Latent Heat Storage for Concentrating Solar Power

Heat Transfer and Latent Heat Storage in Inorganic Molten Salts for Concentrating Solar Thermal Power Plants

Anoop Mathur

Terrafore, Inc

June 5, 2009

terrafore

"….but sir, these are the same questions as last year…"

"Don't worry, the answers are different this year"

Prof. Albert Einstein

Advantages with Latent Heat Storage

- Thermal Energy Storage in Phase Change Material can potentially result in
  - 30% reduction in amount of molten salt
  - 60% reduction in container size
  - 2% to 3% improvement in overall system efficiency
  - Flexibility to operate with different steam cycles
  - Flexibility to store energy when collection temperature less than designed high temperature

Potential to reduce LCOE costs by 6% to 9%

terrafore

Thermal Energy Storage for Solar Thermal Power Plants

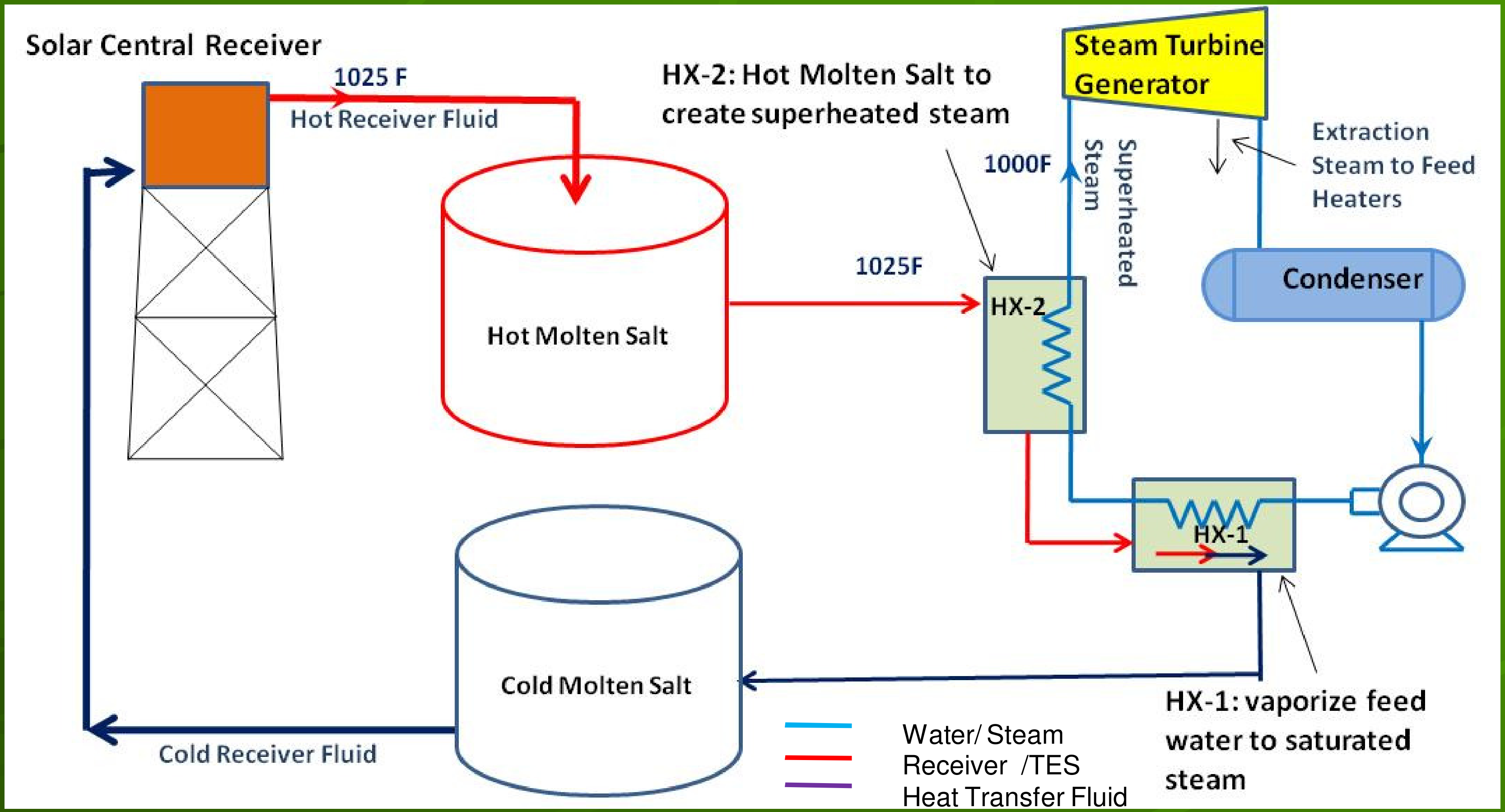
- Generate electricity *when we want and not just when the sun shines*.
- CSP Applications
  - Power Tower, Trough, Linear Fresnel, …
  - Operating temperatures between 275 C to 570 C
  - Sizes 200 kWe to 100's of MWe
  - Urban and Remote Locations

