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Dish Stirling High Performance Thermal Storage

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LPDP

CSP SunShot SUMMIT 2016: HEAT TRANSPORT AND STORAGE

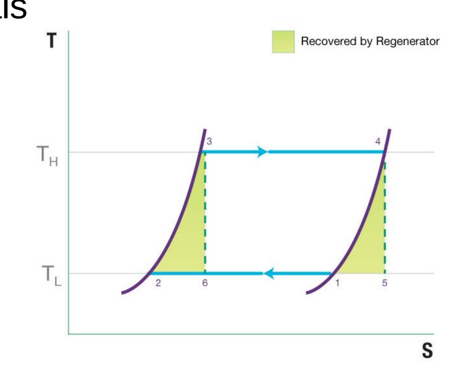
Introduction & Background

Concept

Enhancing high-performance dish-Stirling systems with up to 6 ours of thermal energy storage has the potential to increase performance, improve capacity, and enhance interest, making dish-Stirling systems a leading candidate to meet SunShot goals

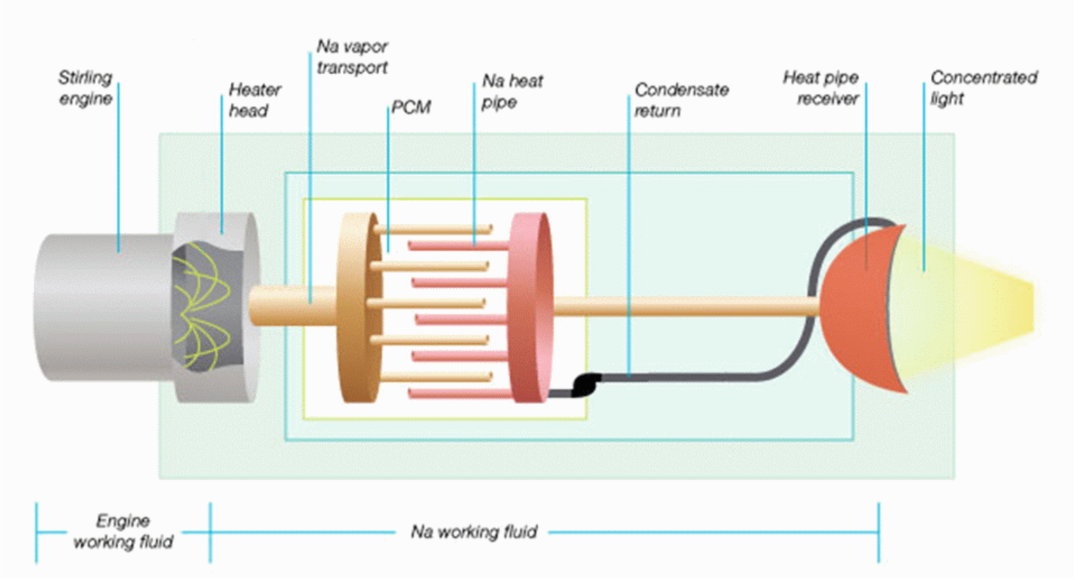
Why dish-Stirling?

- Demonstrated over 31% sun-to-grid, 26% annual
- High temperature, high concentration systems
- Highest efficiency thermodynamic cycle
- 6¢-8¢/kWh attainable with engineering and supply chain



Latent heat transport and storage

- Isothermal input to engine
- Best match to isothermal transport, isothermal storage
- High exergy efficiency
- Isothermal transport has additional demonstrated system performance improvements
- 10-20% system performance boost
- Independent optimization of receiver, storage, engine
- Heat pipe is a "thermal transformer"
- First- and second-law improvements over existing systems



