SunShot U.S. Department of Energy

Using **Encapsulated Phase Change Material for Thermal Energy Storage** for Baseload CSP

Phase 2 Contract: DE-EE0003589
Start Date- July 2012
Expected End Date – Aug 2013

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terrafore

Team Members

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- Jose Mendez
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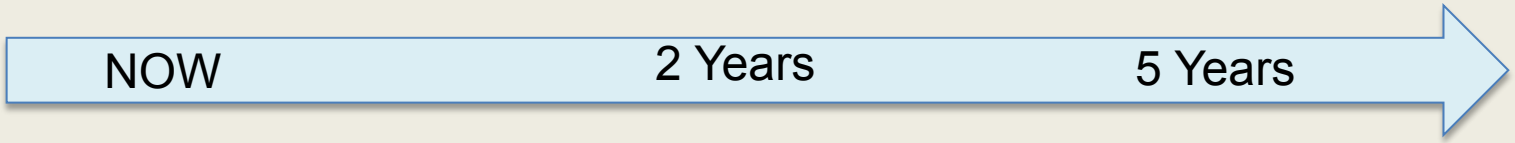
Agenda

- Motivation for PCM storage
- Key Findings from Phase 1
- Encapsulation Methods
- Key Findings Todate from Phase 2
- Next Steps
- Video

Motivation for Phase Change Material Thermal Energy Storage (TES)



Two-Tank Sensible Heat TES ,$30 /kWht)

TerraKline **A Dual Media Managed Thermocline TES $20/kWht**

TerraCaps **Cascaded Encapsulated Phase Change TES $15/kWht**

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Technical Challenge / Solution
Encapsulated Phase Change TES

Challenge

When Salt Melts, Volume Increases. This Increase in Volume can Rupture the Shell

Solution TerraCaps.

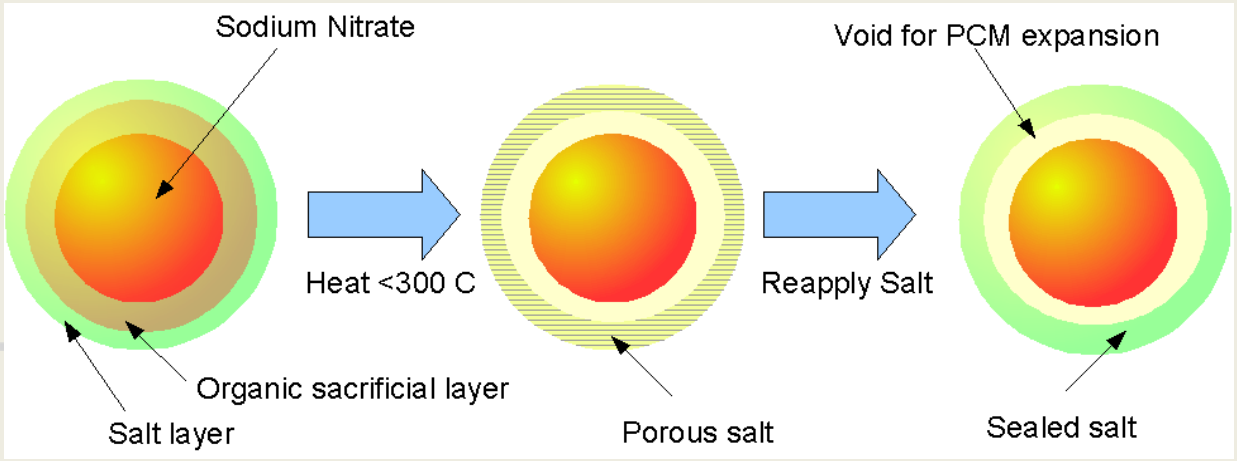
Successfully Produced PCM Salt Capsules with **Void** to accommodate Change in Volume

