# Thermal Energy Storage (TES) for Concentrating Solar Power (CSP)

*CSP –TES Value Proposition :*

*"Solar power generation independent of the diurnal cycle"*


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# Thermal Energy Storage (TES) Roadmap Towards SunShot Cost Goal

NOW → 2 Years → 5 Years

Two Tank Sensible Heat TES ,$30 /kWht)

1. TerraKline A **Dual Media Managed Thermocline TES $22/kWht**

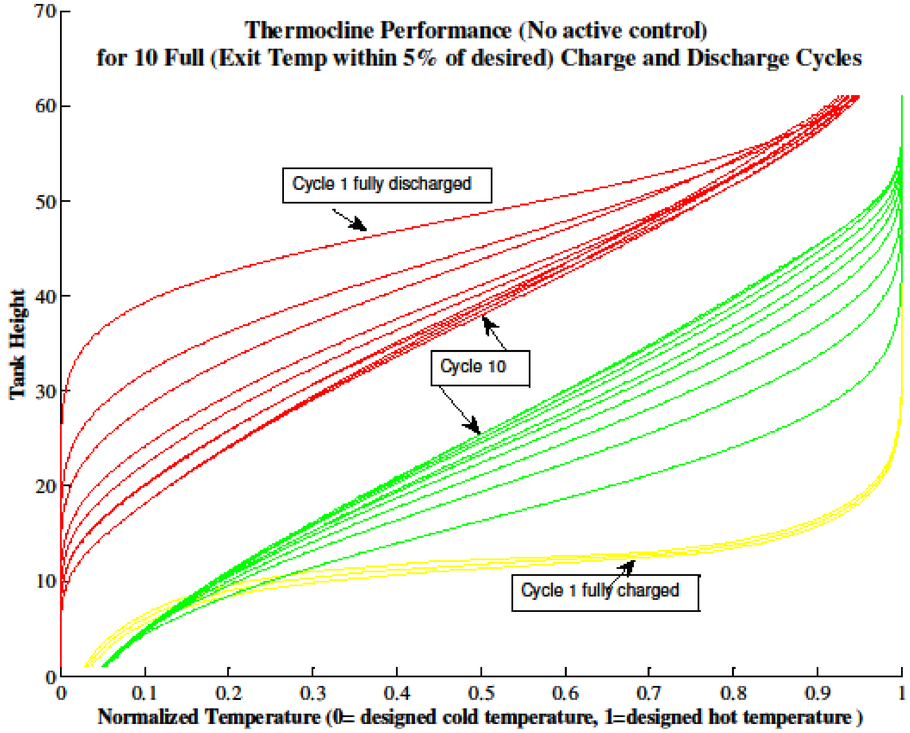
2. TerraCaps **Cascaded Encapsulated Phase Change TES $16/kWht**

SunShot Goal $15/kWht

# 1. A Dual Media Thermocline Thermal Storage

## Challenge

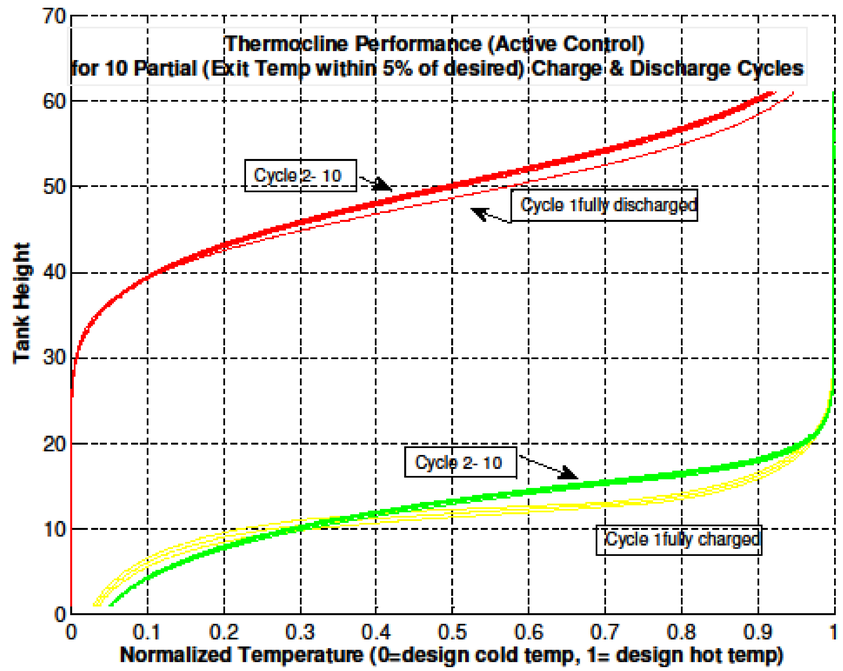
Thermocline Degrades with every charge and discharge




