Novel Molten Salts Thermal Energy Storage for Concentrating Solar Power Generation

Funding Organization: DE-Solar Energy Technologies Program

Performing Organization: The University of Alabama (UA)

Industrial Partner: United Technologies Research Center

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Project Overview Slide

1. Project Objective: To develop low melting point (LMP) molten salt mixtures that have the following characteristics:

- Lower melting point compared to current salts (<225 °C)

- Higher energy density compared to current salts (> 300-756* MJ/m^3)

- Lower power generation cost compared to current salts (target DOE 2020 goal of Thermal Energy Storage(TES) cost < \$15/kWh$_{thermal}$ with >93% round trip efficiency)

2. Major Activities in 2010

(a) Completed experimental determination of melting point, heat capacity, density, viscosity, thermal stability, thermal conductivity and corrosivity to stainless steel of the nine salt mixtures

(b Completed atomic/molecular modeling of heat capacity, density, viscosity, thermal conductivity of the salt mixtures

(c) Completed the TES system modeling and two novel changes were recommended

3. Planned Milestones in 2011

Develop and setup laboratory scale TES system based on the Phase II results for verification and validation of molten salts and system concepts

Major Accomplishments in 2010

(a) Nine salt mixtures were identified as possible TES materials (M.P. <222 C)

(b) Experimental determination of melting point, heat capacity, density, viscosity, thermal stability, thermal conductivity, and corrosivity of stainless steel in the nine salt mixtures was completed

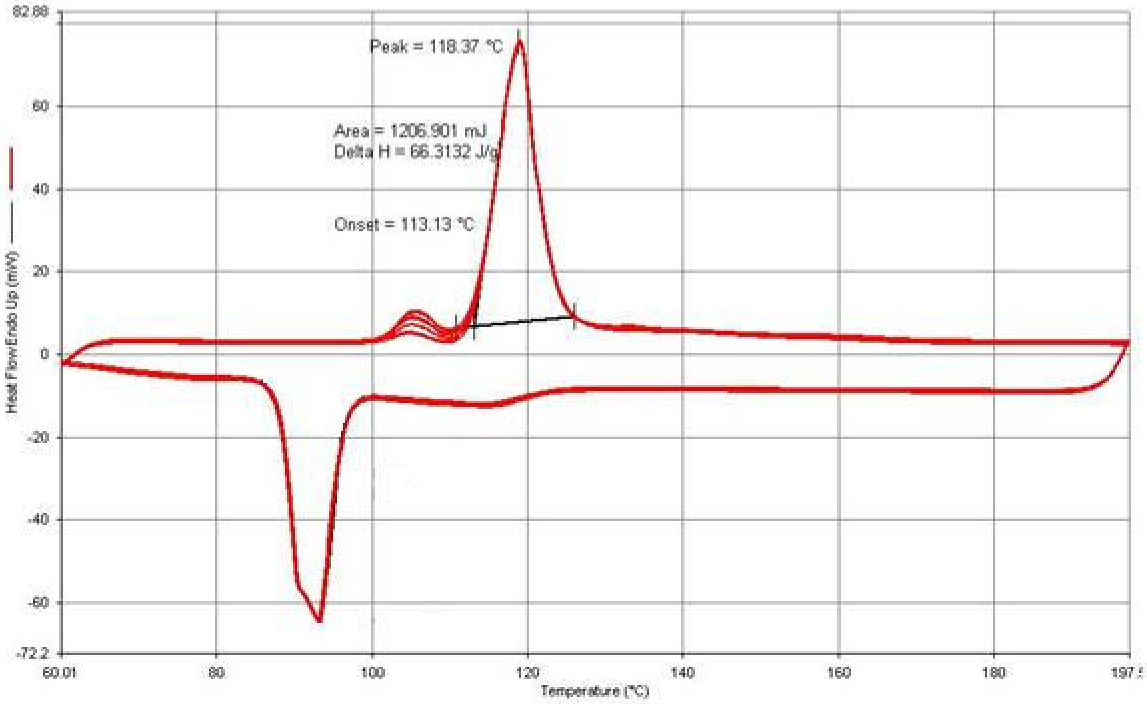
(c) Atomic/molecular modeling of heat capacity, density, viscosity, thermal conductivity was completed for the salt mixtures