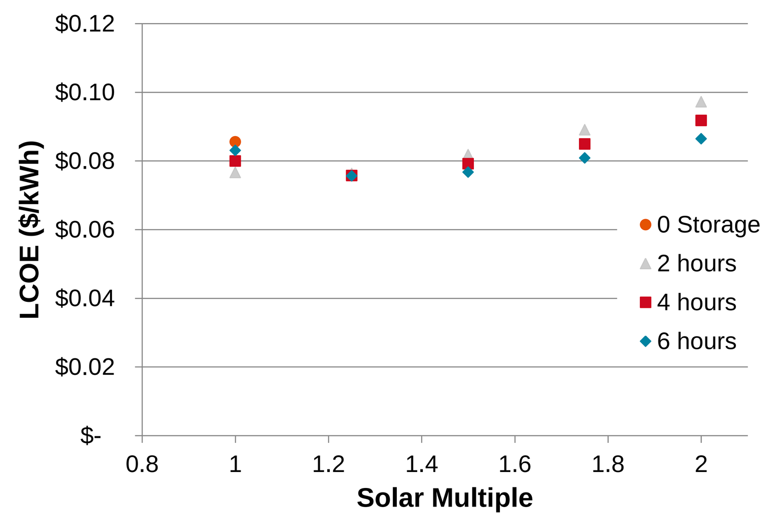
System Level Model

Field-level model

- Dish-to-dish shading
- Annual meteorological data (15-minute)

Storage accumulator model

- Thermal input from met data
- Thermal output when engine running
- Shed energy when full (lost)
- Measured data with heat pipe receiver



Clear financial benefit

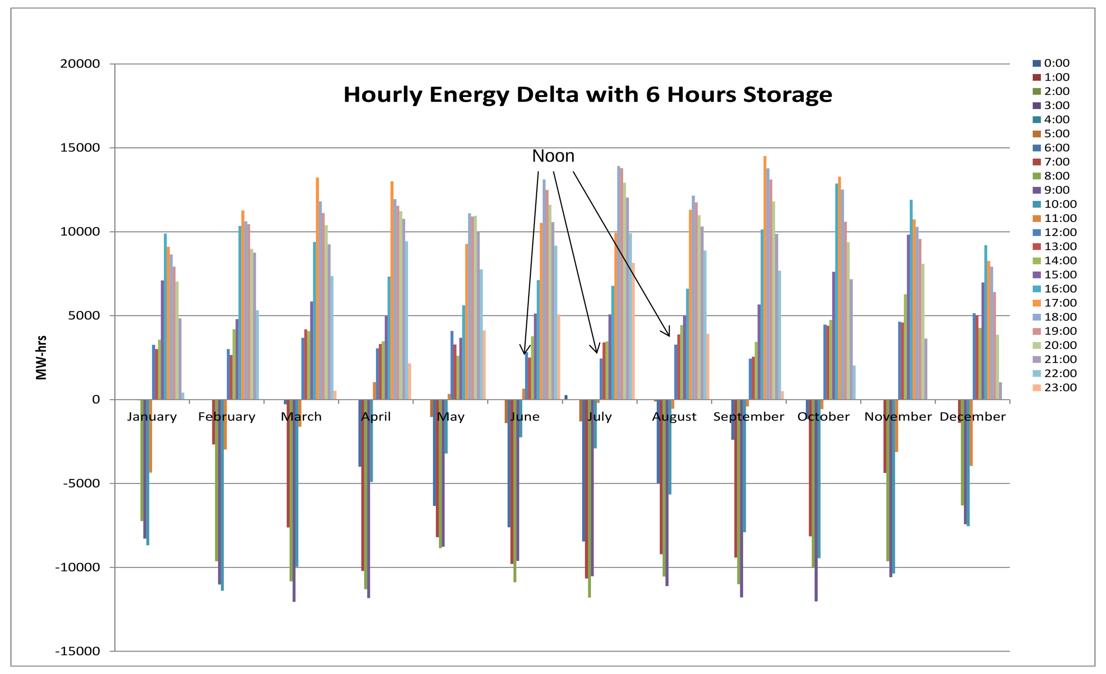
- About 1¢/kWh LCOE
- 2 ¢/kWh profit, due to TOD mapping