## Solution

✓**TerraKline Managed Thermocline**

TerraKline Restores Thermocline diurnally



# 2. An Encapsulated Phase Change TES

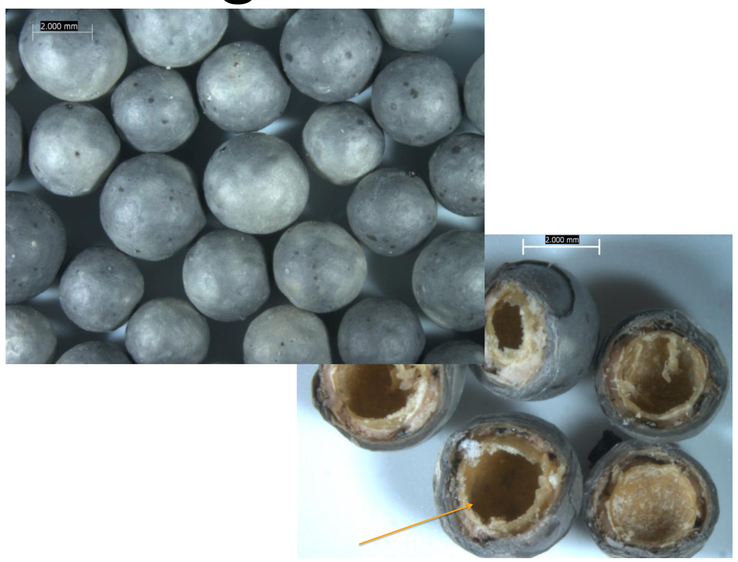
## A DoE Project Technology Breakthrough

### Challenge

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

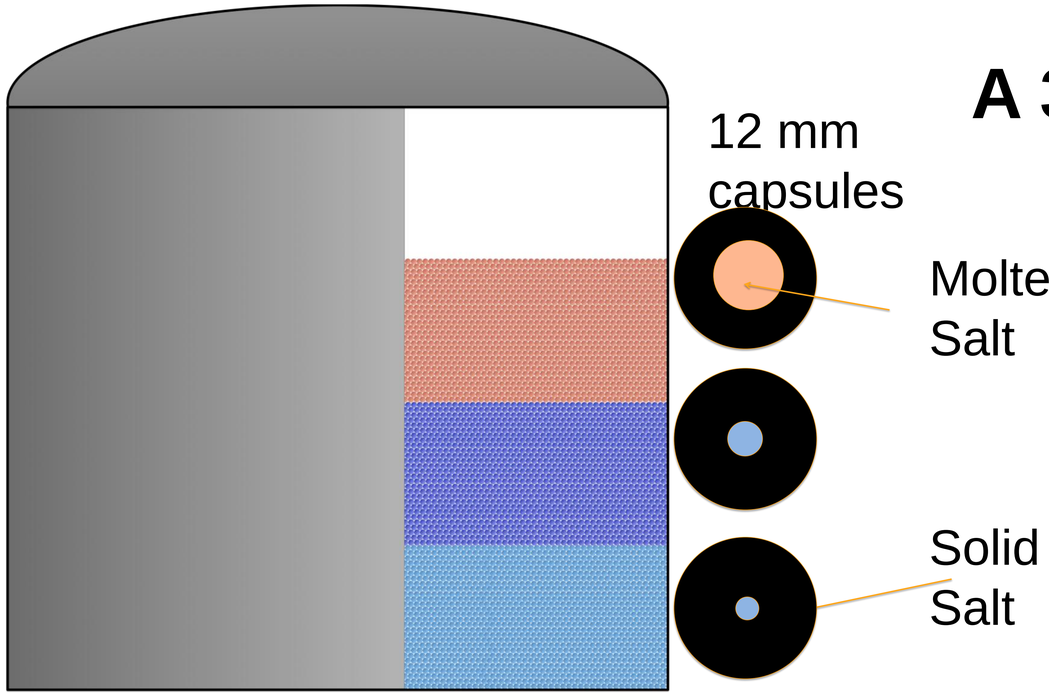
### Solution TerraCaps.

