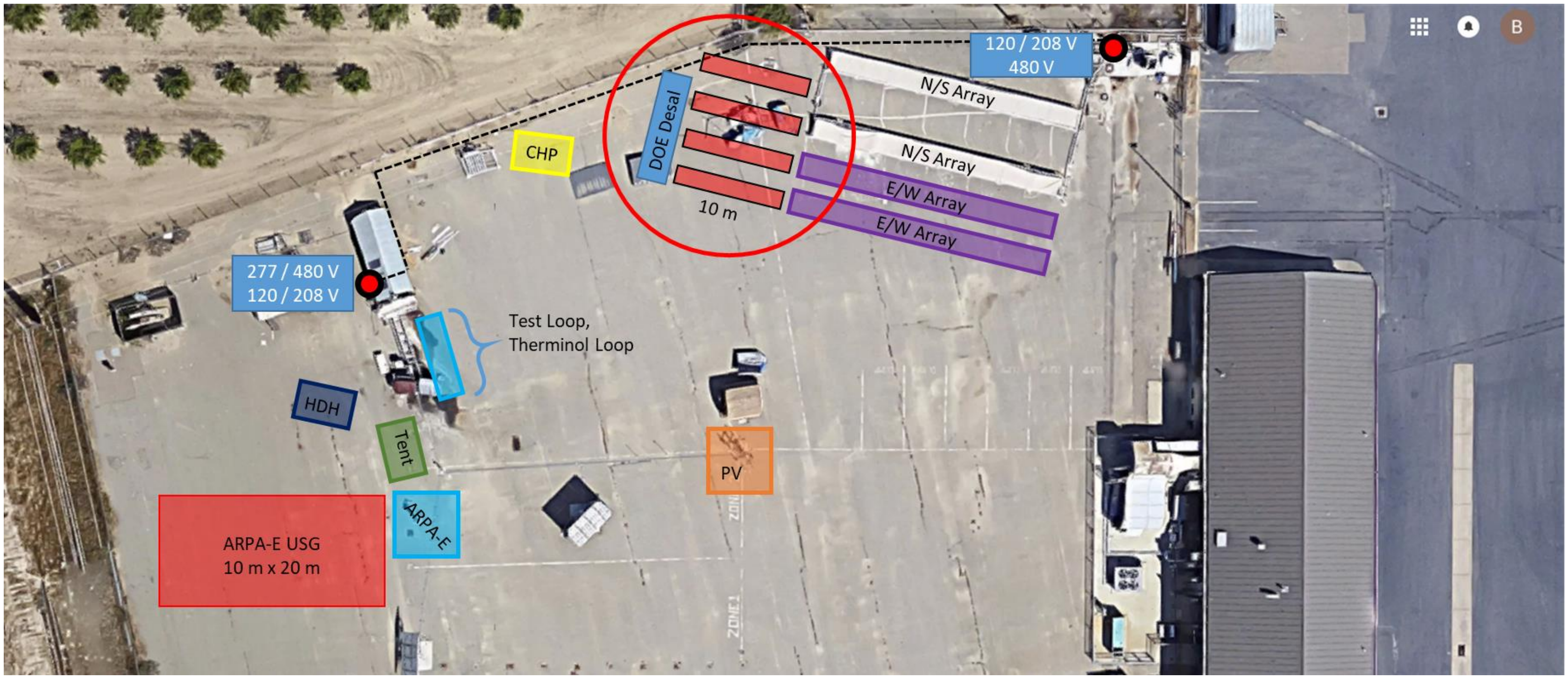


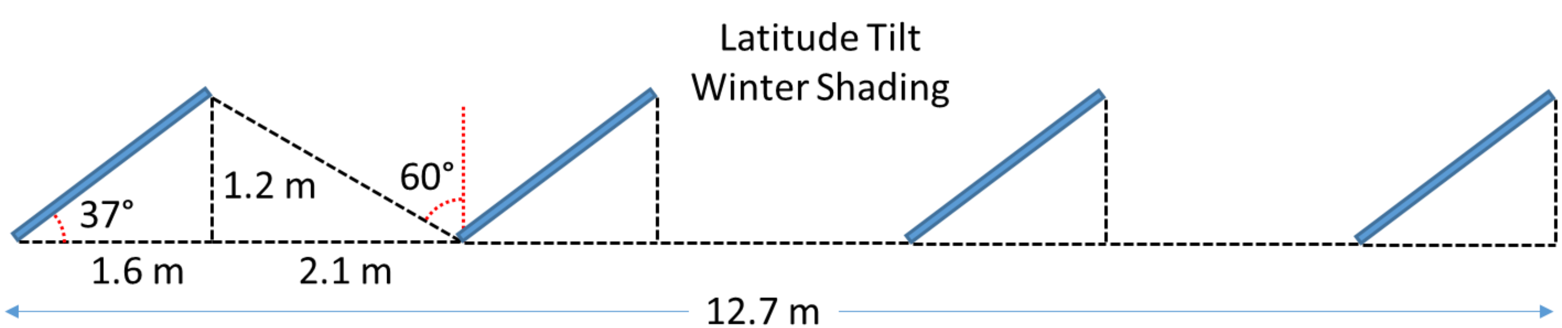
- Latent heat of PCM measured via differential scanning calorimetry
- Latent heat on melting of ~135 J/g for fresh material
- Melting/solidification hysteresis ~9 °C at 1 °C/min
  - Much faster than operational cycle