Require salt mixtures melting between 275 C to 350 C to accommodate most power plant steam cycles

Types of Thermal Storage

- There are different ways to store thermal energy
  - sensible heat in high temperature oils or low melting molten salt mixtures, dual media eg. rock and oil
  - phase change heat or latent heat when solid melts and freezes. Vaporization and boiling phase change is not practical
  - chemical energy. Heat of reaction in reversible chemical reactions, or heat of adsorption /desorption of gases, hydration / dehydration

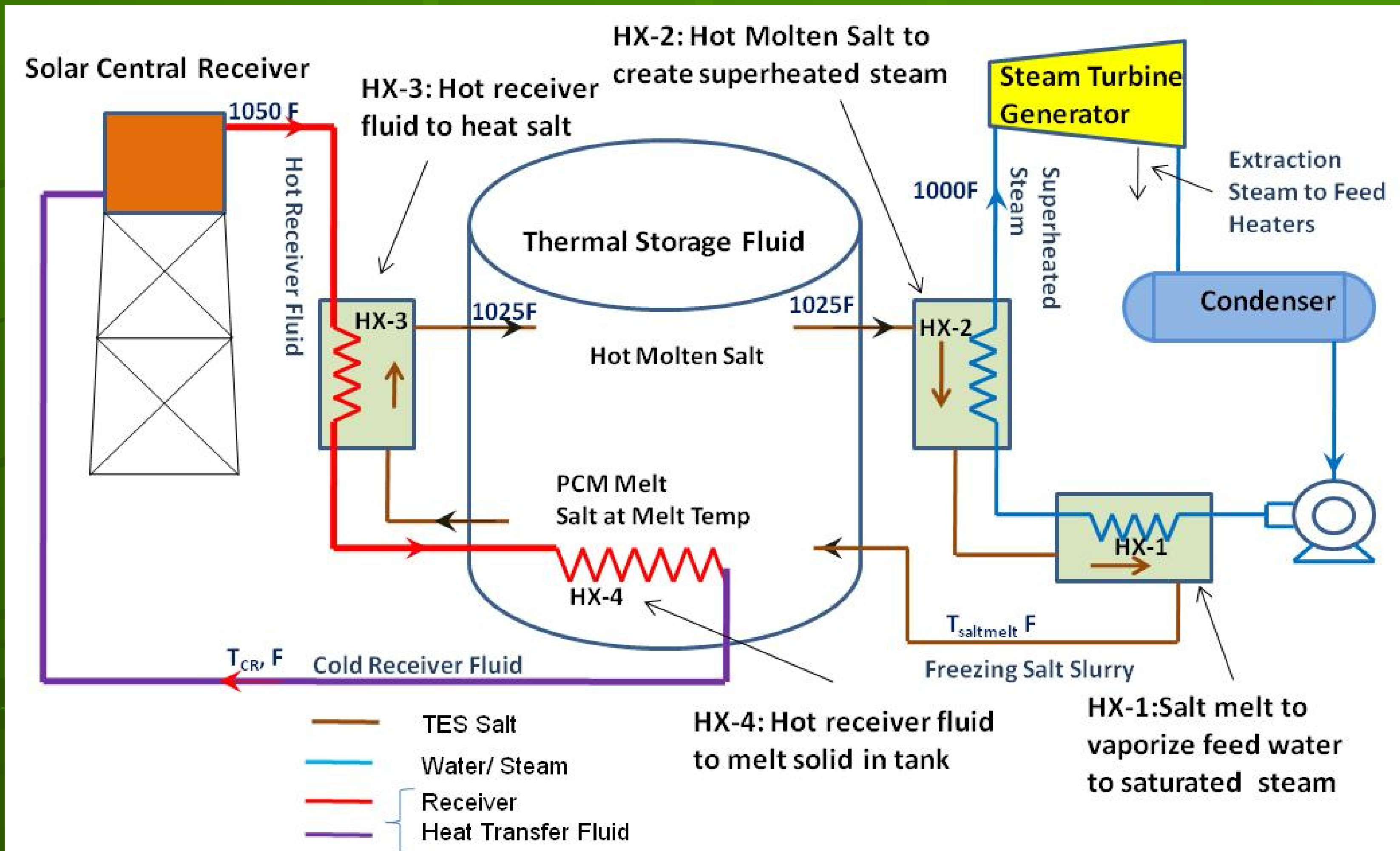
Sensible Heat TES Schematic for Concentrated Solar Power