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



Void for Expansion of Salt

# 2. An Encapsulated Phase Change TES (Contd.)



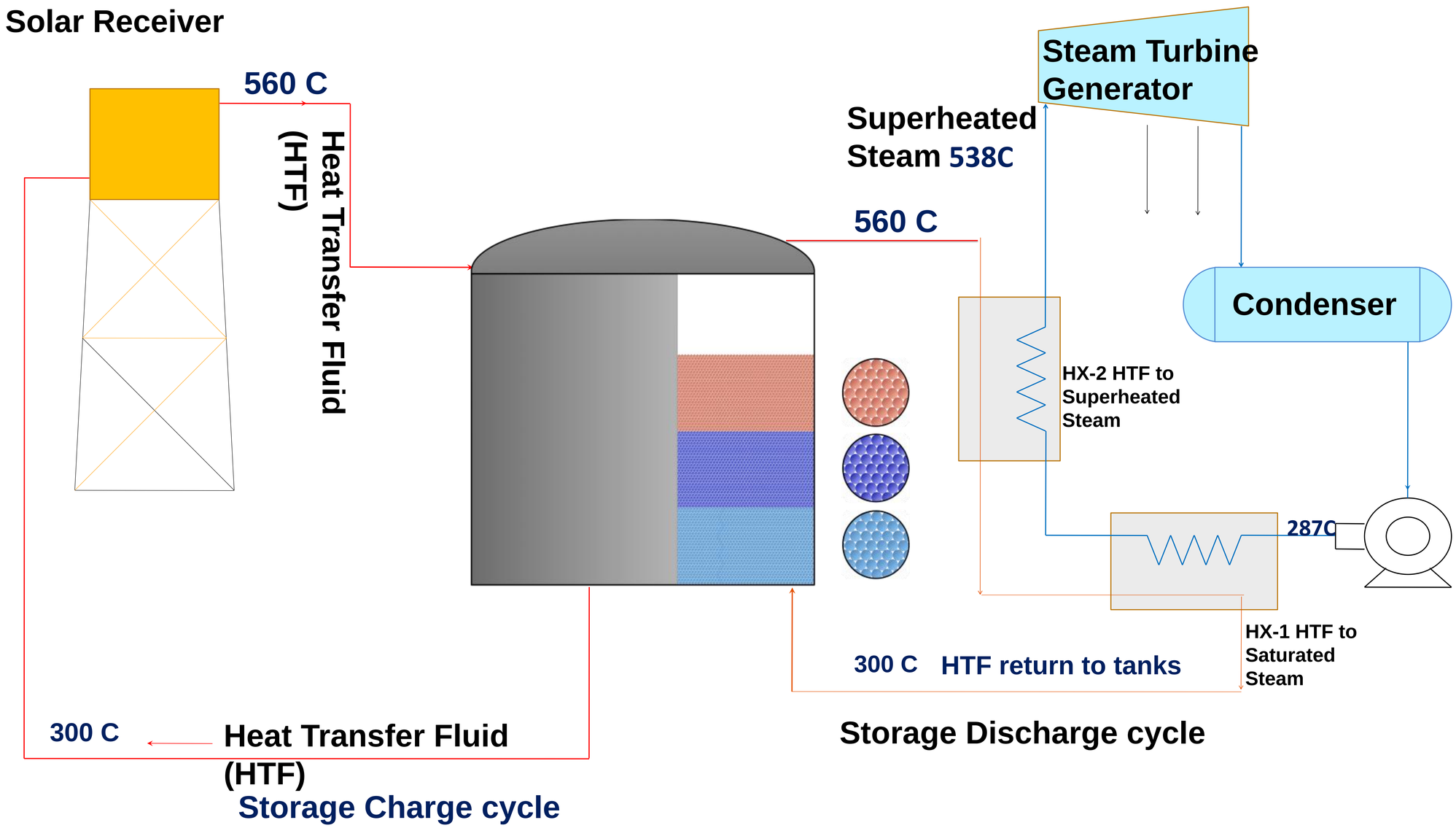

**A 3-PCM Cascaded Encapsulated TES**

Capsules Filled with Salts Melting at Progressively Higher Temperatures