(d) All nine salt mixtures have melting temperatures in the range of 89-124°C, and energy storage density from 980 MJ/m^3 to 1230 MJ/m^3 which is a 29-63% improvement over the current salt

(e) Completed the TES system modeling and two novel changes were recommended (1) use of molten salt as a HTF through the solar trough field, and (2) use the salt to not only create steam but also to preheat the condensed feed water for Rankine cycle.

Melting Point Determination

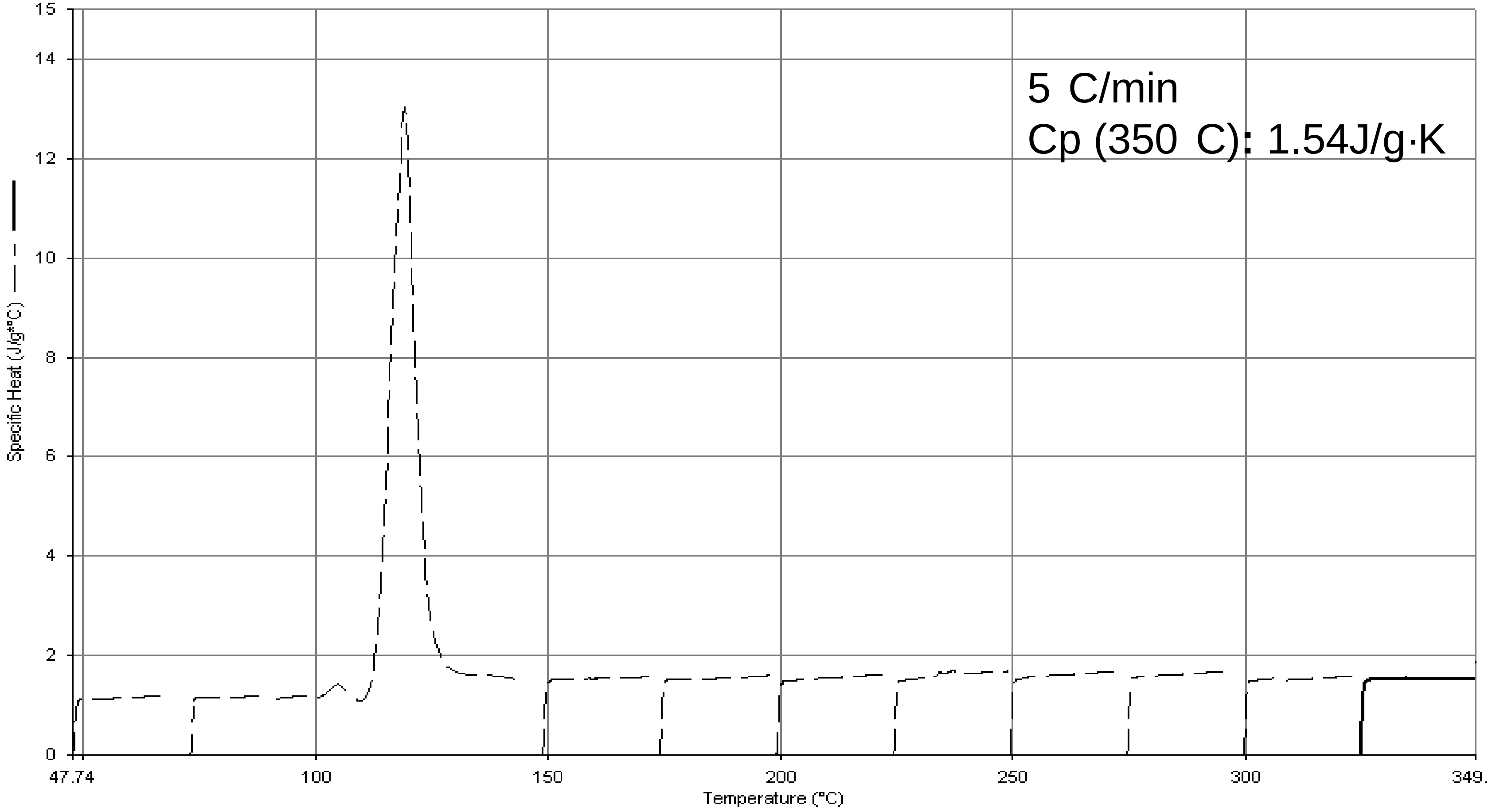
$LiNO_3 – NaNO_3 – KNO_3$



DSC plot for the $LiNO_3$-$NaNO\text{-}_3$-KNO_3 ternary system showing the melting temperature.

