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TES Materials

AAE- E3080 Thermal Energy Storage Systems
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Energy Conversion Research Group
Department of Mechanical Engineering
Aalto University

Learning outcome of this session

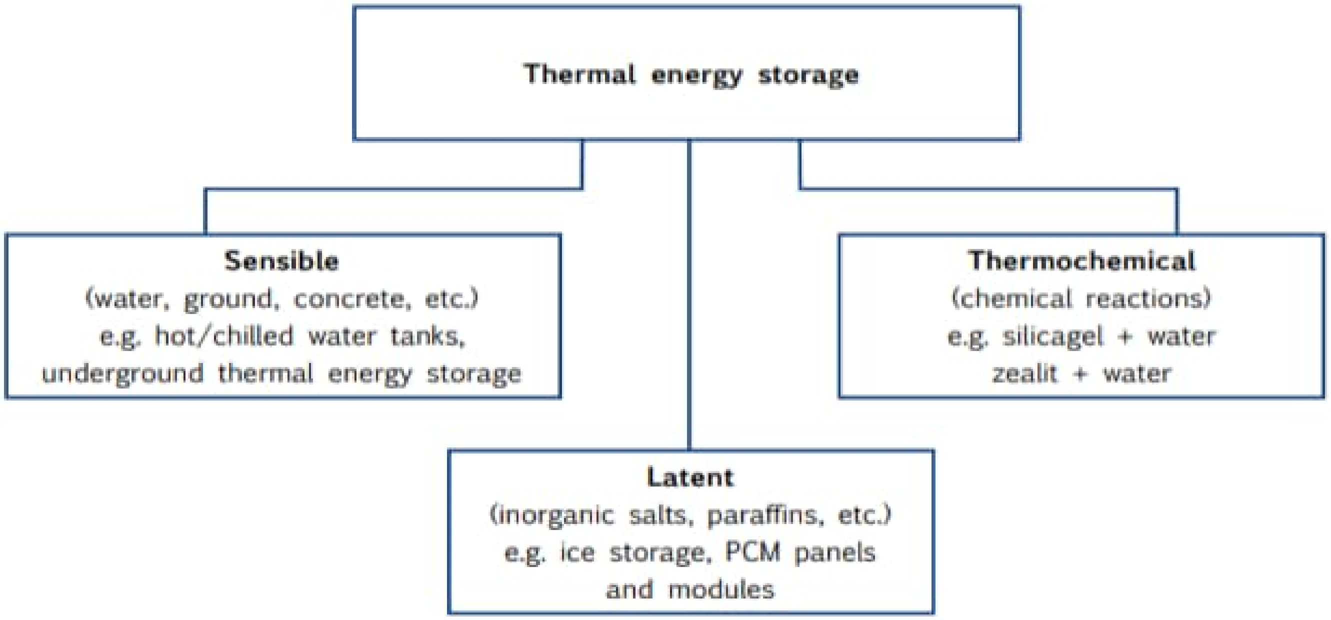
Compare different energy storage materials

Able to characterize energy storage by technology, temperature, and timescale

Learning by Discovery

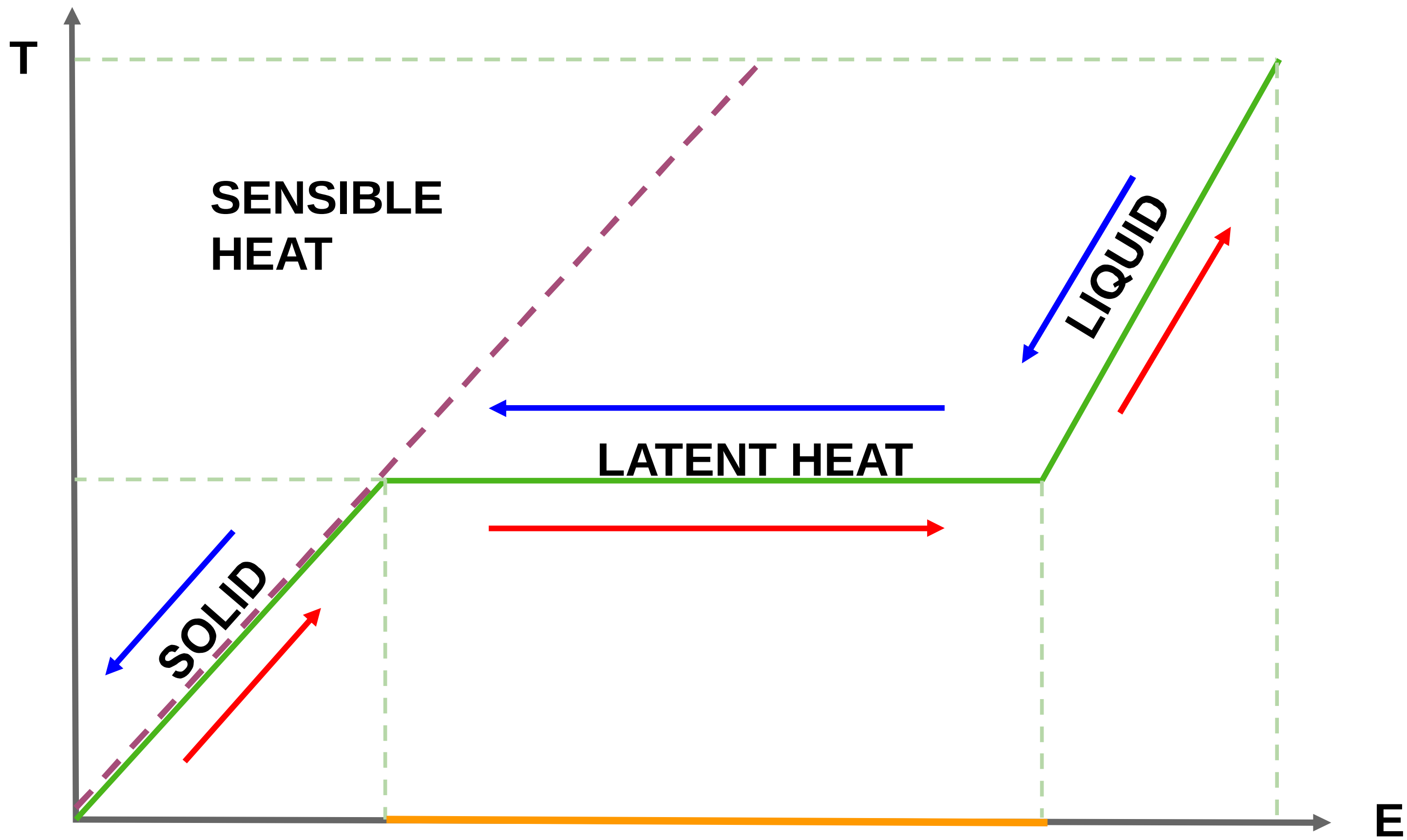
Discuss in group:
Thermal Storage Materials that you know