## TerraCaps Cascaded 3-PCM Encapsulated TES

**Improves Energy Density by 52%**
**No Thermal Ratcheting**

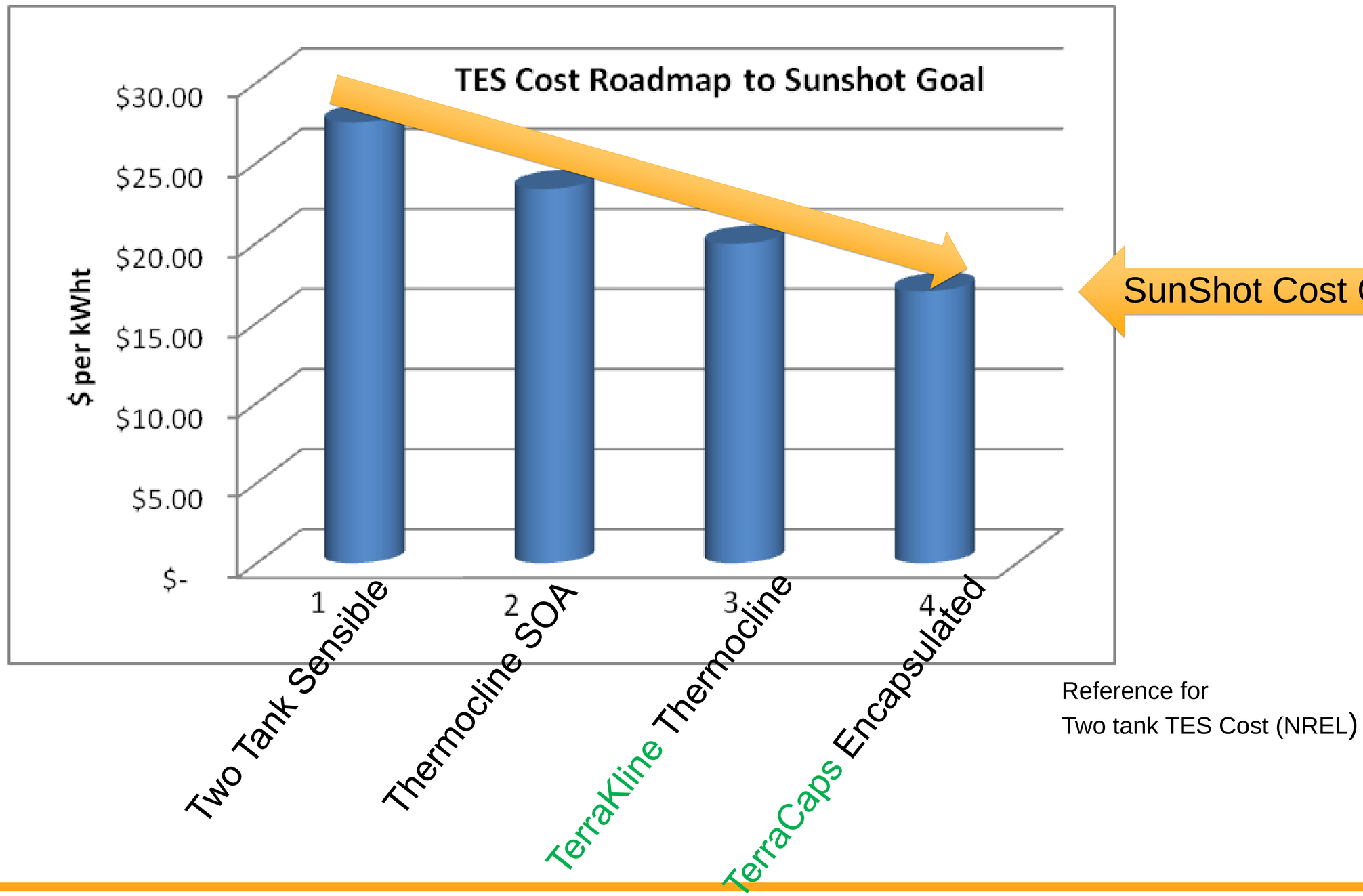
# Solar Power Tower with **Cascaded Encapsulated Phase Change** Thermal Storage