Heat Capacity Determination

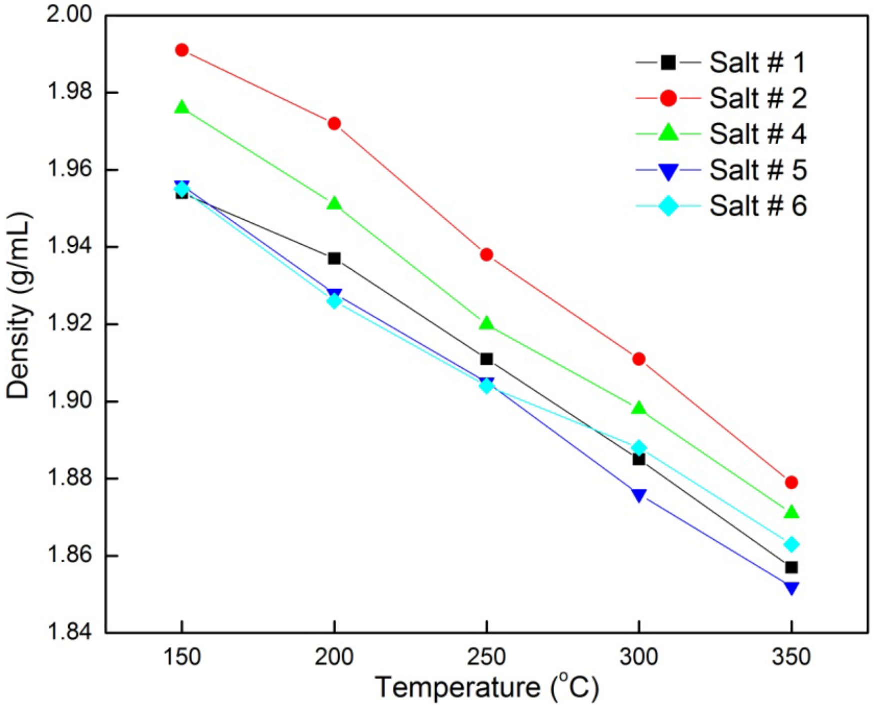
$LiNO_3 – NaNO_3 – KNO_3$

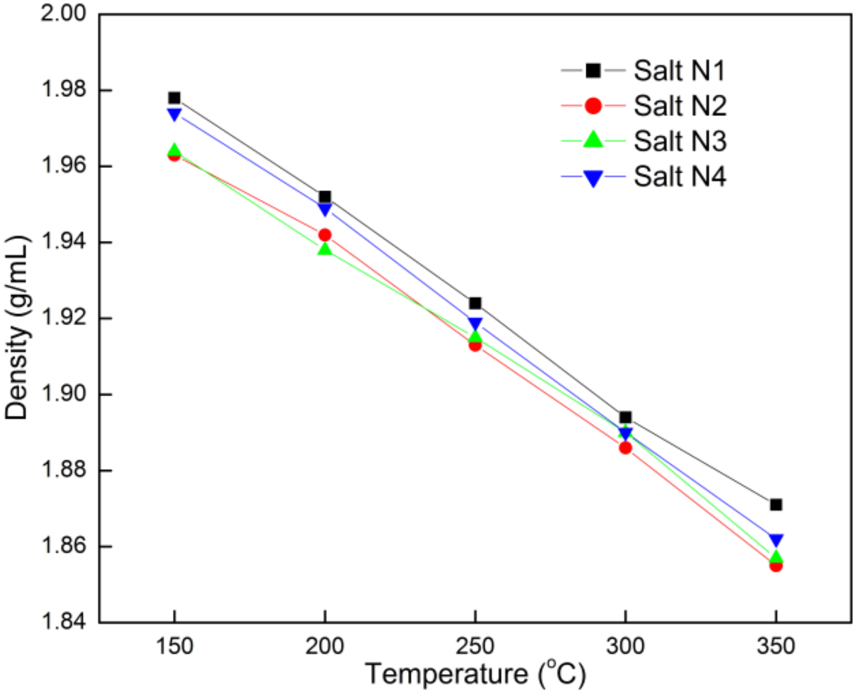


Melting point and Heat Capacities of Salt Mixtures

Salt #	System	Calc. M. P. C	Expt. Peak, C	Calc. Cp, J/g.K	Expt. Cp, J/g.K
1	$LiNO_3$- $NaNO_3$- KNO_3	116	119.1	1.60	1.53
2	$NaNO_3$- $NaNO_2$- KNO_3	123.8	124	1.46	1.43
4	$LiNO_3$- $NaNO_3$- KNO_3- MgK	98.6	101	1.58	1.48
5	$LiNO_3$- $NaNO_3$- KNO_3- $NaNO_2$	98.6	99.9	1.56	1.55
6	$LiNO_3$- $NaNO_3$- $NaNO_2$-KNO_3- KNO_2	95.7	95	1.54	1.51
N1	$LiNO_3$-$NaNO_3$-KNO_3-KNO_2	100	96	1.49	1.51
N2	$LiNO_3$-KNO_3-$NaNO_2$-KNO_2	106.8	100	1.53	1.56
N3	$LiNO_3$-KNO_3-$NaNO_2$-$Mg(NO_3)_2$	108.1	101.9	1.54	1.55
N4	$LiNO_3$-$NaNO_3$-KNO_3-$Mg(NO_3)_2$-MgK	103.6	89.2	1.61	1.61