Different TES materials



Simone Landolina, EUREC Agency, 2012, Strategic Research Priorities for Cross-cutting Technology, European Technology Platform on Renewable Heating and Cooling

Difference: Sensible and Latent Heat SS



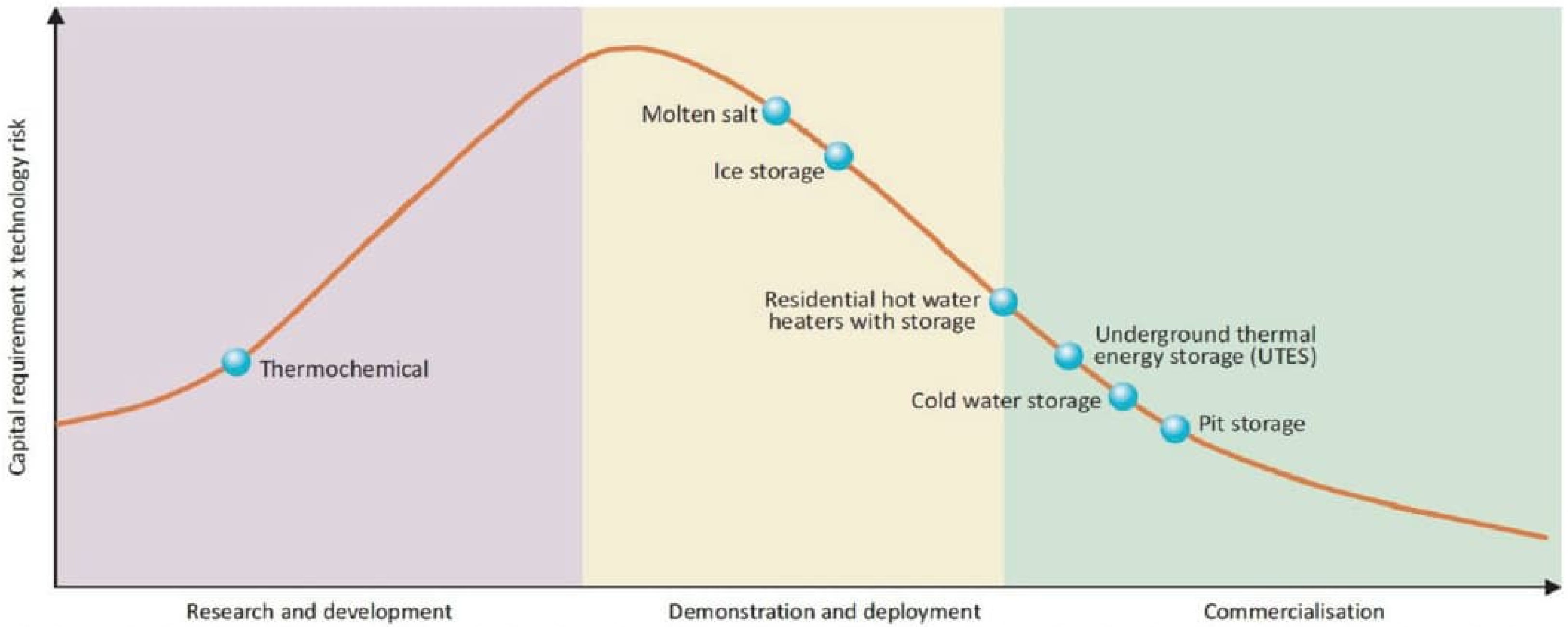
Performance parameters	Types of thermal energy storage		
	Sensible	Latent	Chemical
Temperature range	Up to: 110 ºC (water tanks) 50 ºC (aquifers and ground storage) 400 ºC (concrete)	20-40 º C (paraffins) 30-80 ºC salt hydrates)	20-200 ºC
Storage density	Low (with high-temperature interval): 0.2 GJ/m^3(for typical water tanks)	Moderate (with low temperature): 0.3-0.5 GJ/m^3	Normally high: 0.5-3 GJ/m^3
Lifetime	Long	Often limited due to storage materials cycling	Depends on reactant degradation and side reactions
Technology status	Available commercially	Available commercially for some temperatures and materials	Generally not available, but undergoing research and pilot project tests

N. Ebenezer, Master thesis, Aalto University 2019

Performance parameters	Types of thermal energy storage		
	Sensible	**Latent**	**Chemical**
Pros	Low cost Reliable Simple application with available materials	Medium storage density Small Volumes Short distance transport possibility	High storage density Lower heat losses (storage at ambient temperatures) Long storage periods Long distance transport possibility High compact energy storage
Cons	Significant heat loss over time (depending on the level of insulation) Large volume needed	Low heat conductivity Corrosivity of materials Significant heat losses (depending on the level of insulation)	High capital cost Technically complex

N. Ebenezer, Master thesis, Aalto University 2019

Maturity of different TES solutions



Getu Hailu, 2018. Chapter: Seasonal Solar Thermal Energy Storage, in Thermal Energy Battery with Nano-enhanced PC; http://dx.doi.org/10.5772/intechopen.79576

Sensible TES materials

Sensible Heat Storage System (SHSS)

Are these new ideas?