Types of Sensible TES: Two tank single media in molten salts, oils or one tank stratified tank or dual media stratified tank

terrafore

A PCM-based TES Schematic for Concentrated Solar Power Tower



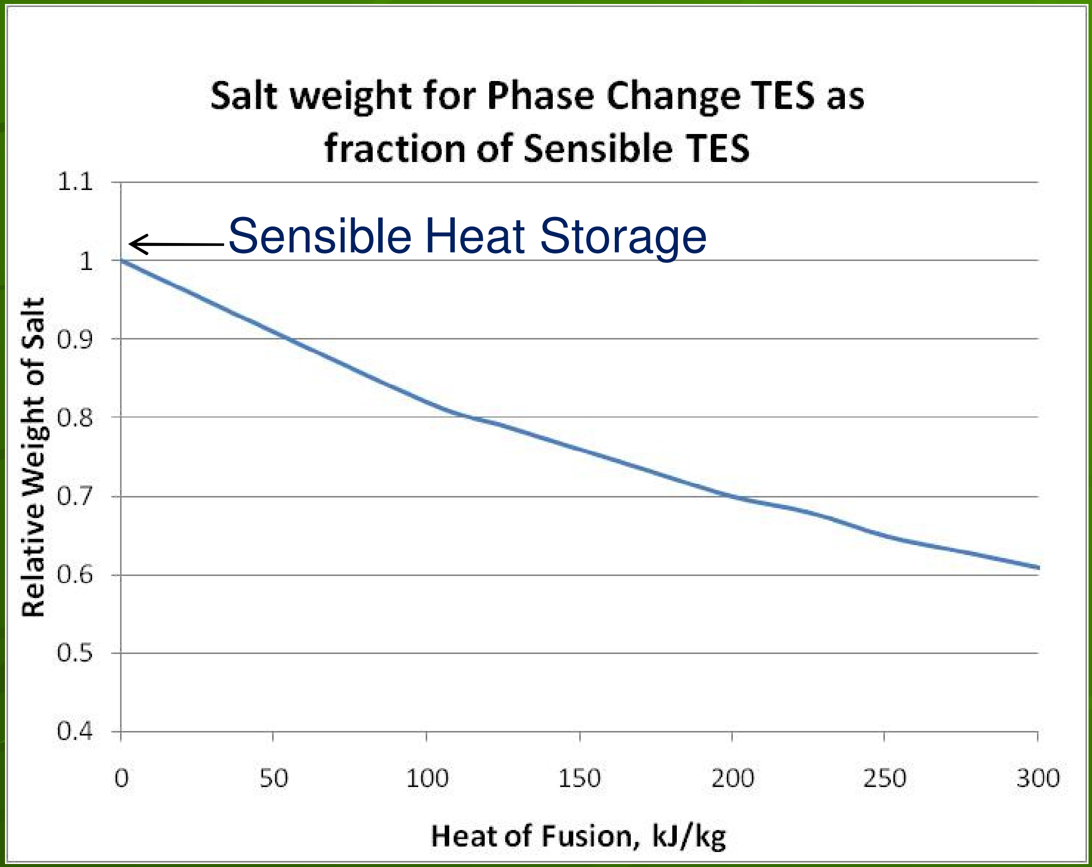
PCM-based TES design reduces TES size by 25% to 56%. Research underway to solve reduced heat transfer when heat is discharged