Void for Expansion of Salt

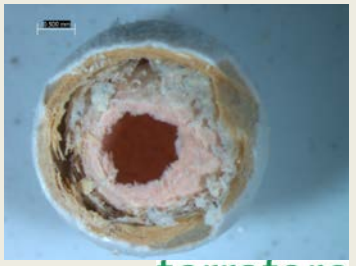
Phase 1 Project Technology Breakthrough

Encapsulation Method 1

Sacrificial Material Concept for Creating Void



Fluid Bed Coater



- Sacrificial polymer selected must completely decompose at low temperatures

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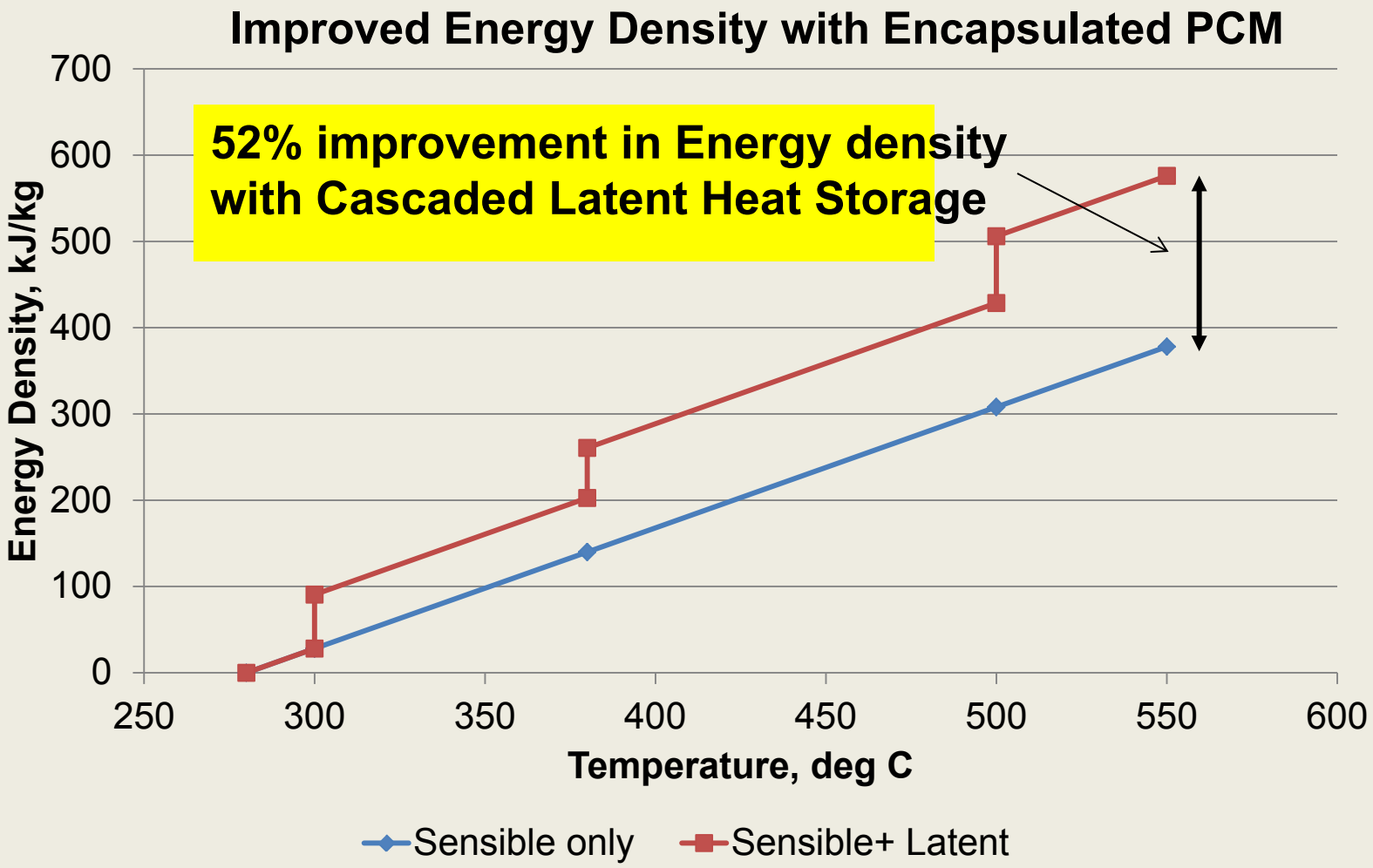
Energy Density Cascaded PCM-TES



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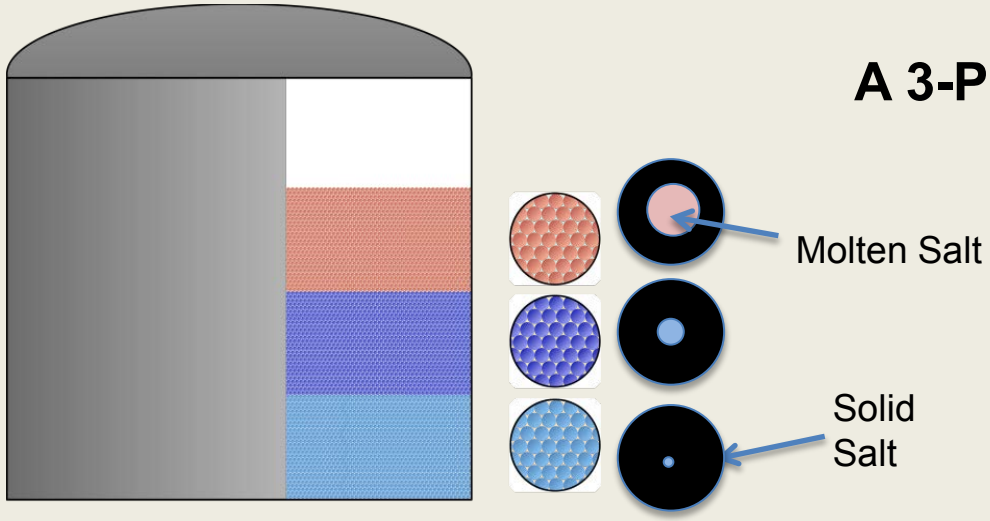
A Cascaded Encapsulated PCM-TES