During night -> cooling down,
During day – cool

During day -> heating up
During night – warm

Could we further improve these?

SHSS materials

Required properties

- High energy density, high thermal conductivity, and high specific heat capacity
- Chemically stable in the long term devoid of any chemical decomposition
- Vast heat storage capacity
- No toxicity, no explosivity, the low likelihood for corrosion or reaction to heat transfer fluid and compatibility with storage medium materials
- High thermal and mechanical stability, low coefficient of thermal expansion and energy efficient
- Low self-discharge
- Low cost

1) S. Kalaiselvam and R. Parameshwaran, 2014. Assessment and Applications, Academic Press
2) S. Khare, et al.,Solar Energy Materials & Solar Cells 115 (2013) 114–122

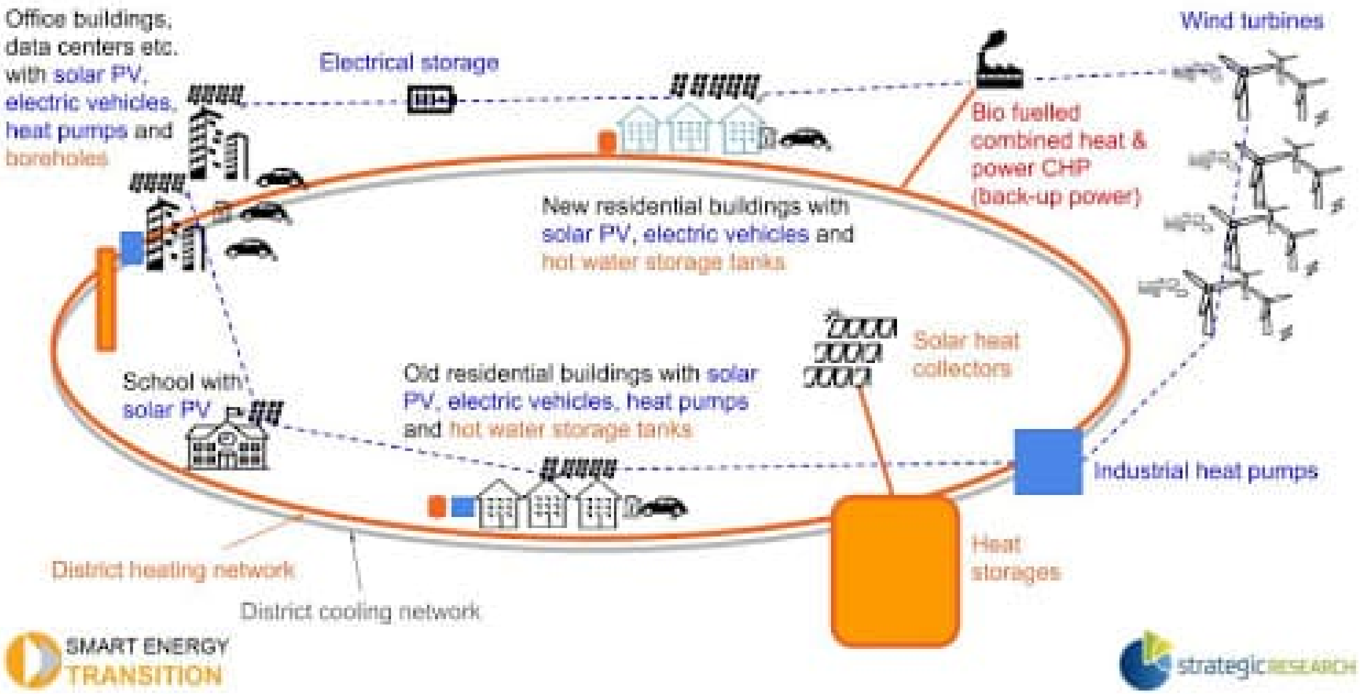
Possible materials

- **Construction materials:** Brick, Concreate, Granite, Limestone
- **Water (high thermal conductivity/cheap)**
- **Molten salts (higher temperature range)**
- **Petroleum based oils**
- **Metals:** Aluminum, Copper, Iron, Lead

Increase the temperature – Easy, Robust, Cheap

Further material properties: *A. Dinker et al.* J. of Energy Institute 90 (2017) 1-11. dx.doi.org/10.1016/joei.2015.10.002

From Wind to heat – Sensible heat storage



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Excellent Reading Material from Finland (in English): http://smartenergytransition.fi/fi/julkaisut/publications/

Latent TES materials

Latent Heat Storage System (LHSS)