Why Store Heat as Latent Heat in PCM

- Reduces the amount of salt required and hence container size

Amount of Salt Required

PCM vs Sensible TES



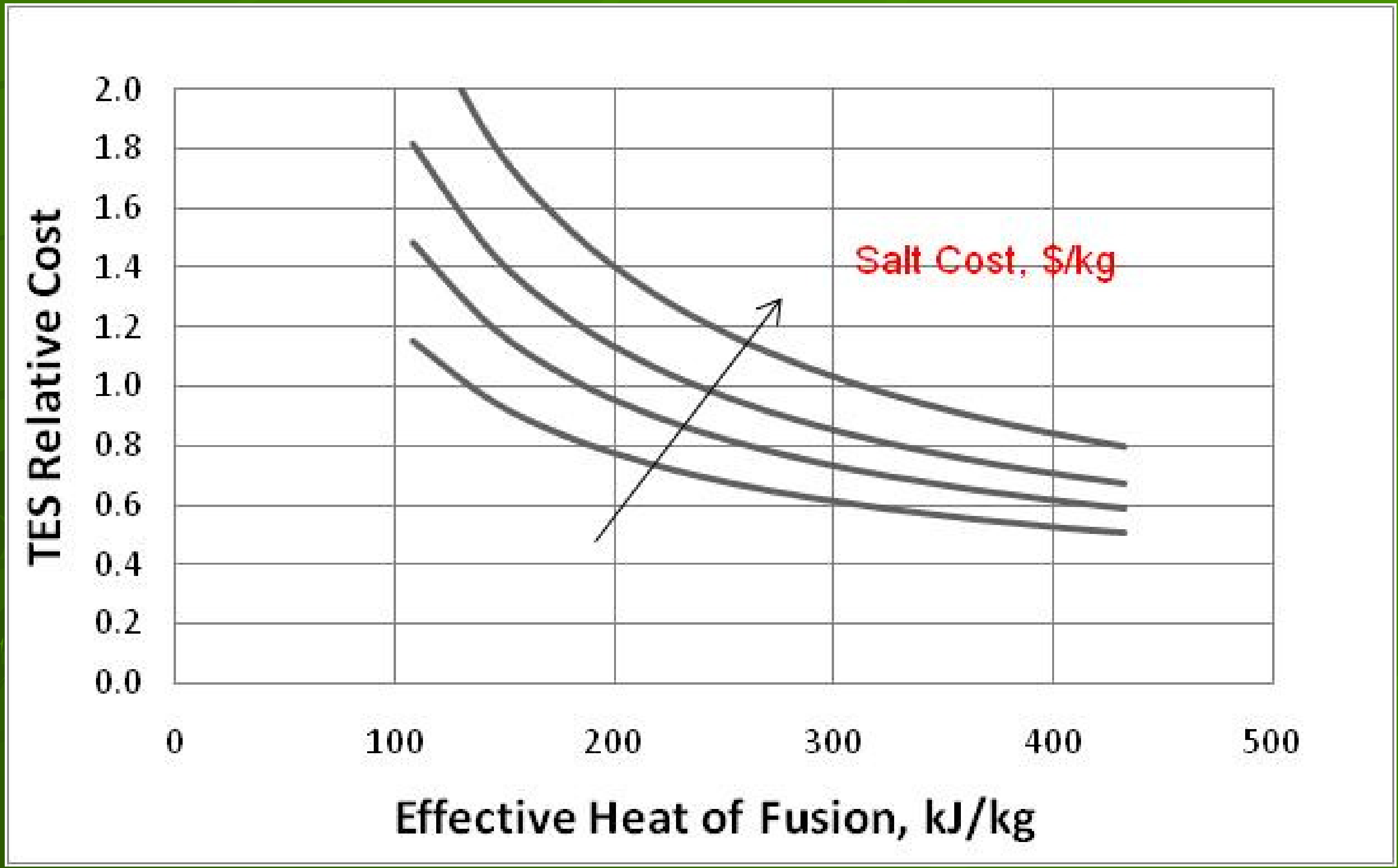
Typical reduction in salt volume over a sensible heat system = 30%