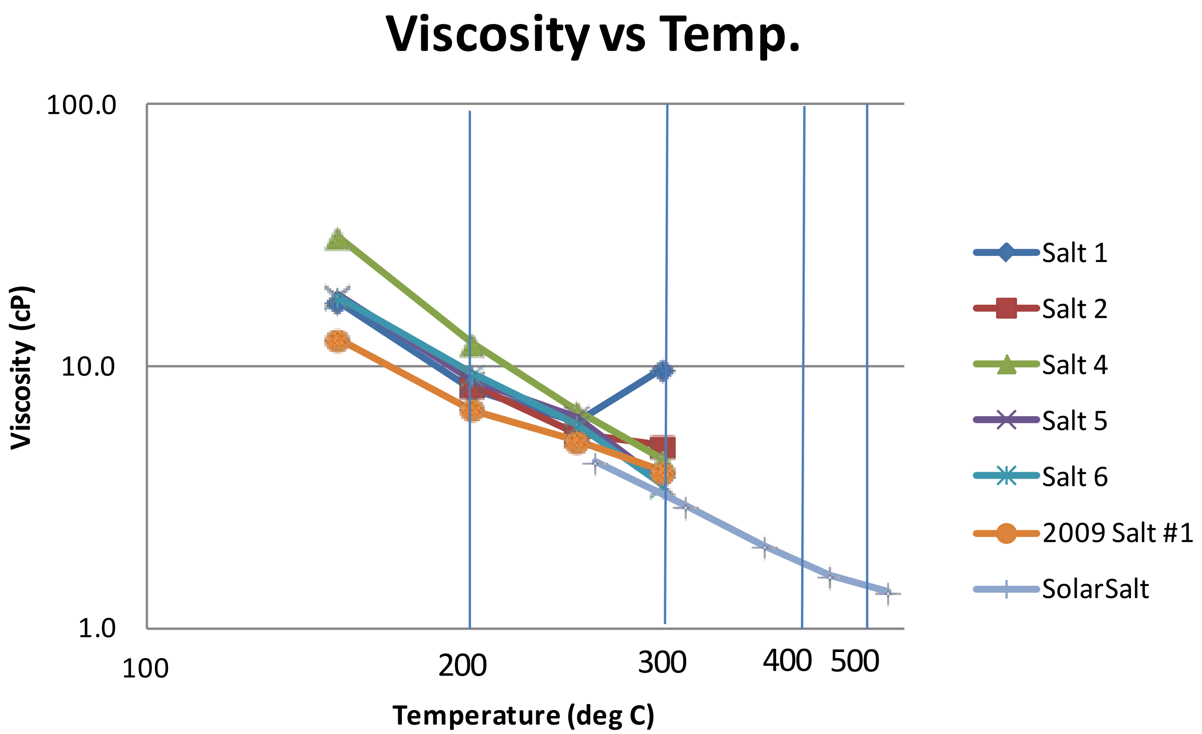
Liquid Densities of Salt Mixtures





Densities as function of temperature

Viscosity of Salt Mixtures