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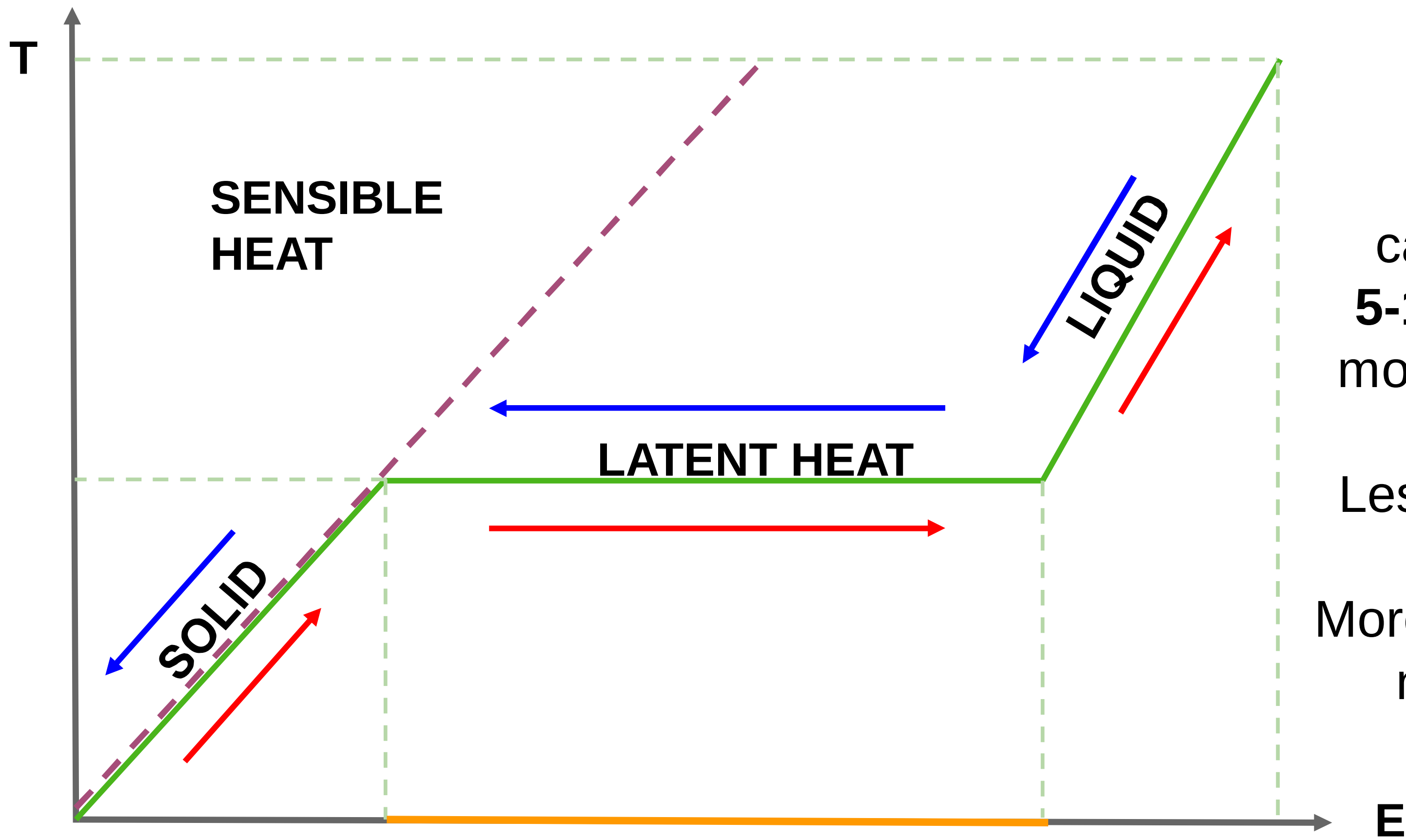
LHSS

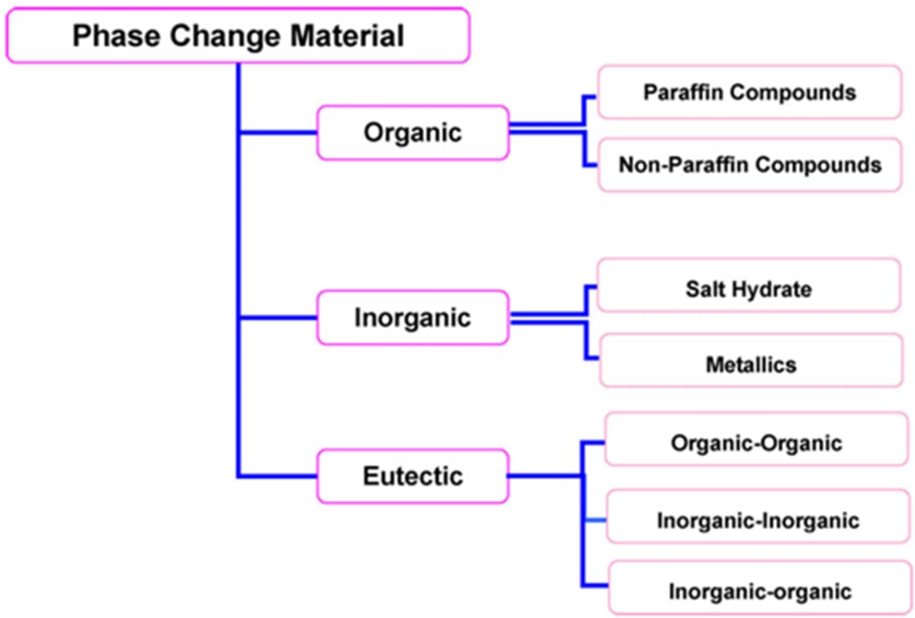


LHSS
can store
5-14 times
more energy

Less mature

More research
needed

PCM Classification



Low temperature - domestic

High temperature - industrial

Increasing flexibility

Atul Sharma, et al. Review on thermal energy storage with phase change materials and applications, Renewable and Sustainable Energy Reviews 13 (2009) 318–345

Phase-Change Material

Single-component

Organic

Paraffin

PCM	T_m[61] [°C]
$C_{18}H_{38}$	28.2
$C_{19}H_{40}$	31.9
$C_{20}H_{42}$	37
$C_{21}H_{44}$	41
$C_{22}H_{46}$	44
$C_{23}H_{48}$	47
$C_{24}H_{50}$	51
$C_{25}H_{52}$	54
$C_{26}H_{54}$	56
$C_{27}H_{56}$	59
$C_{28}H_{58}$	61
$C_{29}H_{60}$	64
$C_{30}H_{62}$	65

Non-paraffin

PCM	T_m[61] [°C]
Capric acid	28.2
Lauric acid	42–44
Myristic acid	49–51
Erythritol	118

Inorganic

Hydrate

PCM	T_m[61] [°C]
$CaCl_2 \cdot 6H_2O$	29–30
$CH_3COONa \cdot 3H_2O$	58
$MgCl_2 \cdot 6H_2O$	115–117

Molten salt

PCM	T_m[58] [°C]
$NaNO_2$	282
$NaNO_3$	307
NaOH	318
LiOH	462
NaCl	800

Metallic

PCM	T_m [°C]
Al-Si (88-12 wt%)	587[66]
Cu	1084[52]

Multi-component

Eutectic

Organic-organic

PCM	T_m [°C]
Lauric-Capric acid (35–65 mol%)	18[65]