Clear optimum in Solar Multiple at 1.25 for cases studied

- Greater storage improves LCOE to a point
- Better amortization of equipment costs
- Too much storage cannot be consistently used

Financial model

- Calculate LCOE based on 7.42% FCR
- Calculate "profit" based on SCE TOD
- Adjust dish and spacing proportional to solar multiple
- Fixed and variable cost of storage
  - $3k/dish fixed
  - $20/kWh$_{th}$ variable with storage size
- System cost set to $2/W



Total energy increase

- Greater collection area (solar multiple)
- Higher efficiency (always at design point of engine)

Summer afternoon critical to profit

Model inputs exercised

- Size of storage
- Solar multiple
- Control modes

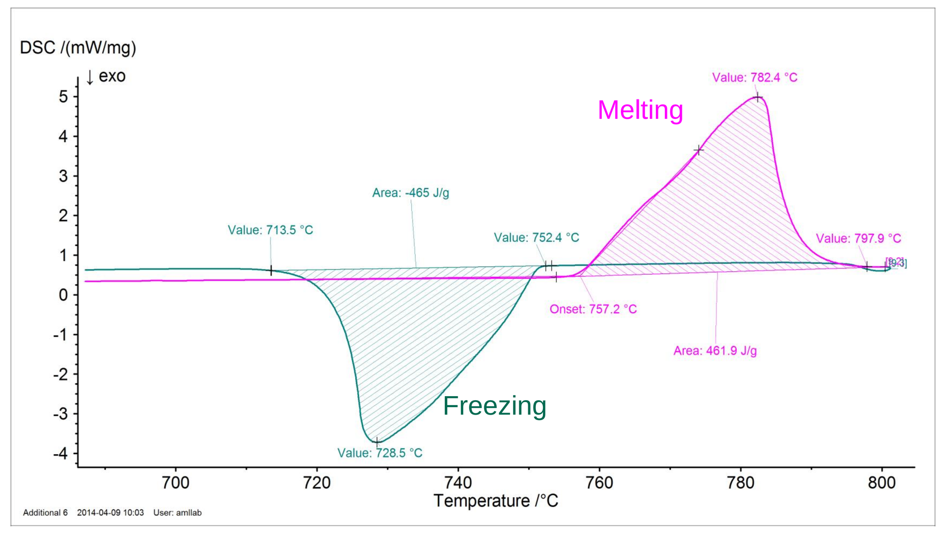
Phase Change Material (PCM)

PCM Development and Selection

- Melting point goal 750-800°C
- Down Selected to metallic PCM's
  - High conductivity
  - High storage capacity
  - 2-D numeric modeling
- Two potential PCM's identified
  - Literature
  - FactSage modeling
  - Phase diagrams
- Ternary CuMgSi Selected

PCM Fabrication

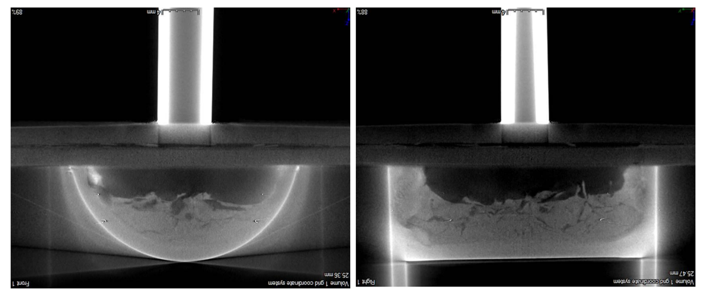
- Literature compositions varied
- Large variations of melt points of constituents and volatility made manufacturing technique elusive
- Successfully fabriacted 3 literature compositions
  - Confirmed Birchenal
  - Confirmed high heat capacity
- Detailed exploration around terminal eutectic
  - 462 J/g
  - 757°C Onset of Melt
  - 10°C/min ramp rate in DSC