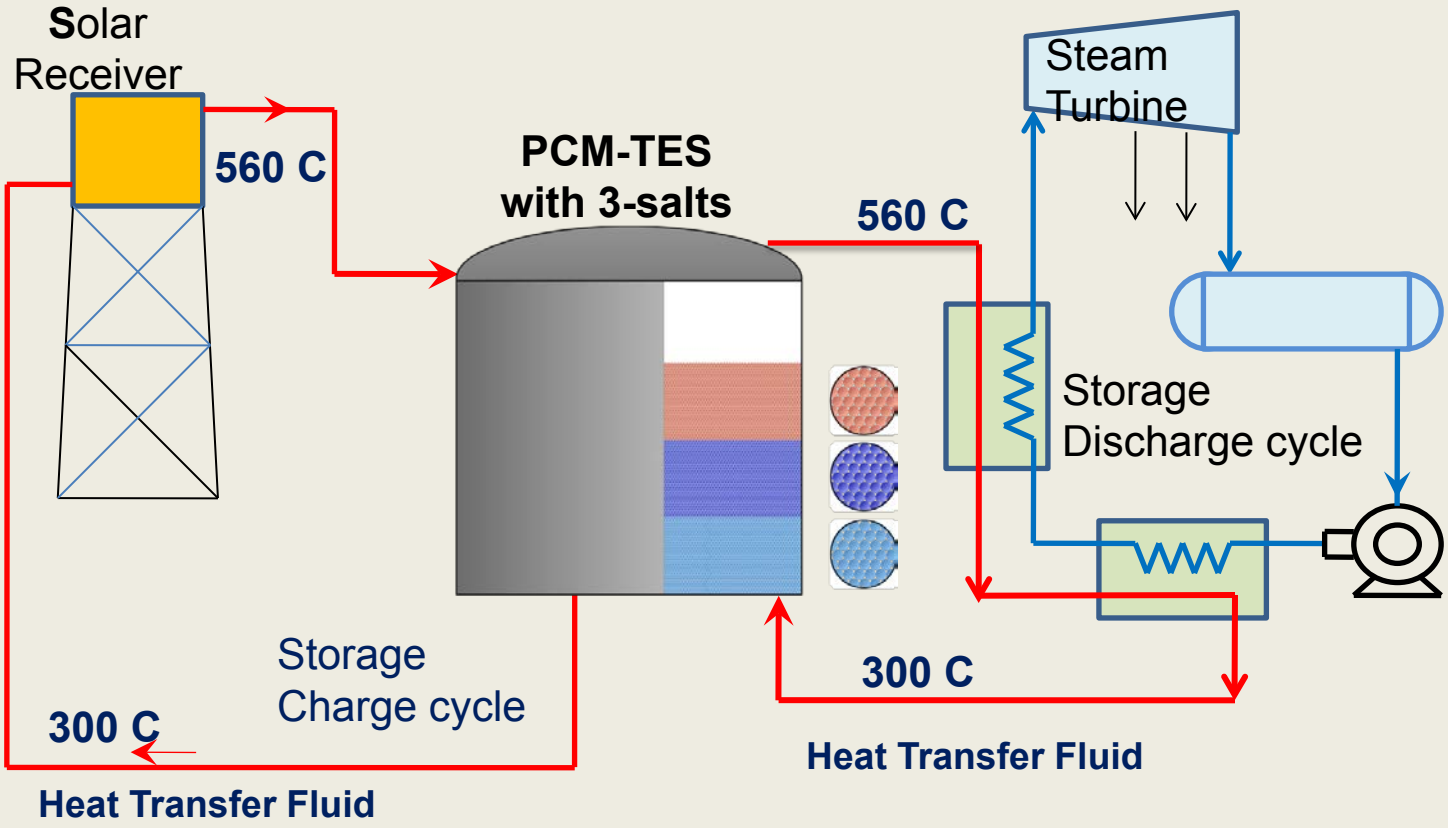
A 3-PCM Cascaded Encapsulated TES

Capsules Filled with Salts Melting at Progressively Higher Temperatures

TerraCaps **Cascaded 3-PCM Encapsulated TES**

Improves Energy Density by 35% to 50%

CSP with Cascaded Encapsulated PCM-TES



- **Direct contact heat transfer with HTF**
- **90% utilization of latent heat in salt capsules**