Inorganic-inorganic

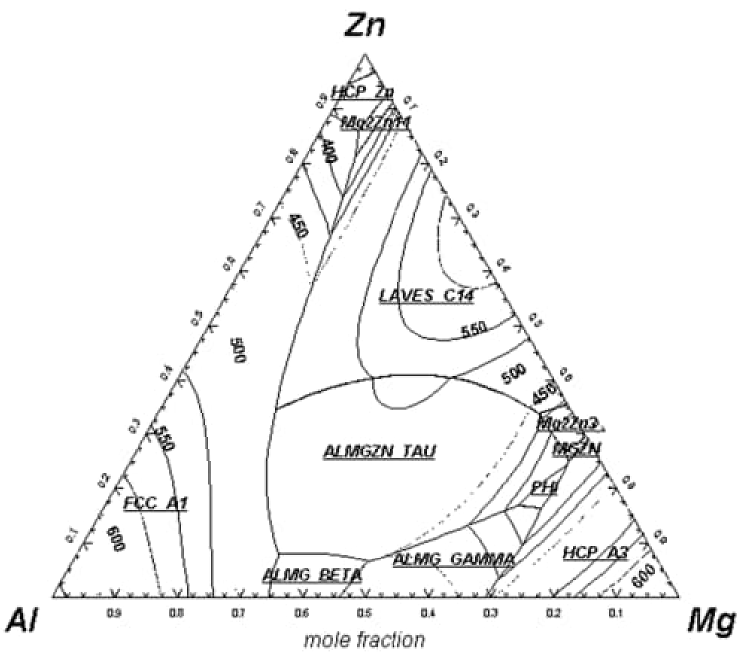
PCM	T_m [°C]
$NaNO_3$- KNO_3 (50–50 mol%)	220[47]

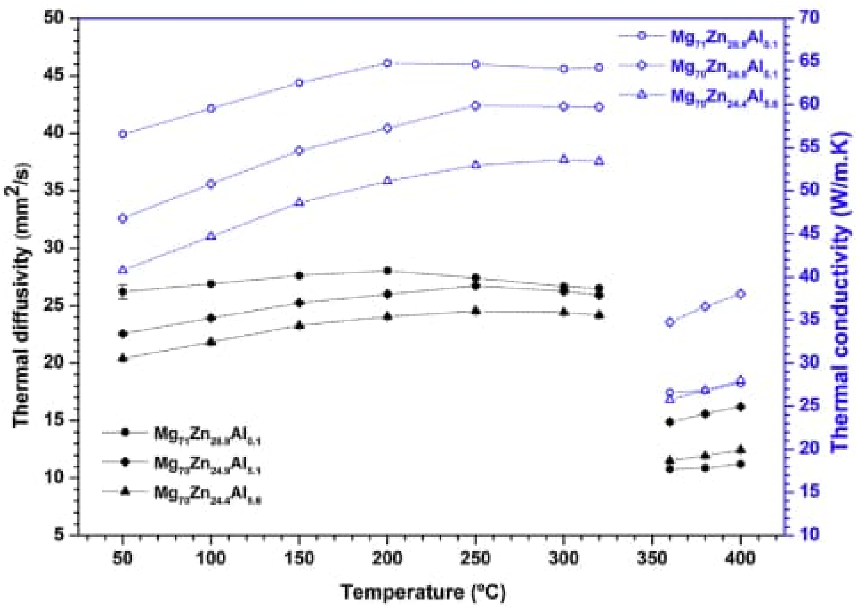
Organic-inorganic

PCM	T_m [°C]
NH_2CONH_2-NH_4NO_3	46[61]

Takahiro Nomura ,et al. Technology of Latent Heat Storage for High-Temperature Application: A Review, ISIJ International, Vol. 50 (2010), No. 9, pp. 1229–1239

Example: Metal alloys Mg-Zn-Al



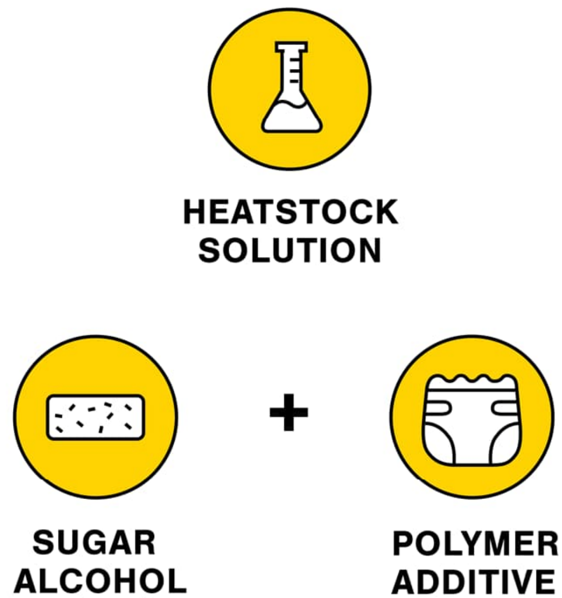


Modification of the alloy you can affect to the thermal properties

E. Risueño et al. J. of Alloys and Compounds 685 (2016) 724.
Available in MyCourses and dx.doi.org/10.1016/j.jallcom.2016.06.222