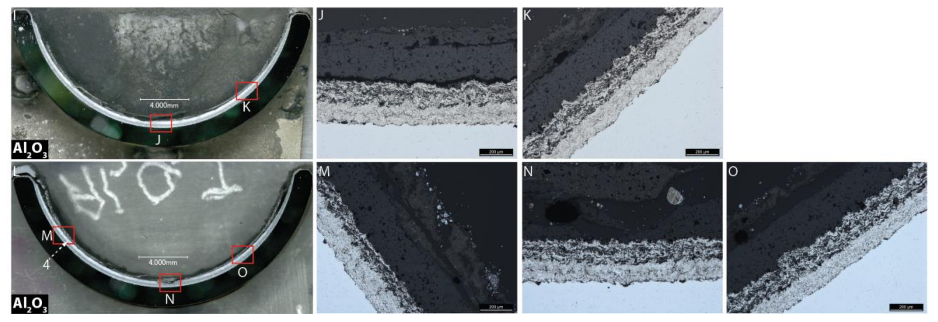
Ternary PCM Heat of Melting Characterization

PCM Compatibility

- Short-term testing demonstrated acute attack
  - 30% loss of containment in 150 hours
  - 3 containment alloys tested
- Protective coating development
  - Complex geometry limits options
  - Initial focus on solution coatings
  - Later focus on commercial thermal spray
  - J-tube test avoided weld and sealing issues
- Approach
  - Identify potential candidates by Gibbs Free Energy
  - Powdered XRD after crucible exposure
  - Sample boat coating exposure
    - Sectioning
    - X-Ray CT scans
- Results
  - $MgAl_2O_4$ and Al_2O_3 promising
  - Inconsistent vendor-to-vendor results