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PHASE 1 SUMMARY

- **Objective**

  Develop Economical Method to Encapsulate Nitrate Salt in Suitable Shell Material

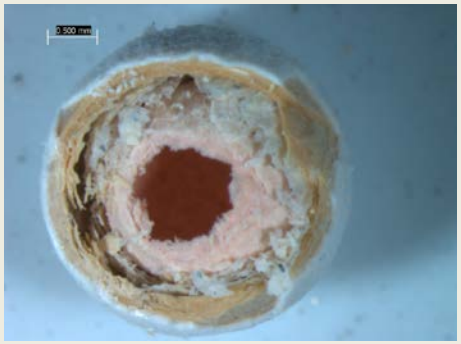
- **Technical Barrier**

  Produce salt capsules with adequate void for salt to expand on heating

- **Key Results**

  Successfully developed a recipe to make 5mm capsules in lab

  Mathematical Model for Encapsulated TES



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PHASE 2 OBJECTIVE

- Make Larger Capsules (~10mm)
- Optimize Recipe with small capsules
- Demonstrate Capsules are Robust

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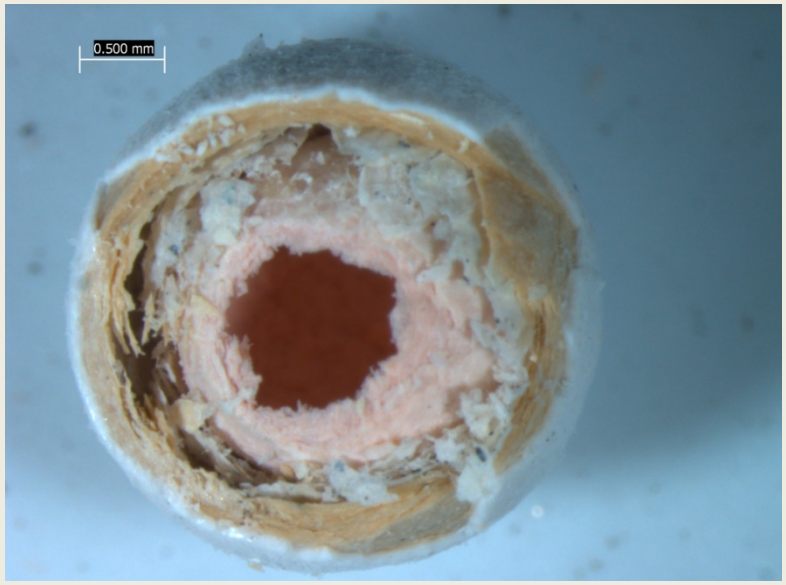
PHASE 2 MILESTONES

- Thermal cycling failure rate <0.1% per year
- Isothermal hold failure rate <0.1% per year
- FMEA of capsule breakage on HTF and TES system
- Optimize recipe
  - minimize heat treatment time (<48 h heat treatment time)
  - minimize expendable material
  - Robust to material composition variations
- Cost of capsules <$5 per kWht

Repeat of Phase-1 Formulation – MOMs Recipe

- Formulation survives heating to >500°C
- Cross section shows salt



Designed Experiments for Recipe Robustness

RUN	ICON	BCON	MIDDLE	OUTER
1	Low	Low	13	19
2	Low	Low	13	29
3	Low	Low	16	24
4	Low	Low	19	19
5	Low	High	13	19
6	Low	High	16	24
7	Low	High	19	24
8	Low	High	19	29
9	High	Low	13	24
10	High	Low	16	19
11	High	Low	19	24
12	High	Low	19	29
13	High	High	13	24
14	High	High	13	29
15	High	High	16	19
16	High	High	16	29
17	High	High	19	19

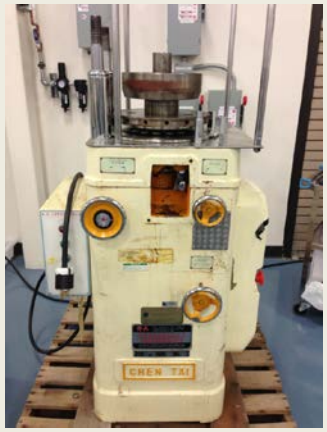
Repeats to be added

ICON = inorganic concentration
BCON = binder concentration
MIDDLE = middle layer thickness/mass %
OUTER = outer layer thickness/mass %