UCM – DOE Desal System
1/10/2019



Selected Site Location @ UCM





Questions

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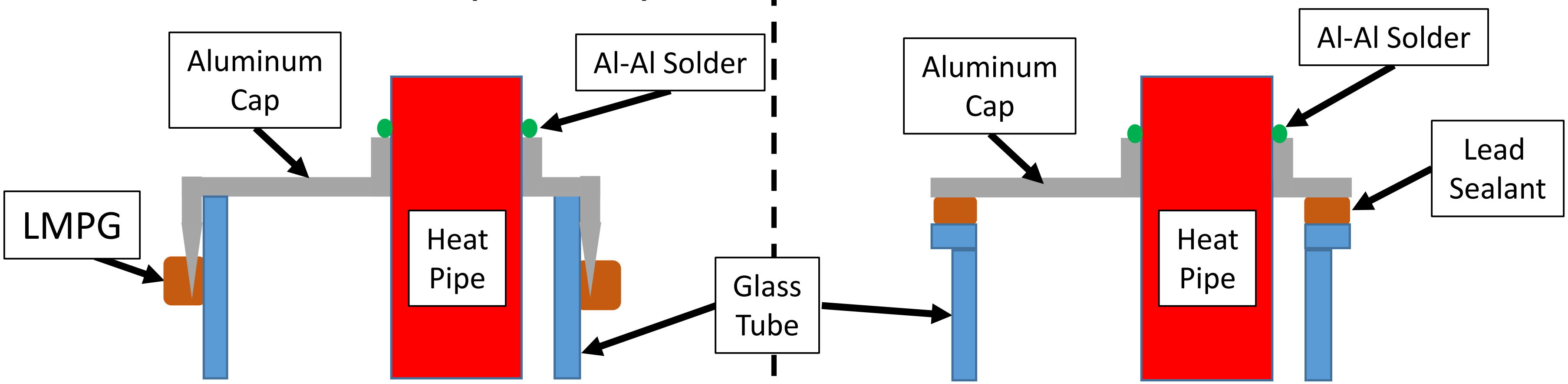
Lun Jiang

Metal-Glass Seal

Path #1 – Low Melting Point Glass (LMPG)

Path #2 – Lead-based sealant



Path #1:

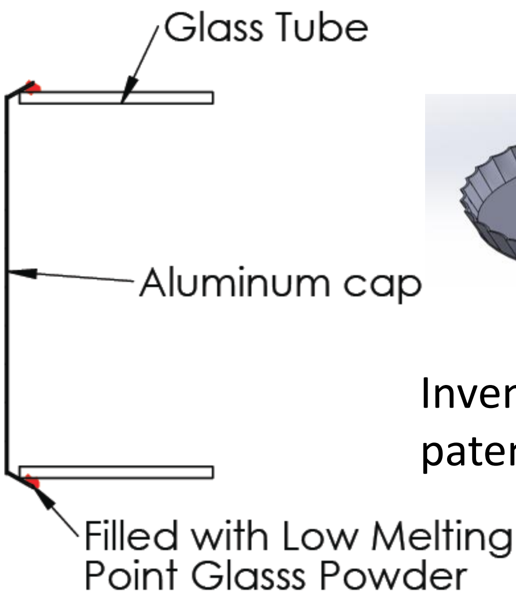
- Thermal mismatch is a challenge
- No need to form glass flange
- Low cost LMPG sealant
- Low cost aluminum cap

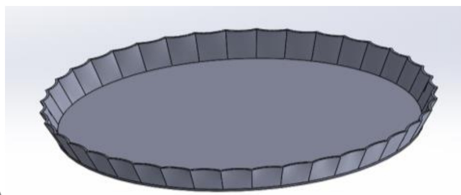
Path #2:

- Thermal mismatch is *not* a challenge
- Need to form glass flange
- Medium cost sealant
- Low cost aluminum cap

Metal-Glass Seal

Path #1 – Low Melting Point Glass (LMPG)



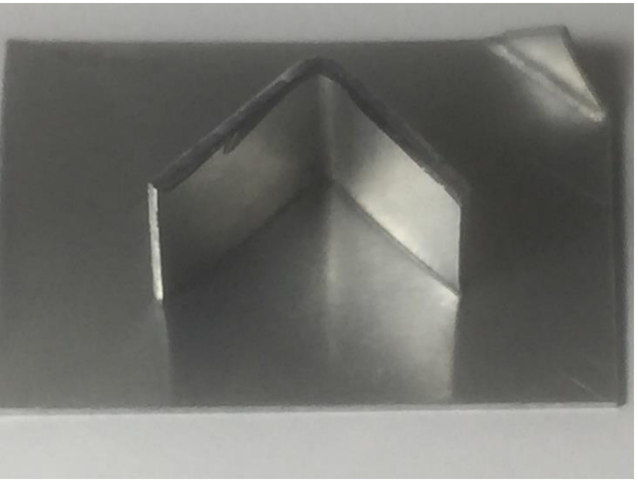


Invention disclosure filed, patent filing pending

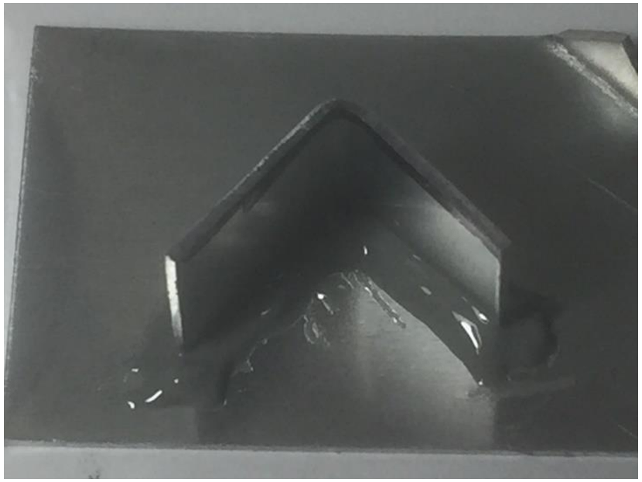
Path #2 – Lead-based sealant

- Preliminary trial with aluminum cap using lead as the seal material is successful
- Potential pathway for prototype tubes

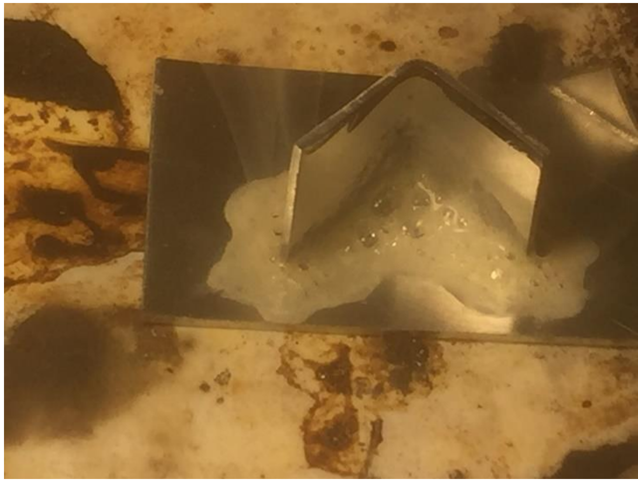
Al-Al solder (300 °C)