Coating Boat x-ray CT for Al_2O_3



Sectioning of AL_2O_3 showing no degradation after 500 hours

Air furnace and closed boat assembly

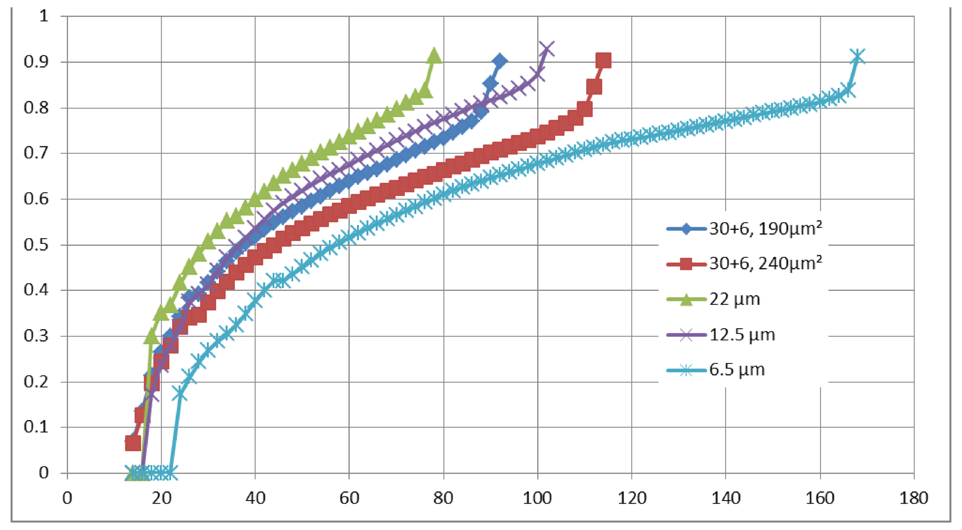
Advanced Heat Pipe Receiver

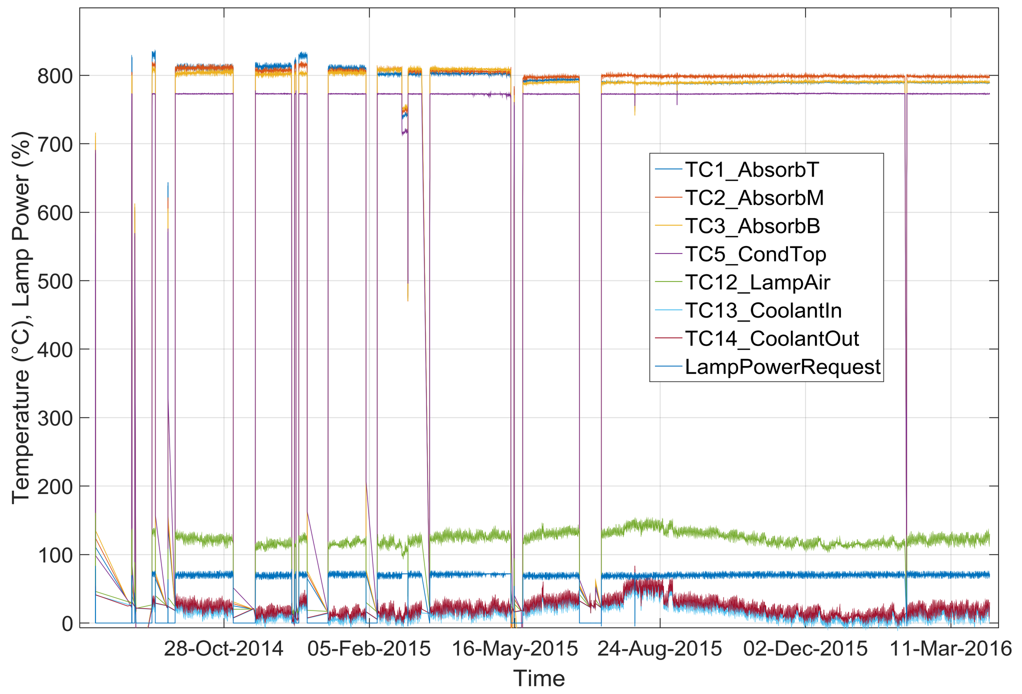
Advanced Wick Development

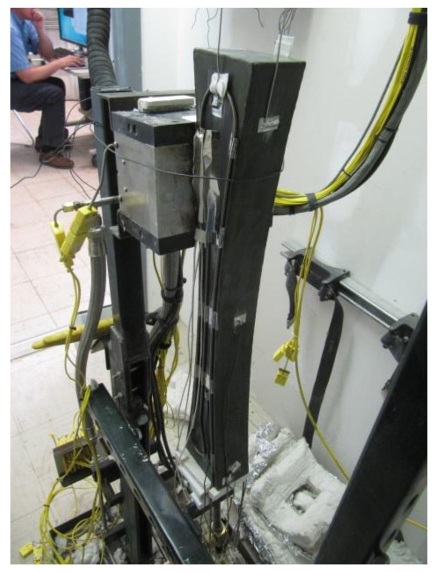
- Leverage felt wick concept for high performance through distributed pore sizes
- Enhance durability
  - Blended fiber sizes
  - Periodic support posts
- Permeability and pore distribution characterization
- Thermal loading

Wick Model

- Full scale receiver with realistic flux distribution
- 80kW throughput
- Correlate to bench scale 2.1kW model
- Permit vapor generation within wick



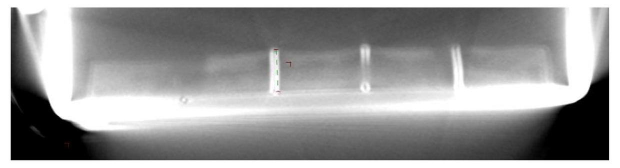




Bench-scale heat pipe durability test rig

Durability Testing

- Completed over 12,000 hours
  - 1.5kW throughput
  - 800°C
- Periodic x-ray tomography confirms no wick collapse
- No change in operational characteristics



X-ray CT confirms no wick compression

SunShot U.S. Department of Energy

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