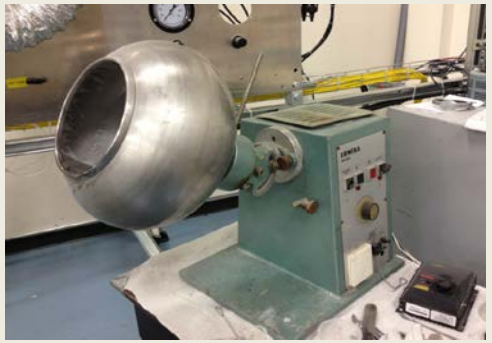
Encapsulation Method 2

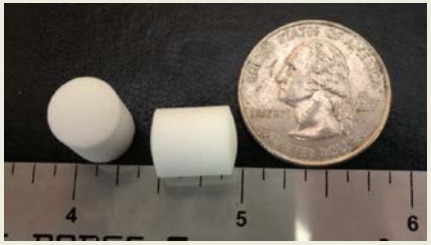
- Granules of Salt Pressed in Tablet Press
- Coated in a Pan Coater
- ~10 mm capsules undergoing thermal cycle tests

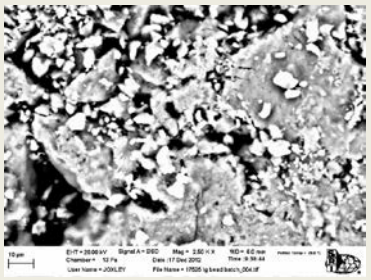
Rotary Tablet Press