**TerraCaps Technology Successfully Demonstrated in Lab**

**Estimate 5 years to Commercialize**

# Roadmap to SunShot Goal of $15 per kWht




Reference for
Two tank TES Cost (NREL)

# DOE **Encapsulation Project Goals in Phase 2**

- Determine integrity of capsules to thermal cycles and thermal shock
- Estimate breakage rate (goal <0.1% per year)
- Determine effect on HTF when capsules break
- Optimize time to process capsules
- Determine sensitivity on capsule properties to variations in recipe and chemical composition
- Produce capsules of different size and encapsulate different salts

# Thermal Energy Storage (TES) Math Models for Concentrating Solar Power (CSP)

## A California Energy Commission Project

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# Mathematical models

- First Principles Dynamic Model captures important dynamics to -
  - Evaluate control strategies
  - Evaluate and optimize CSP-TES designs
  - Model startup transients

- Flow, Temperature vs time to and from TES

# Key Features for CSP-TES Dispatchability

- **Dynamic Response**
- **Capacity as Function of State-of-Charge**
- **Discharge Efficiency (Available Volume)**
- **Charge Efficiency**

## Thermal Energy Storage

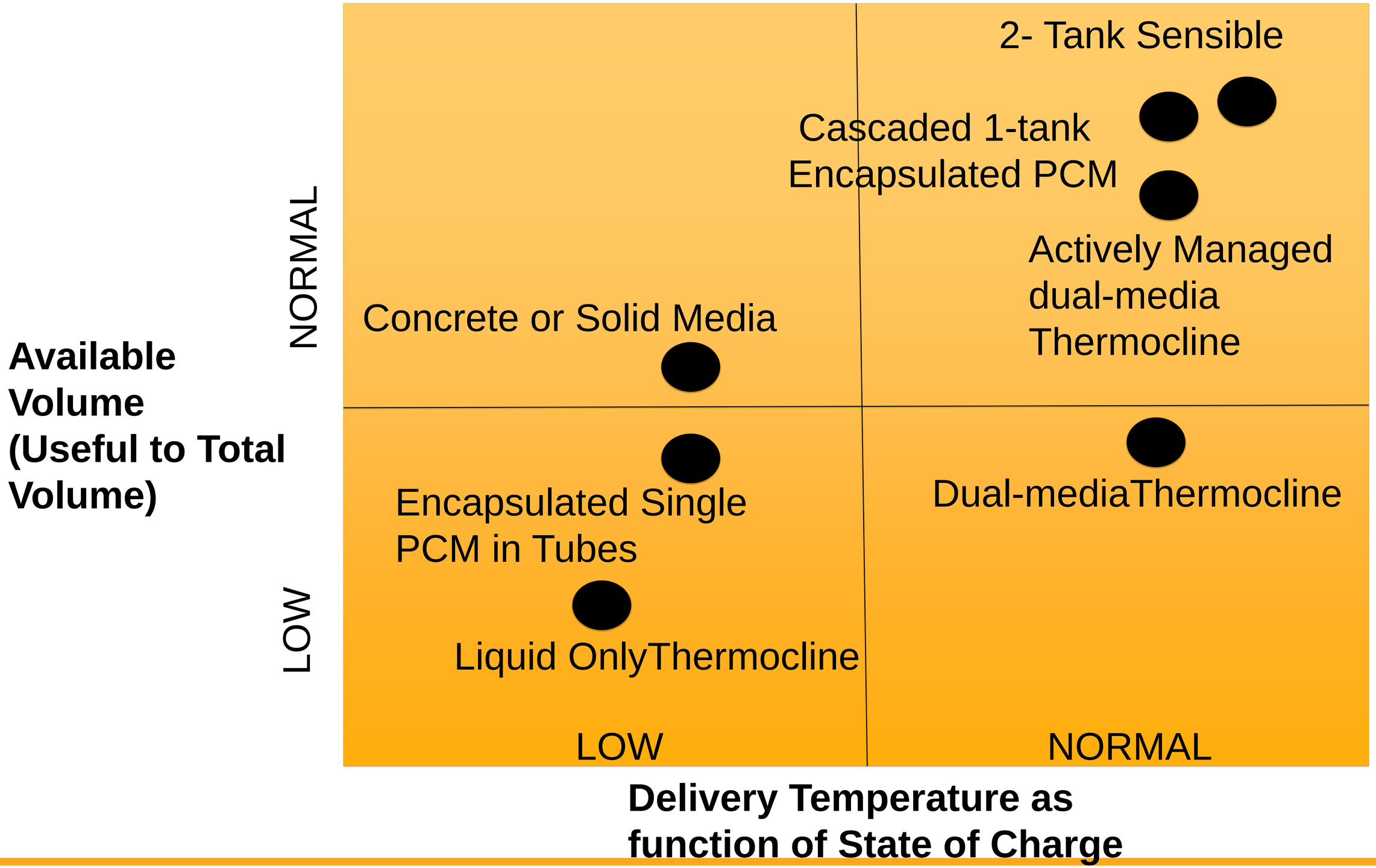
- Encapsulated PCM in a Single tank (single or cascaded) with thermal stratification
- Thermal Stratification
  - Dual Media
  - Actively managed thermocline
- Solid Media (Concrete 2d-model)
- 2-Tank Sensible Heat