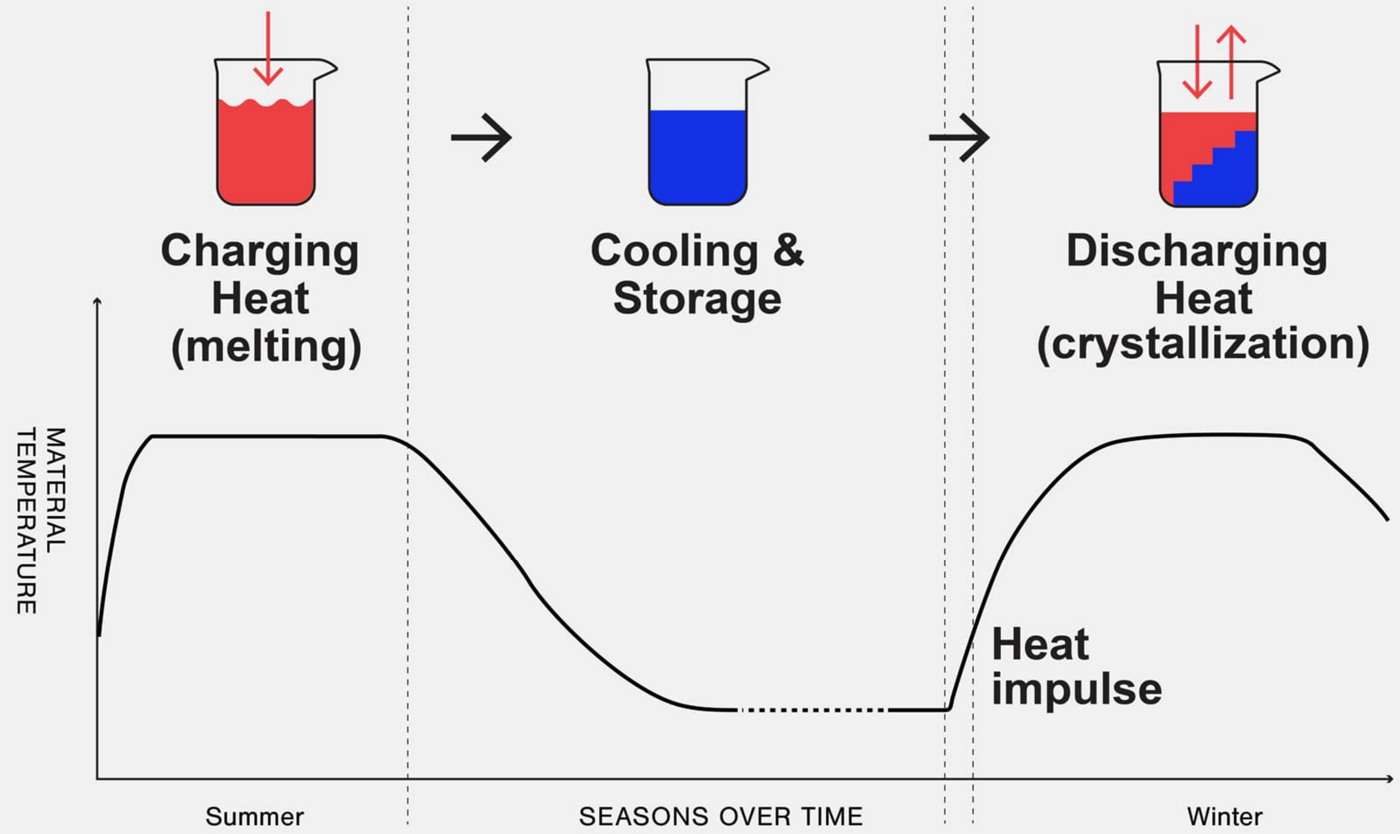
Heat Stock – Sugar alcohol & polymer material