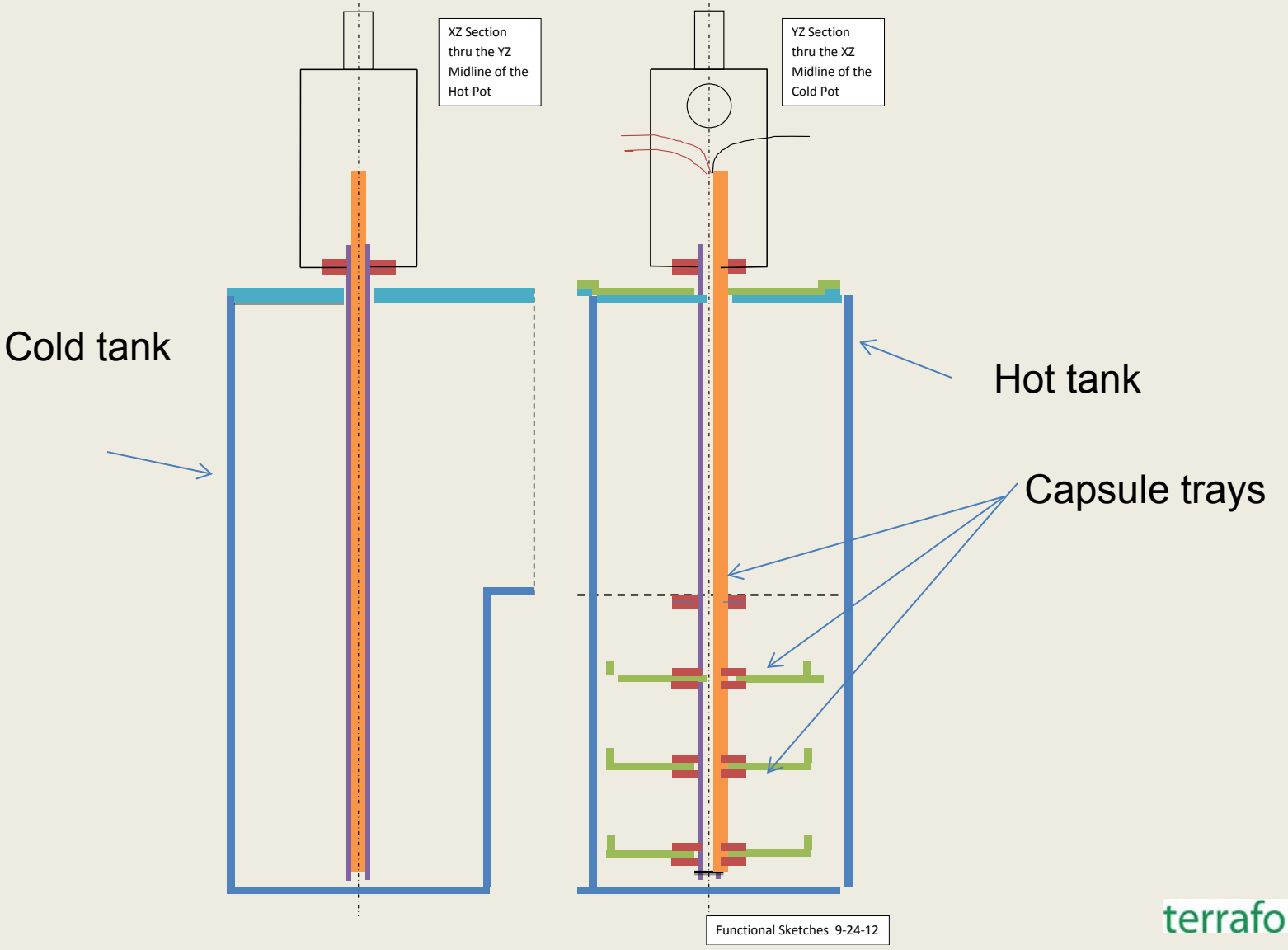
Pan Coater







TerraDipper - Thermal Cycling Capsule Tester



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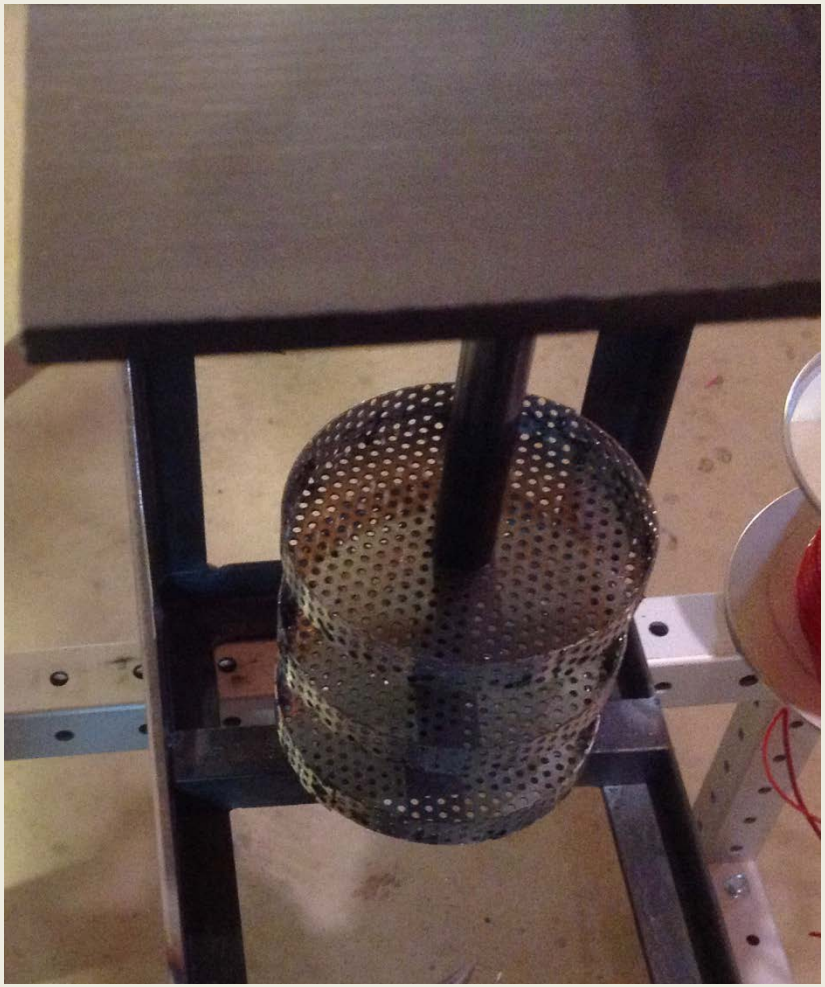
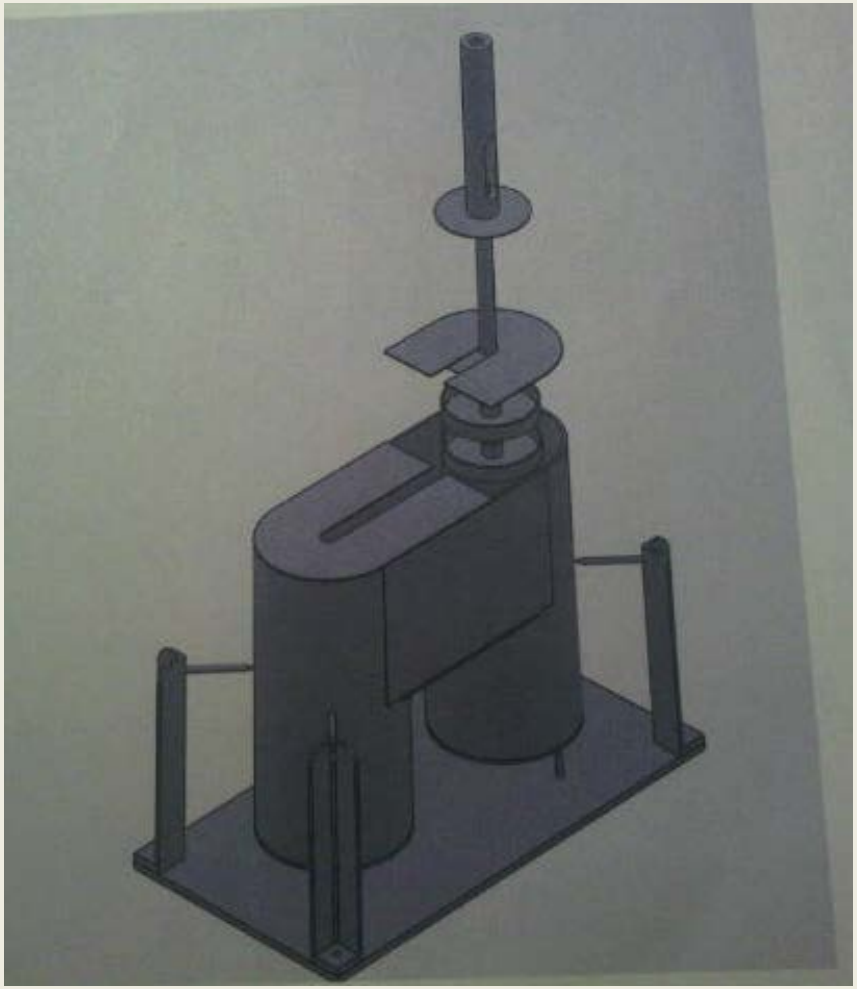
Thermal Cycling Capsule Tester