## CSP

- Trough and Molten Salt Receiver thermal dynamics

# Thermal Energy Storage Technologies

## A Qualitative Performance Evaluation



# Approach to Modeling

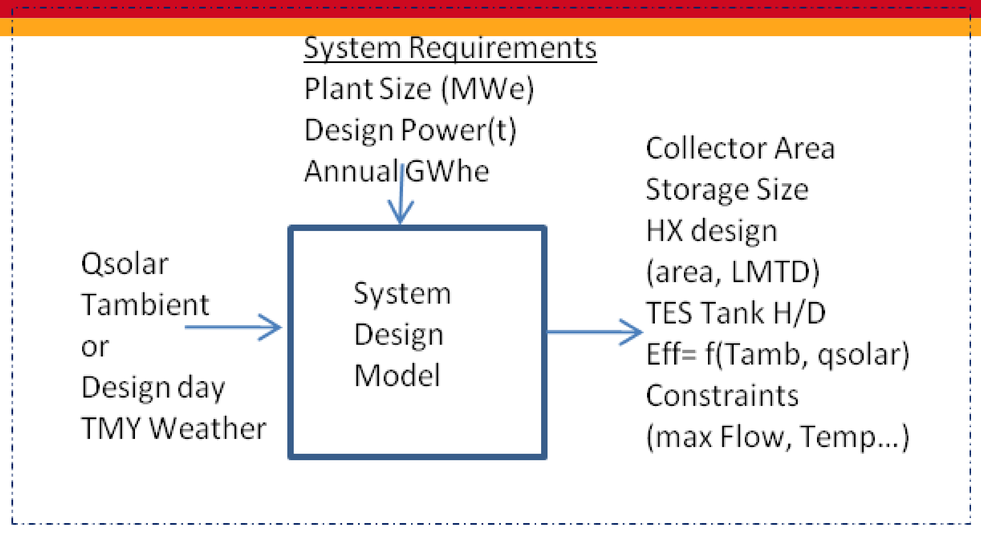
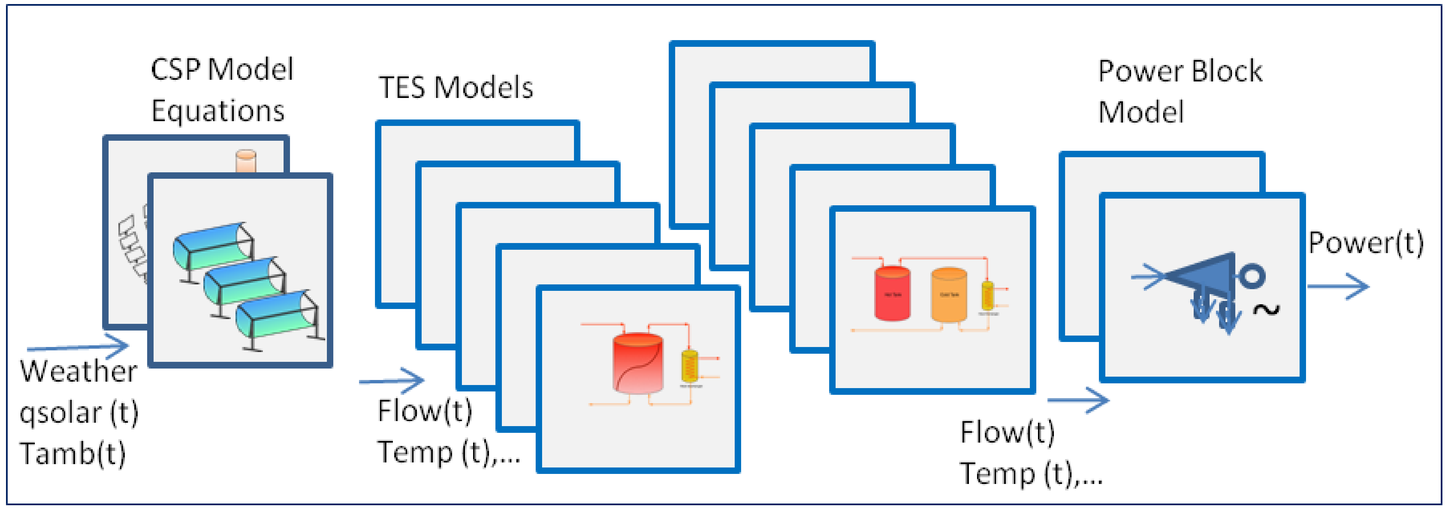