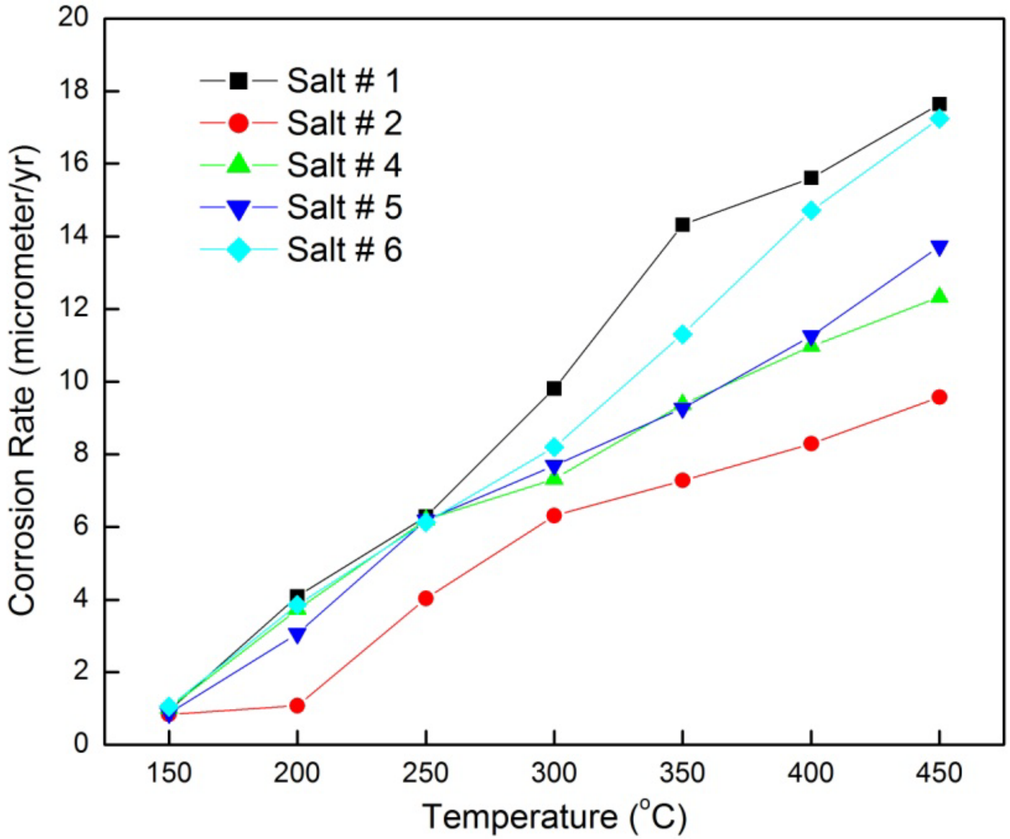
Viscosity data for Phase 1 mixtures compared to Solar Salt literature values