Typical reduction in tank volume over a sensible heat system = 65%

Much less salt is required for PCM-based system than sensible heat TES systems because of high heat of fusion of PCM

terrafore

Relative TES Costs vs Heat of Fusion and Salt Cost



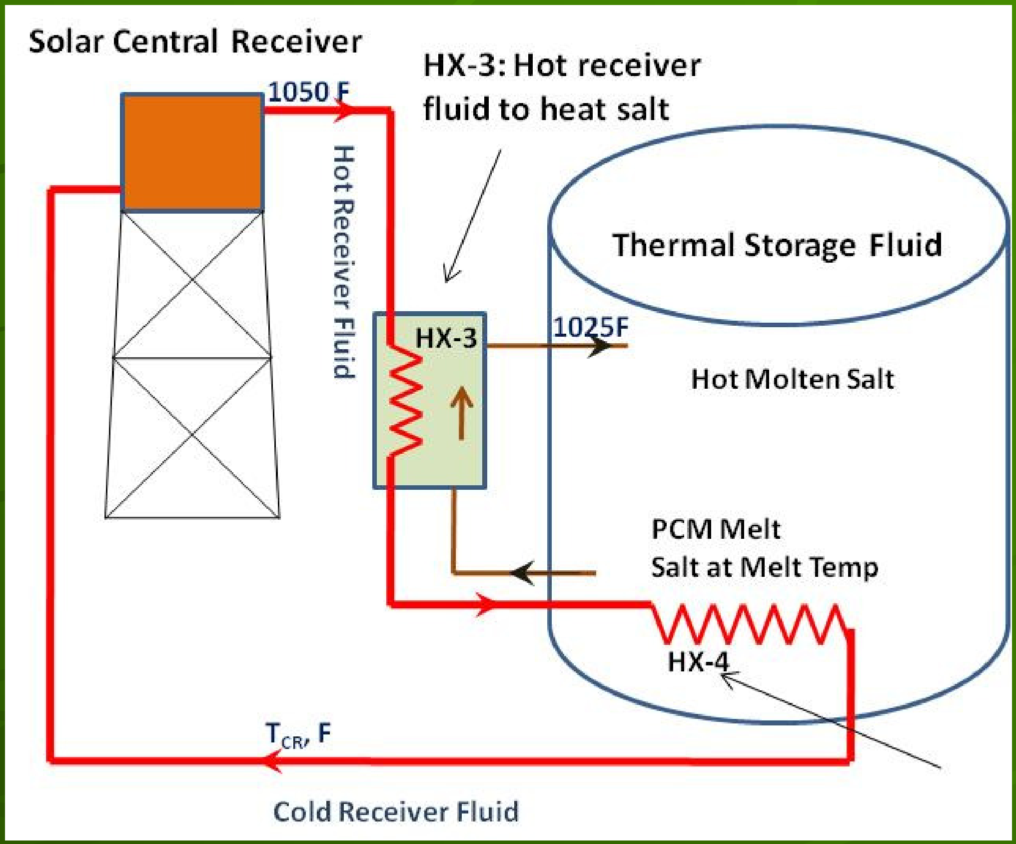
High heat of fusion and low salt specific cost desired

terrafore

Why Store Heat as Latent Heat in PCM

- Reduces the amount of salt required and hence container size
- Improves charge cycle efficiency and provides operational flexibility