Fig.a. Output from Terrafore's system design model to component models

Fig. b. Component Models in Matlab



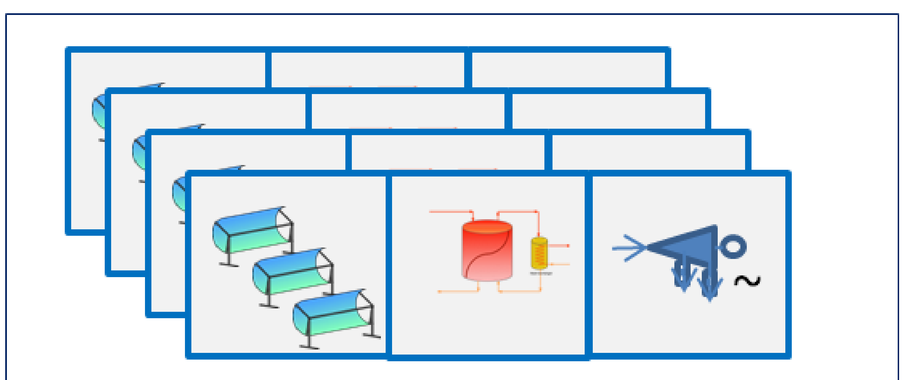



Fig. c. Simulink Models System Configurations

# System Components

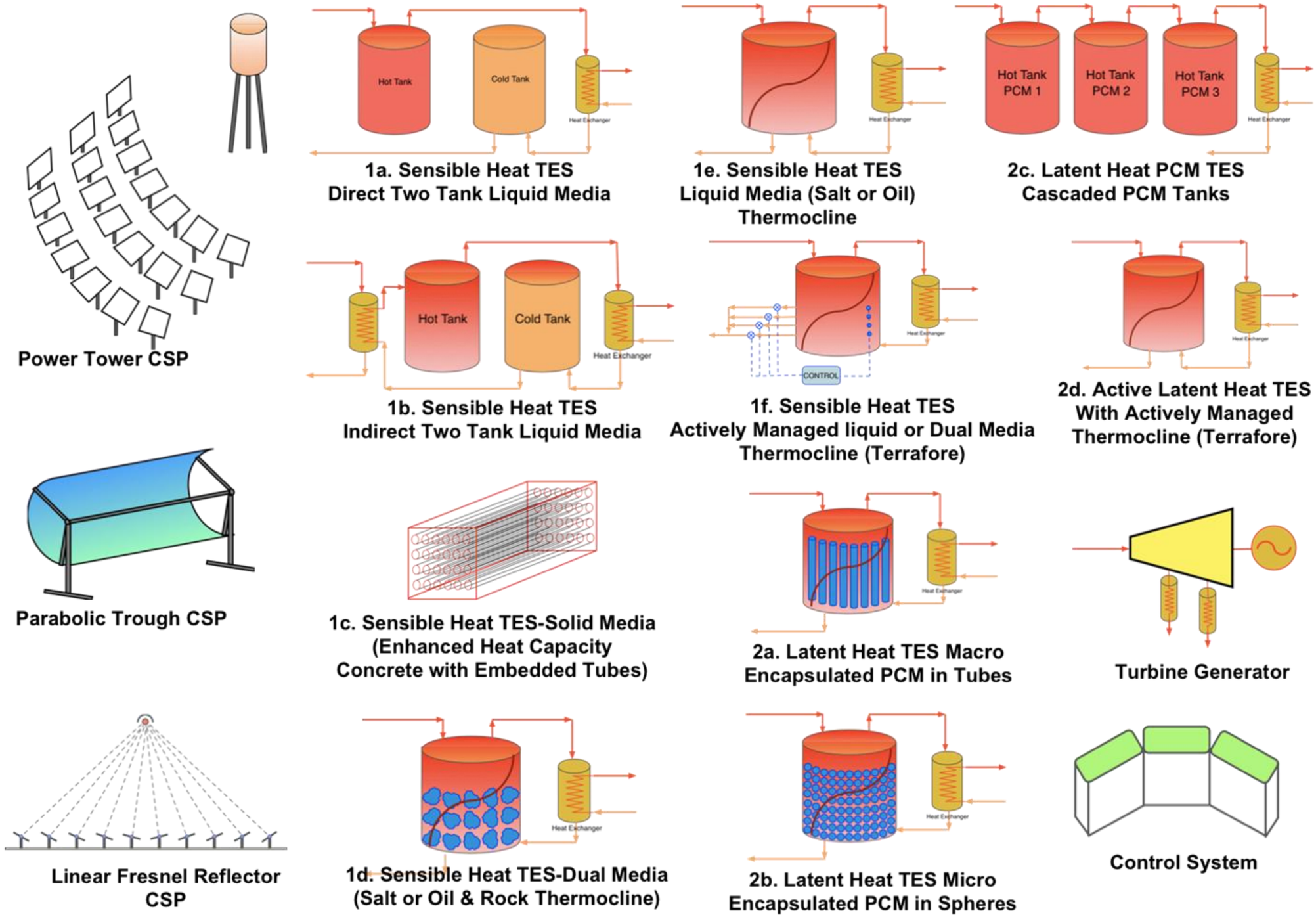



**Figure 1. Components of Solar Power Generation & Thermal Energy Storage System**

# Relative Costs of TES Systems

| | | | |
|---|---|---|---|
| **2-Tank Sensible SOA Trough (280C -372C)** | **$ /kWht** | **82.18** | 292% |
| **2-Tank Sensible Salt C Receiver (280C -550C)** | **$ /kWht** | **28.10** | **100%** |
| **Thermocline TES (Sensible 280C - 550C)** | **$ /kWht** | **23.36** | 83% |
| **TerraKline TES (Sensible 280C-550C)** | **$ /kWht** | **21.15** | 75% |
| **TerraCaps TES (Cascaded Encapsulated3- PCM)** | **$ /kWht** | **16.97** | 60% |

2-Tank costs: based on Source :DOE/NREL