Viscosity curves mirror response of solar "nitrate" salt

Thermal conductivities of Salt Mixtures

Salt #	Expt. M. P. C	Thermal Conductivity (at M.P.), W/m.K
1	119	0.60
2	124	0.54
4	101	0.53
5	99	0.55
6	96	0.54
N1	96	0.54
N2	100	0.56
N3	102	0.55
N4	89	0.50

Corrosion Rates



$$r = \frac{3.27 i_{corr} W_i}{\rho}$$

In all cases, the corrosion rate at 500C is < 20 µm/year. This would imply less than a 400 µm corrosion over a 20 year lifetime, well within practical equipment limits for design purposes.

Heat and fluid flow modeling

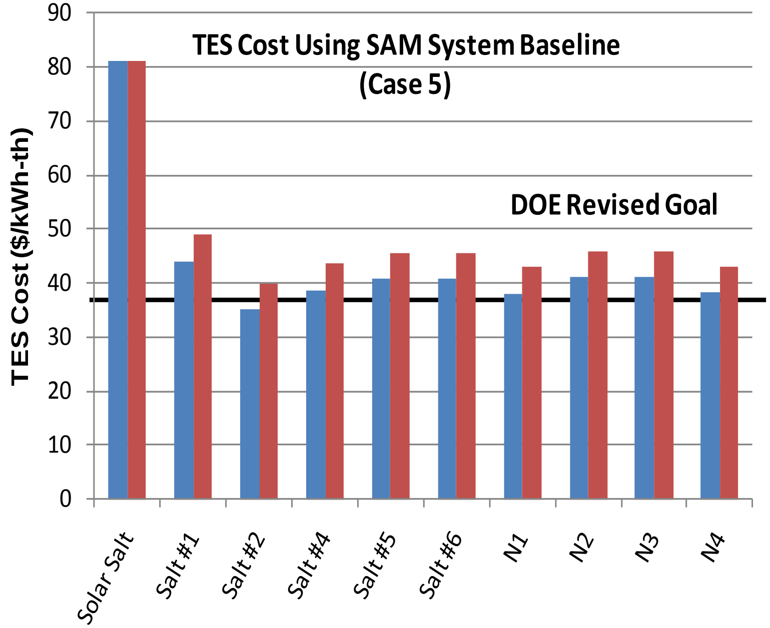
The goal is to conduct heat transfer and fluid dynamics modeling to enable selection of the best Thermal Energy Storage (TES) system, including system geometry for laboratory scale testing, and required data such as heat transfer coefficient and thermal conductivity.

Several concepts evaluated; two proposed for use of salt latent heat – two dismissed

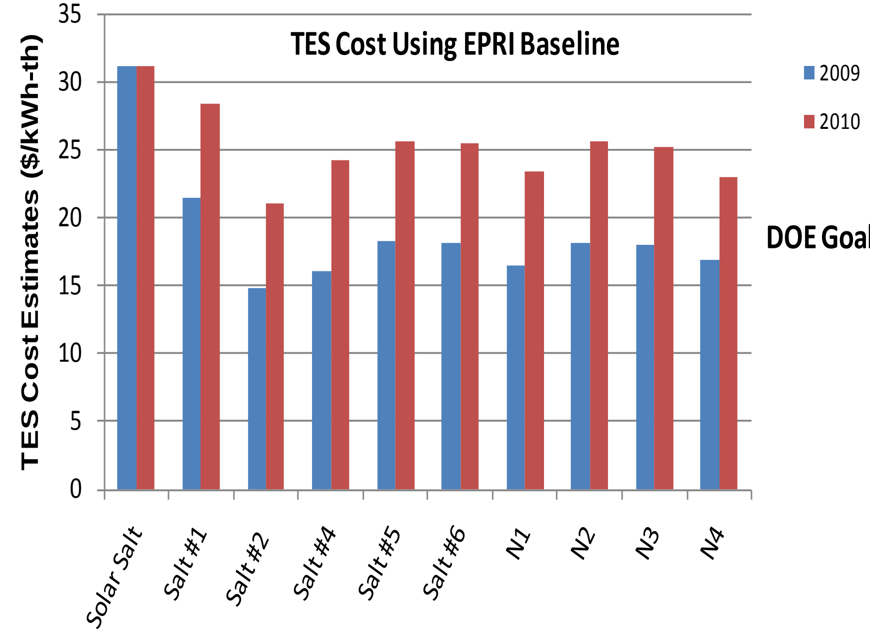
- **Use of 500 C heat capability for higher efficiency steam Rankine cycle (salt as HTF)**
- **Use of low temp range for feedwater preheating**
- **Use of low temp salt in an “additional” low pressure turbine re-heater**
- **Incorporate a separate bottoming cycle to utilize available thermal energy**