Charge Cycle

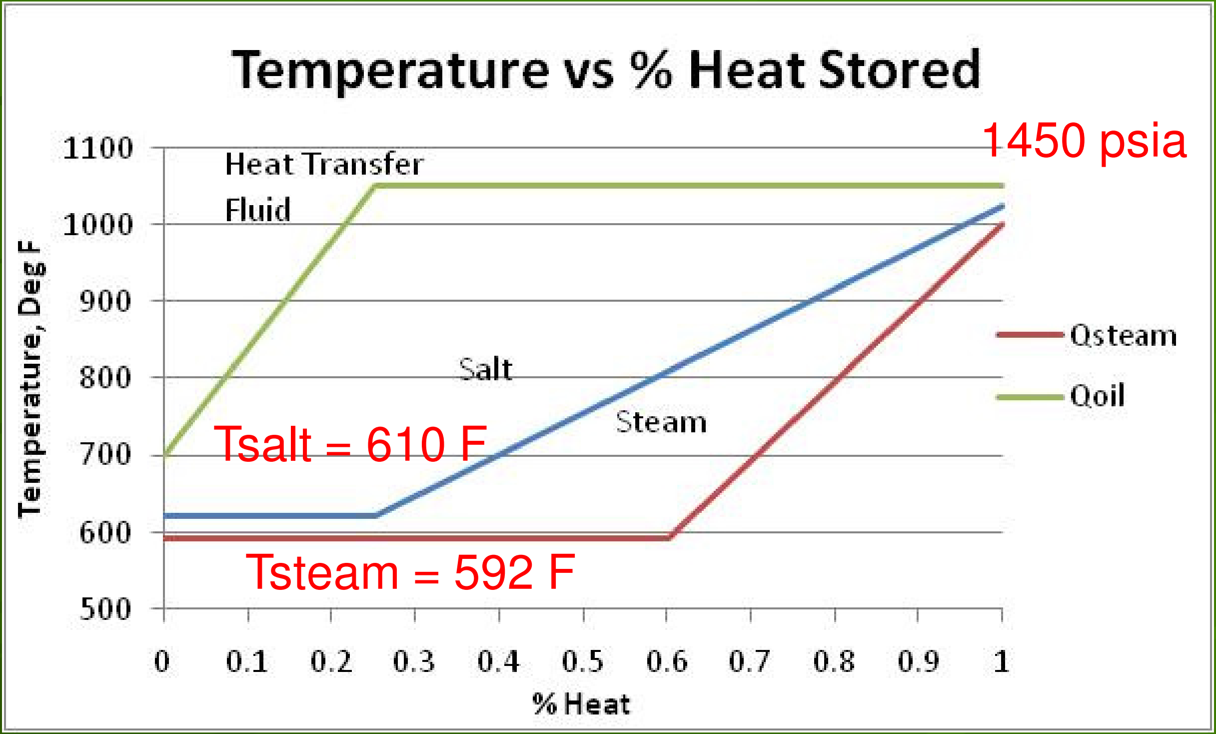


- **HTF temperature is allowed to float to an optimum temp during low solar insolation**
- **PCM melt flow is controlled to maintain hot molten salt temperature**

Average HTF temperature during charge cycle can be lower than for a sensible heat storage

terrafore

Improved Charge Cycle Efficiency



25% of the time the HTF temperature from Tower can be less than the design temperature but controlled to be greater than the salt melting temperature .