Capsule Trays



Test Rig Schematic

Capsule Integrity Measurements

- Optical Microscopy
- Differential Scanning Calorimetry
- Scanning Electron Microscopy
- Strength (Texture Analyzer)

Planned Activities Through August 2013

- Produce capsules and tablets with recipes using design experiments
- Conduct thermal cycling tests (> 5000 cycles), measure for integrity, calculate statistical failure rates
- Scale-up and manufacturing method
- Design TES System Test bed for Phase 3

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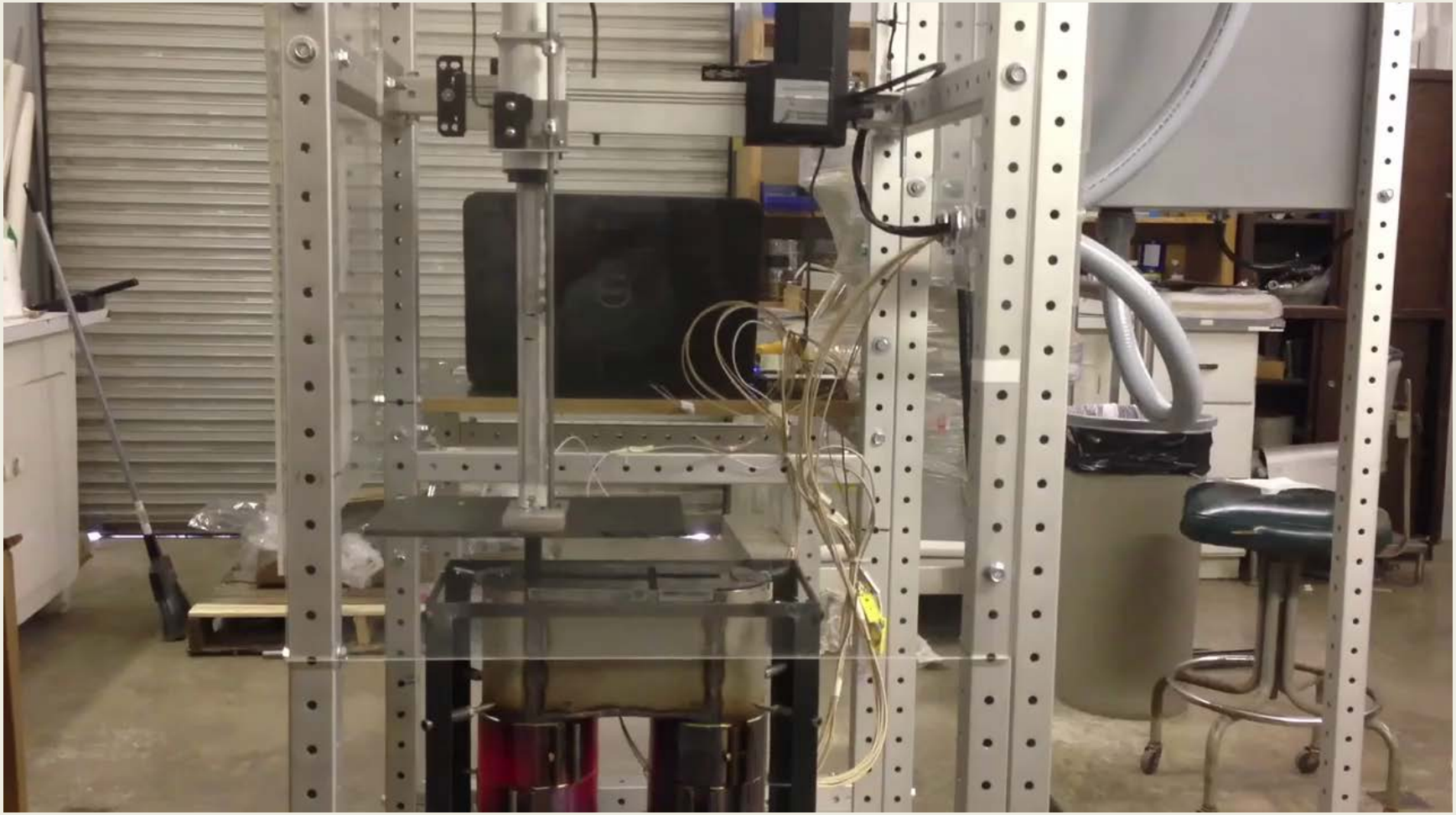
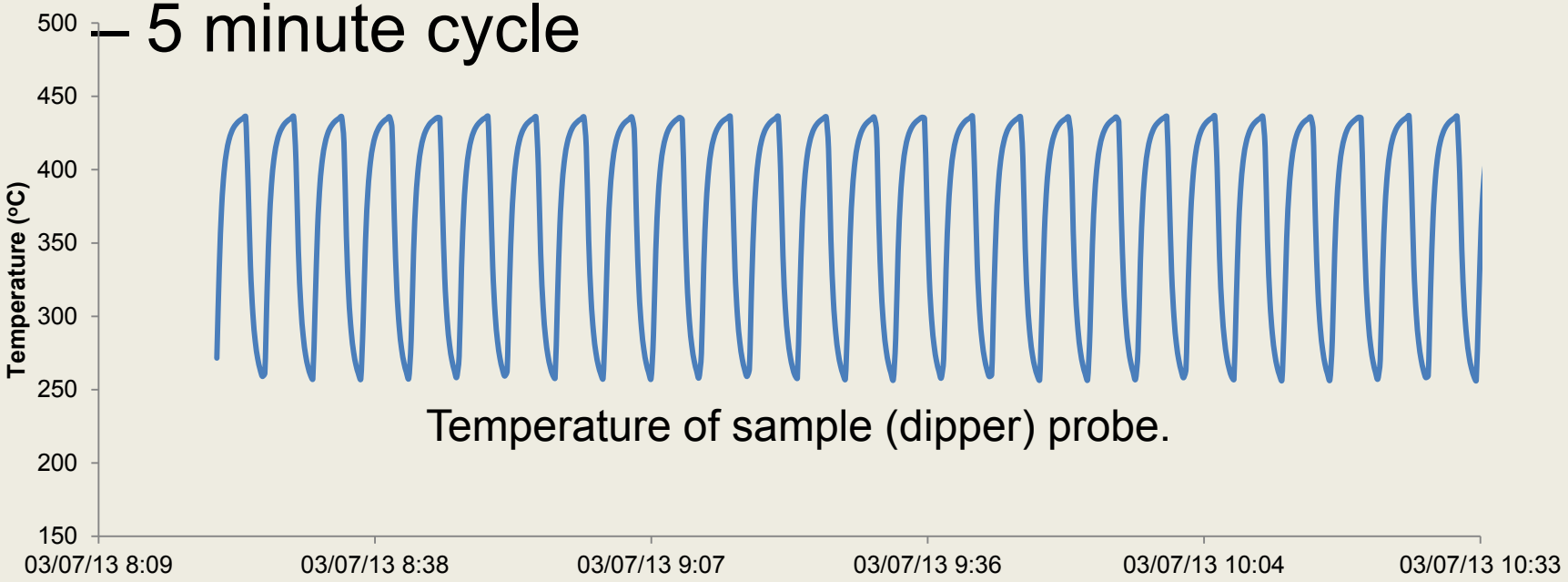
Movie of Thermal Stability Capsule Tester



Thermal Cycling: Teradipper

- Process setup to expose capsules to thermal cycle
  - 250 °C to 430 °C
  - 5 minute cycle



Temperature of sample (dipper) probe.