One winner of Helsinki Challenge competition

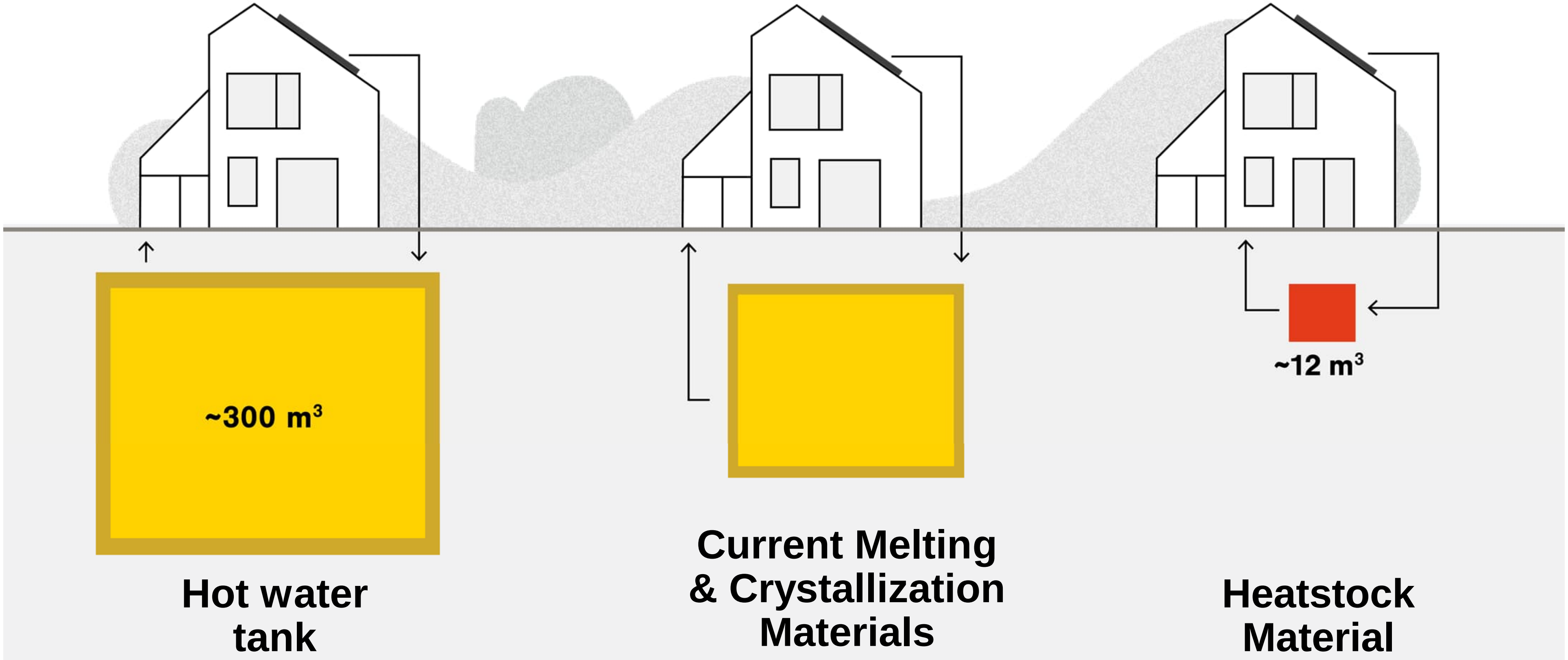


Research group of Energy Conversion,
Ari Seppälä’s team

HOW – Polymer prevents crystallization



WHAT – A new material for long-term heat storage



K. Turunen et. al, *Applied Energy*, **266** (2020) 114890. https://doi.org/10.1016/j.apenergy.2020.114890

Thermochemical energy storage

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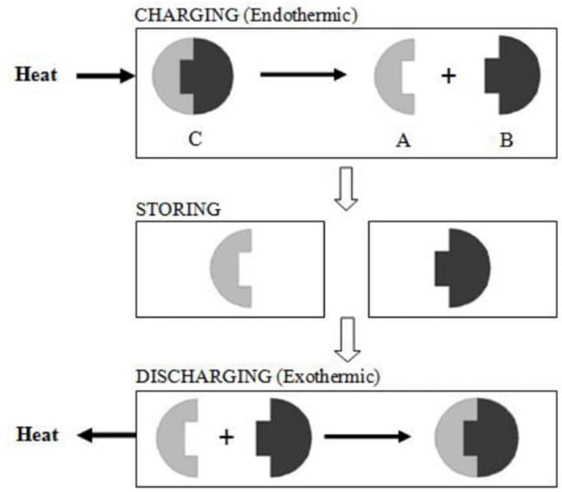
Chemical reactions

Chemical reactions

$$C + heat \leftrightarrows A + B \; (charge + discharge)$$

As the heat is stored in form of chemical potential, **no continuous losses** should occur over time as long as the containers are tightly sealed.



Ali H. Abedin and Marc A. Rosen, A Critical Review of Thermochemical Energy Storage Systems, The Open Renewable Energy Journal, 2011, 4, 42-46

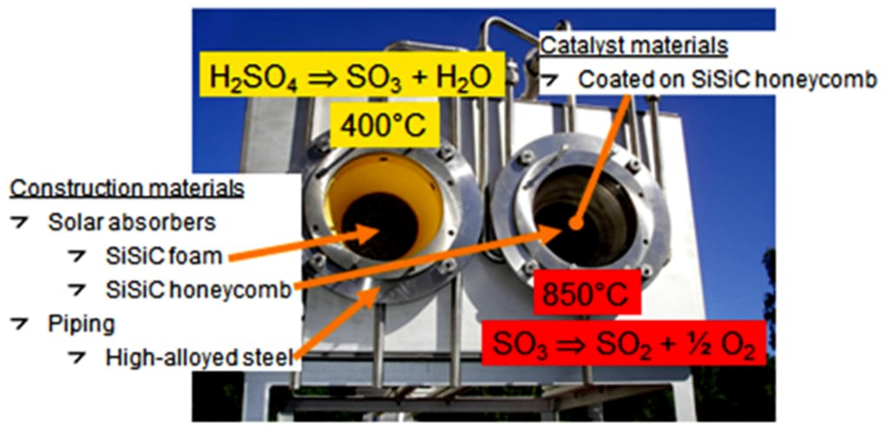
Thermochemical Energy Storage

Different type of chemical reactions to use as thermal storage

- Very long lasting, low loss TES systems
- Might be costly – complicated, but when secured storage is needed

Example:
Sulphuric Acid

Dissolution to water is exothermic ->
With solar energy -> evaporate the water (concentrate + store)



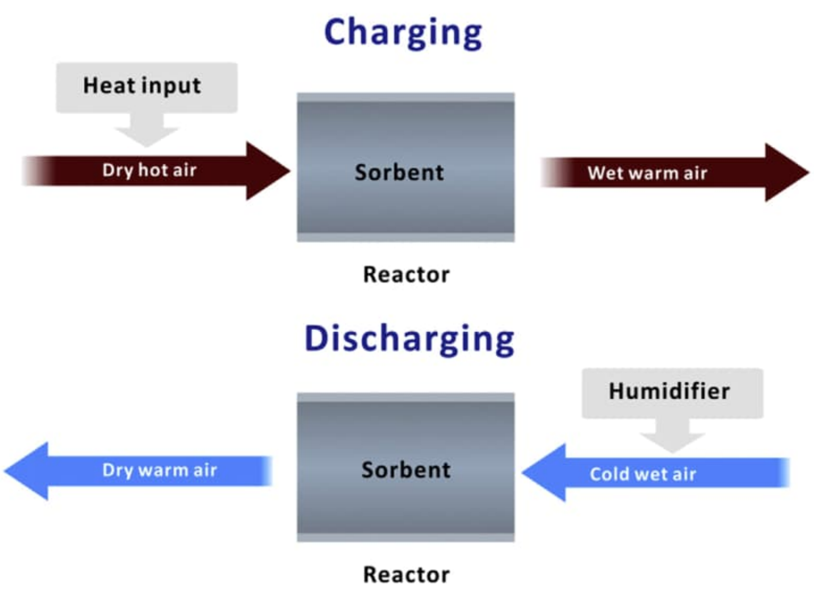
SOL2HY2 project, funded by EU Horizon 2020: www.sol2hy2.eu