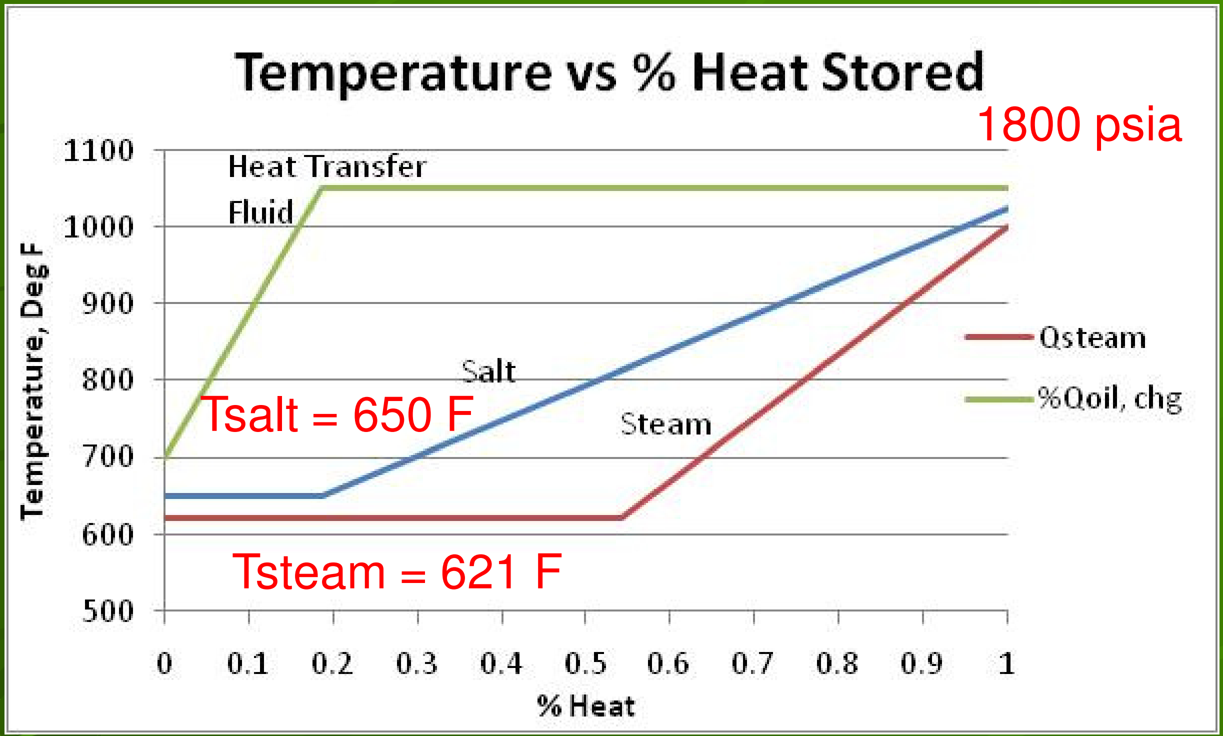
Optimize for receiver collection temperature during cloud transients and low solar insolation.

terrafore

Why Store Heat as Latent Heat in PCM

- Reduces the amount of salt required and hence container size.
- Improves charge cycle efficiency and provides operational flexibility
- Improves the thermal to electric conversion thermodynamic efficiency

Improved System Efficiency



Since HTF is independent of storage media, higher steam pressure cycles can be used.

Select salt melting point to be above the steam vaporization temperature

terrafore

Salt Melting Point vs. Steam Turbine Cycle Conditions

Salt Melting Point (deg F)	Steam Turbine Cycle (psia/ deg F)	Normalized Turbine Heat Rate
570	1250 / 950	93%
620	1450 / 1000	100%
650	1800 / 1000	105%
660 to 900	2400 /1000	109%

Higher pressure steam cycles improve turbine heat rate and system efficiency

How do we Select Salt Mixture

- Salt melting temperatures between 275C to 350C
- Salt Mixtures with following desired properties:
  - High heat of fusion
  - High chemical and thermal cycling stability
  - Low specific cost
  - Low toxicity
  - Low corrosivity
  - Withstand >5000 freeze-thaw cycles
  - *Simple eutectic phase diagram*

Identified eighteen salt mixtures that meet our criteria

terrafore

What is the Major Challenge with Latent Heat Thermal Energy Storage

- When salt solidifies on heat exchanger surfaces, the heat transfer rate decreases significantly requiring large heat exchangers

Getting heat out cost effectively is difficult

Heat Rate Issue with PCM-TES

Heat Rate (q) Equation

$q = U \; A \; \Delta T$

To increase heat rate two options:

Increase (U) or Increase (A)

- **Actively remove salt to Increase U**
  - **Several active salt removal techniques**
  - ***Research underway on DOE /Terrafore project for large scale CSP systems***
- Encapsulate to Increase A
  - Issue is finding shell material compatible with salt
  - Issue is dealing with salt volume change on freezing
  - *Research underway at Terrafore*