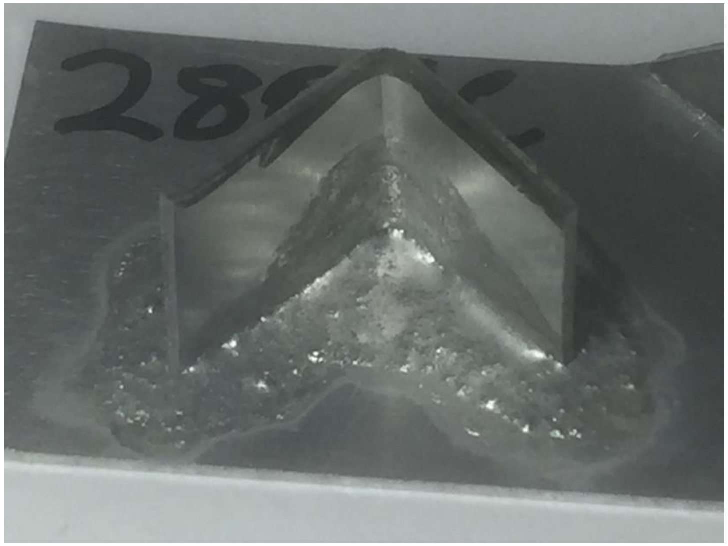
1) Parts



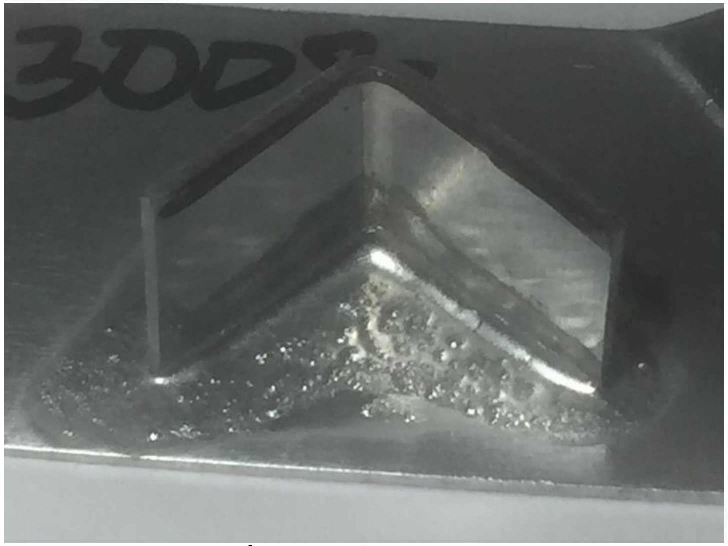
2) Flux Applied



3) Heated via hot plate



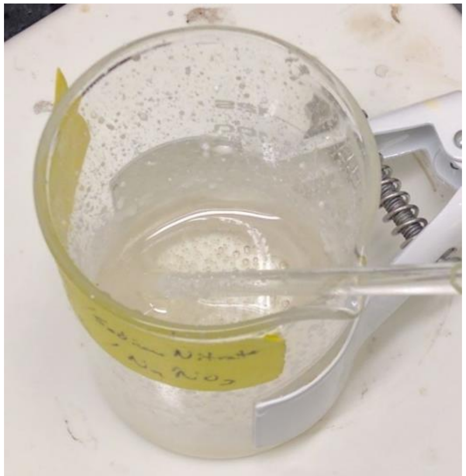
4) 280 °C Joint



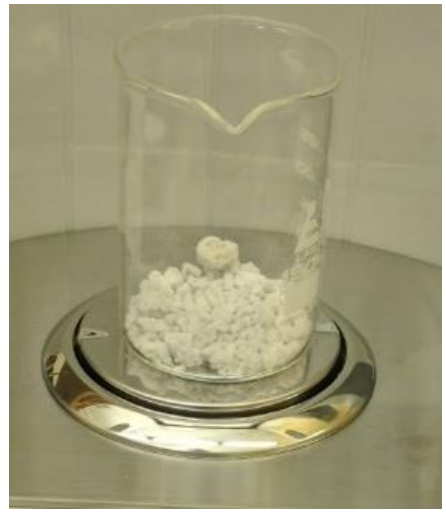
4) 300 °C Joint

Media candidate 1: Absorbed nitrate

- Stabilized $NaNO_3$/perlite composite storage media synthesized



Molten Sodium Nitrate



Expanded Perlite

Nitrate/Expanded Perlite composite phase change material

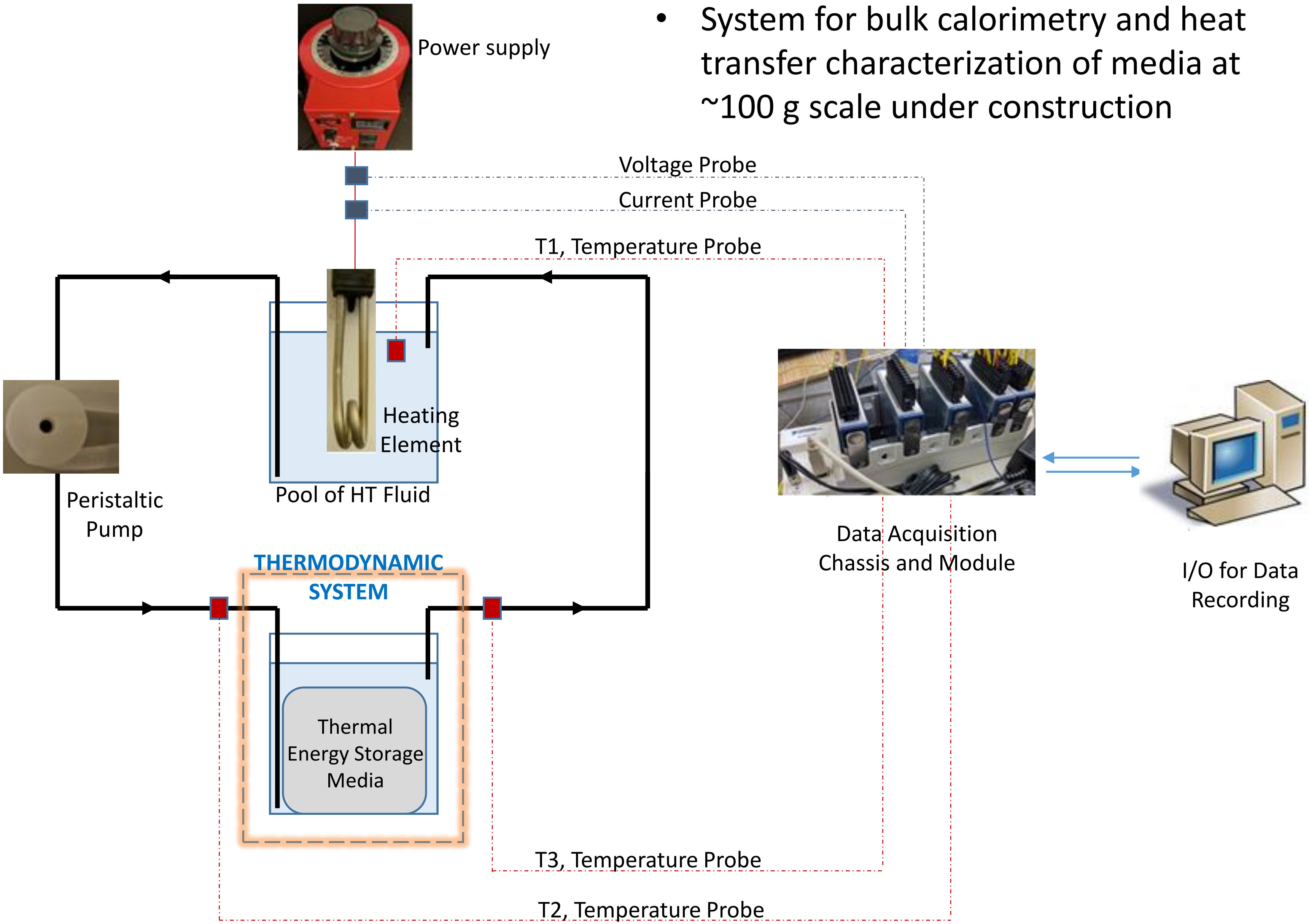
Expanded Vermiculite can also be used as absorbent

- Absorption of molten nitrate in porous ceramic allows stabilization
- Disadvantages
  - Hygroscopic
  - Reactive with organics
  - Requires additional robust encapsulation

James Palko

Bulk calorimetry and heat transfer characterization

- System for bulk calorimetry and heat transfer characterization of media at ~100 g scale under construction



Task 3 – Preliminary System Design & Validation

- M3.3 – 3rd party TEA reviewers
  - Due 4/1/2019 – 33% complete
- Current accomplishments:
  - Preliminary system design developed
  - Pressure drop & heat loss models developed
  - Installation, operations, maintenance, failure modes identified
  - System location identified @ UCM
  - 3 third-party TEA reviewers identified

Location Data (Merced, CA)	
Solar Irradiance	800 W/m²
Global Horizontal	5.14 kWh/m²
Direct Normal (beam)	5.65 kWh/m²
Diffuse Horizontal	1.62 kWh/m²
Annual Average Daily Solar	5.86 kWh/m²
Latitude	37 °N

Tube Performance	
Optical Efficiency	75%
Thermal Efficiency @ 150 C	65%
Aperture Length	1.8 m
Aperture Width	66 mm
Aperture Area per tube	0.12 m²
Gross Length	2 m
Gross Width	90 mm
Gross Area per tube	0.18 m²
Output per tube	61 Watts

Array Performance	
Design Point	24 kW_{th}
Required Aperture Area	47.5 m²
# of tubes	400 tubes
# of banks	4 banks
Array Width	10 m
Array Length	13 m