Sorption process

Sorption process

$$A \cdot (m+n)B + Heat \rightleftharpoons A \cdot mB + nB$$

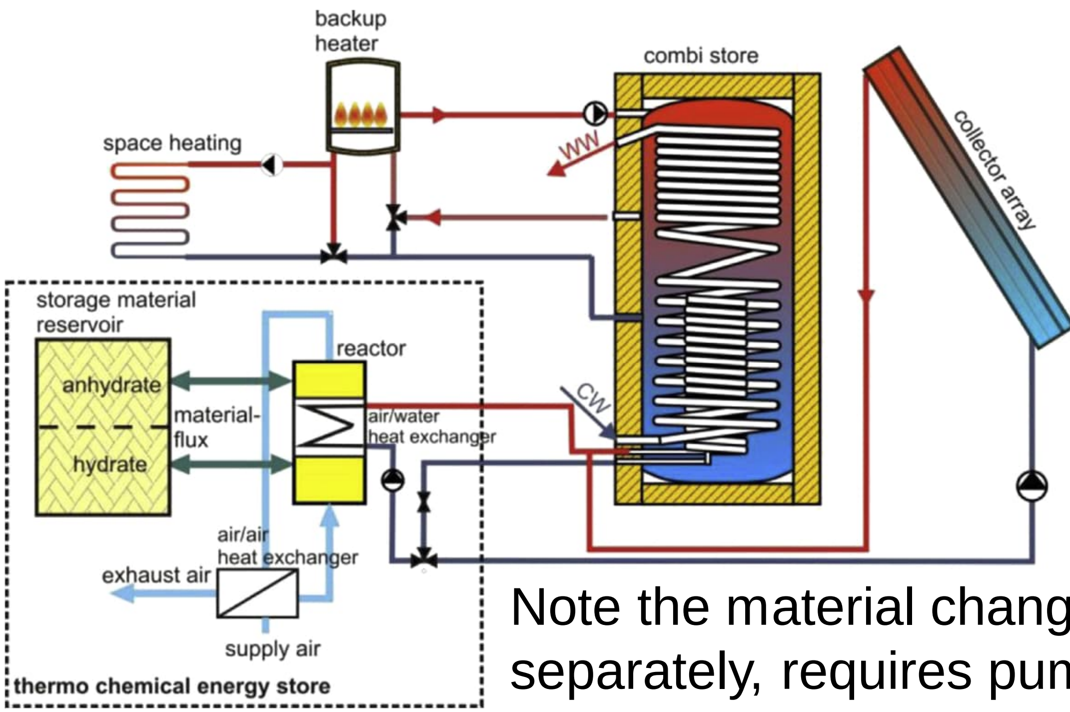
A is the sorbent
B is the sorbate and
m and *n* represent molar amounts



Most common case: crystal water

Yu, N., et al. Sorption thermal storage for solar energy. *Progress in Energy and Combustion Science.* (2013) DOI: 10.1016/j.pecs.2013.05.004

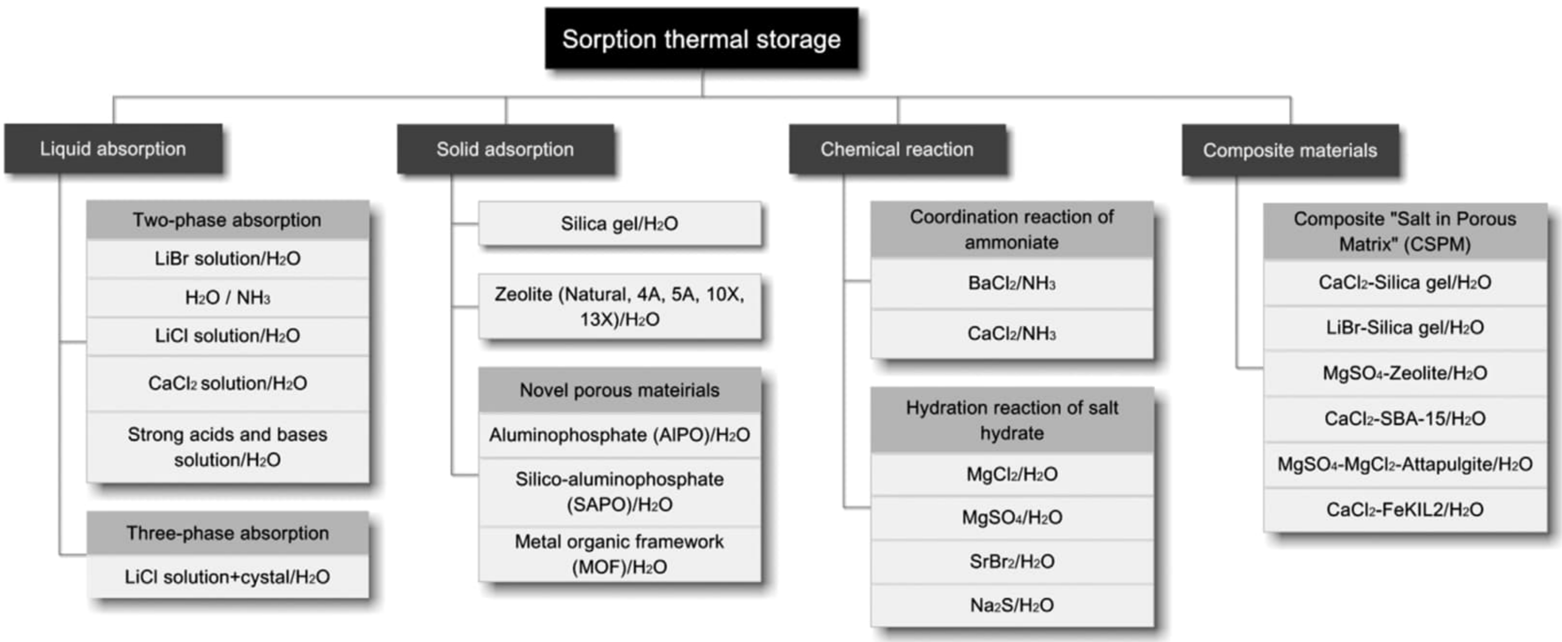
Example: Thermochemical system in place



Note the material change, reactor separately, requires pumping of the materials

Kerskes H et al. Chemical energy storage using reversible solid/gas-reactions (CWS)eresults of the research project. *Energy Procedia 30 (*2012) 294-304.

Thermochemical Energy Storage reactants



Yu, N., et al. Sorption thermal storage for solar energy. *Progress in Energy and Combustion Science.* (2013) DOI: 10.1016/j.pecs.2013.05.004

Take a home Message

1) Different TES materials have different properties
   - > suitable for different applications

2) knowledge/experience on TES material cycle lives
   -> Significant research efforts in the future

3) Large variety of different solutions needed to overcome heating need challenges in the future

Could this work for your application?