Benefits outweigh the initial costs

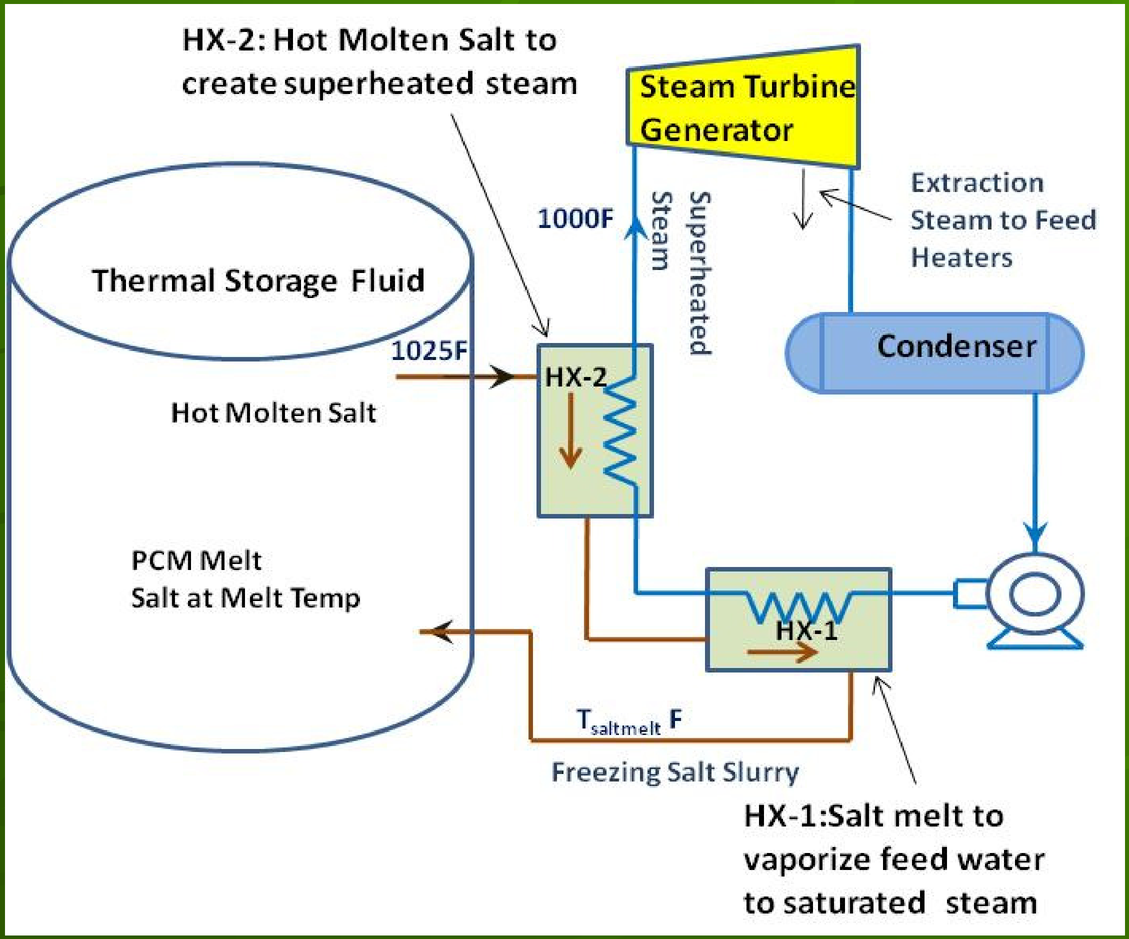
A Solution for Latent Heat Transfer

Terrafore's innovative approach (active removal of salt from tubes) has three elements:

- A *dilute* composition of salt mixtures that form a eutectic with a specific phase diagram called *simple* phase diagram
- An additive(s) that will cause the salt to solidify as a slush which can be easily washed off the heat transfer surface;
- A coating on the heat exchanger tubes that discourages strong adhesion of freezing salt;

Use a shell and coated tube heat exchangers

TES Discharge Cycle



- Research underway at Terrafore to select salt mixture, and design *active* heat exchangers to improve heat transfer coefficient

- *Microencapsulation is another technique to increase surface area and hence heat rate*

Experiments with a laboratory prototype planned for 2010.

terrafore

Summary

- Thermal Energy Storage in Phase Change Material can potentially result in
  - 30% reduction in amount of molten salt
  - 60% reduction in container size
  - 2% to 3% improvement in overall system efficiency
  - Flexibility to operate with different steam cycles
  - Flexibility to store energy when collection temperature less than top storage temperature
  - Net decrease in life cycle cost of energy by 6% to 9%