Graphical Comparison of TES Cost estimates

(SAM and EPRI Baselines – linear (blue) and .07 power (red) scaling)



Comparative TES costs using 2009 salt component prices. Blue bars use "linear" equipment cost scaling, red bars utilize "0.7 power law" equipment cost scaling.



TES Calculations using 2009 EPRI Baseline (from Phase I report). Blue bars assume full delta T and linear equipment scaling; red bars assume average properties at 350 C and 0.7 power scaling.

Linear TES scaling calculates to be lower than cost target – reasonable because of dramatic reduction in TES size (only 1/3 baseline)

Power factor scaling very close to cost targets

Round Trip Efficiency for TES System

Initial – efficiency	**100 %**
Loss to ambient due to tank storage time	**- 2.0 %**
Loss due to heat exchanger pinch point effect	**- 0.2 %**
Projected TES Efficiency	**97.8 %**

No oil-to-salt HEX reduces TES losses
Round trip efficiency exceeds 93% goal

Summary

- **Project work is progressing as per schedule**
- **Phase 2 Task accomplishments were presented**
- **Laboratory scale TES system will be developed and set up based on the modeling results from Phase II for verification and validation of molten salt system concepts.**
- **Detailed tests will be conducted to investigate the thermal performance of system, cycle life of molten salts and determine round-trip efficiency.**

Acknowledgements

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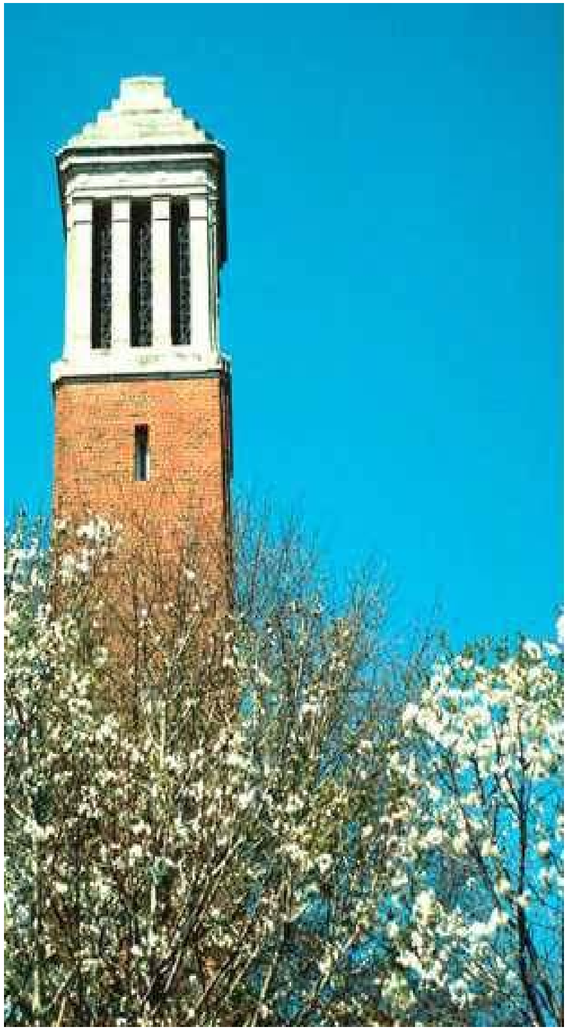

Thank you