Energy Storage

- Energy is stored in a medium to use it at different time and/or place
- Energy storage is useful to compensate for lack of sunshine during nighttime or at times of sunshine interruptions

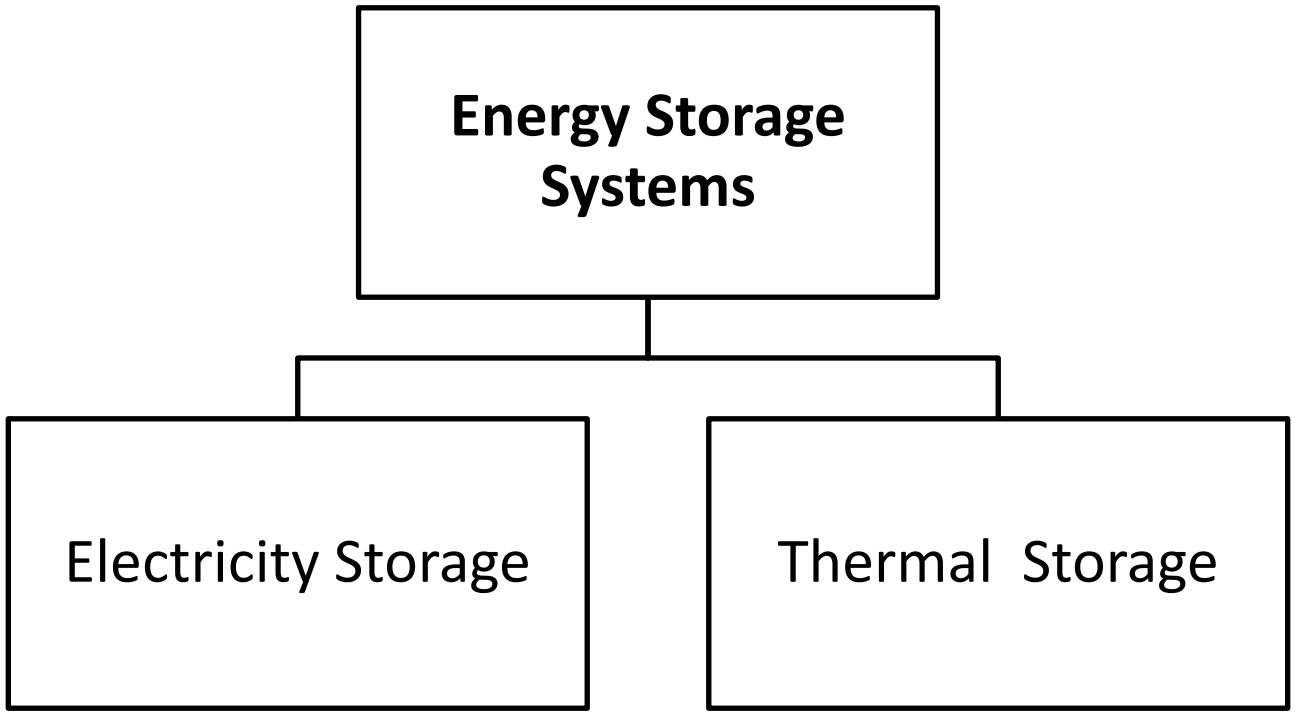
Applications of Energy Storage

- Power generating systems
- Solar heating
- Cooling
- Process heat applications

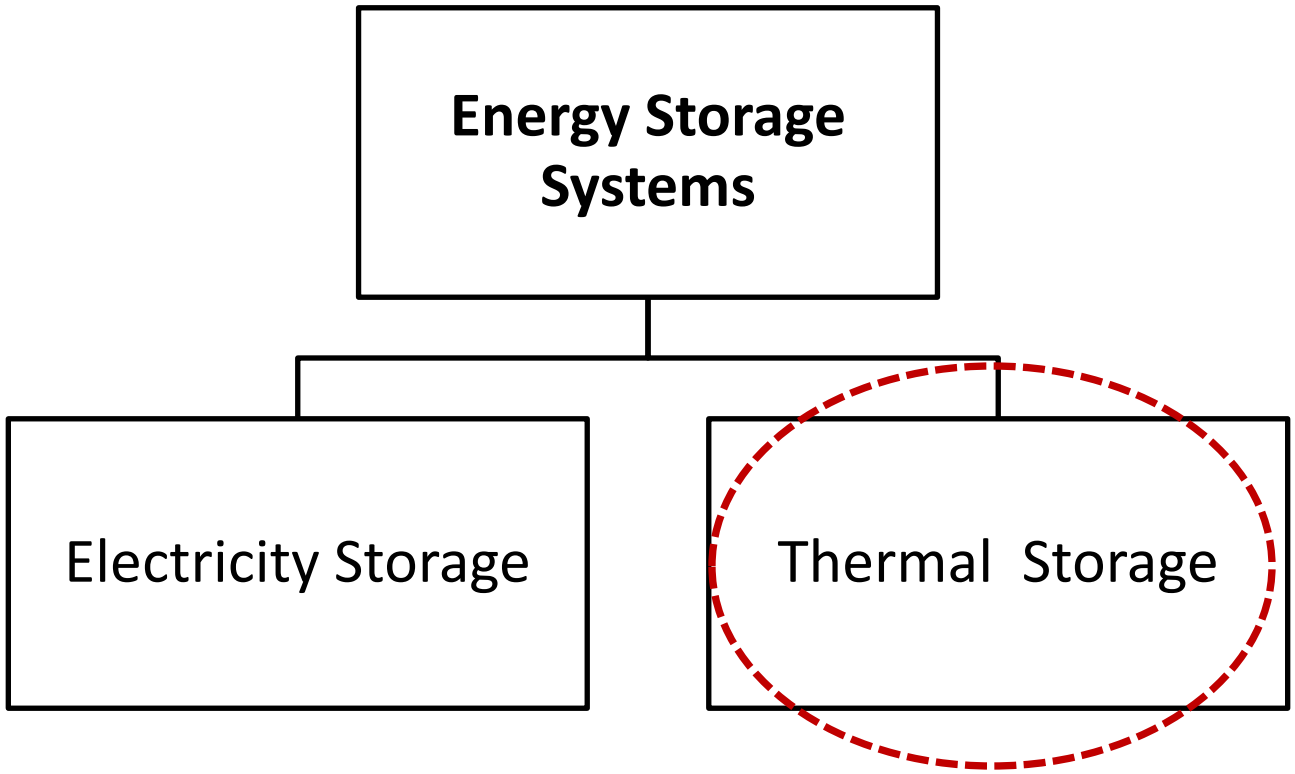
Advantages of Energy Storage

- Improved system reliability
- Extended system availability
- Cost reduction

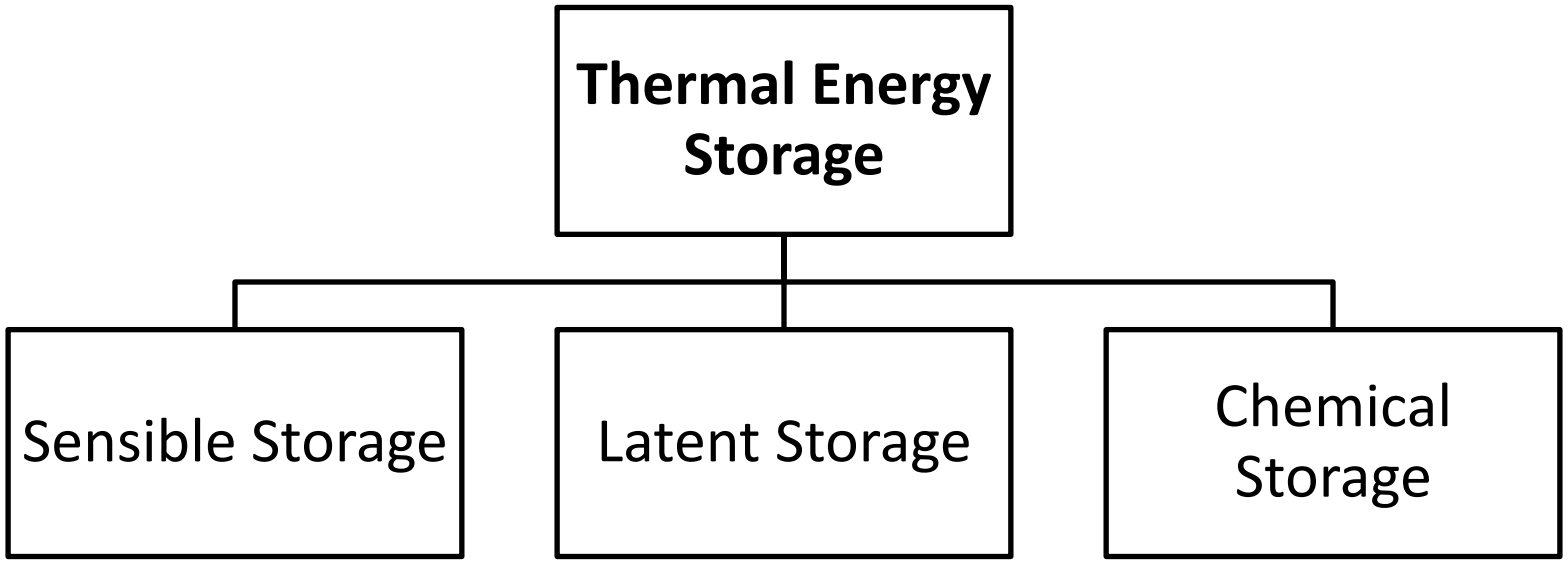
Types of Energy Storage



Types of Energy Storage



Types of Thermal Energy Storage



Types of Thermal Energy Storage

- ***Sensible storage:*** by change in temperature
- ***Latent storage:*** by change of phase
- ***Chemical storage:*** by exo- or endo-thermic chemical reactions

Technical Requirements for Thermal Energy Storage Systems

- High energy density (per-unit mass or per-unit volume) in the storage material
- Good heat transfer between heat transfer fluid (HTF) and the storage medium
- Mechanical and chemical stability of storage material
- Chemical compatibility between HTF, heat exchanger and/or storage medium
- Complete reversibility for a large number of charging/discharging cycles

Technical Requirements for Thermal Energy Storage Systems

- Good relationship between heat storage capacity and cost
- Very low vapor pressure at working temperatures
- Low thermal losses
- Ease of control
- Not flammable

Thermal Energy Storage
Sensible Storage

- ***Definition:*** A thermal energy storage system where the addition or removal of energy results in a change in temperature
- The energy storage medium could be liquid or solid

$$\dot{Q} = \dot{m} C_p \Delta T$$

- Examples of energy density of sensible storage materials:
  - Stone, concrete, etc: **1.5-3.5 MJ/m^3°C**
  - Water: **4.15 MJ/m^3°C**

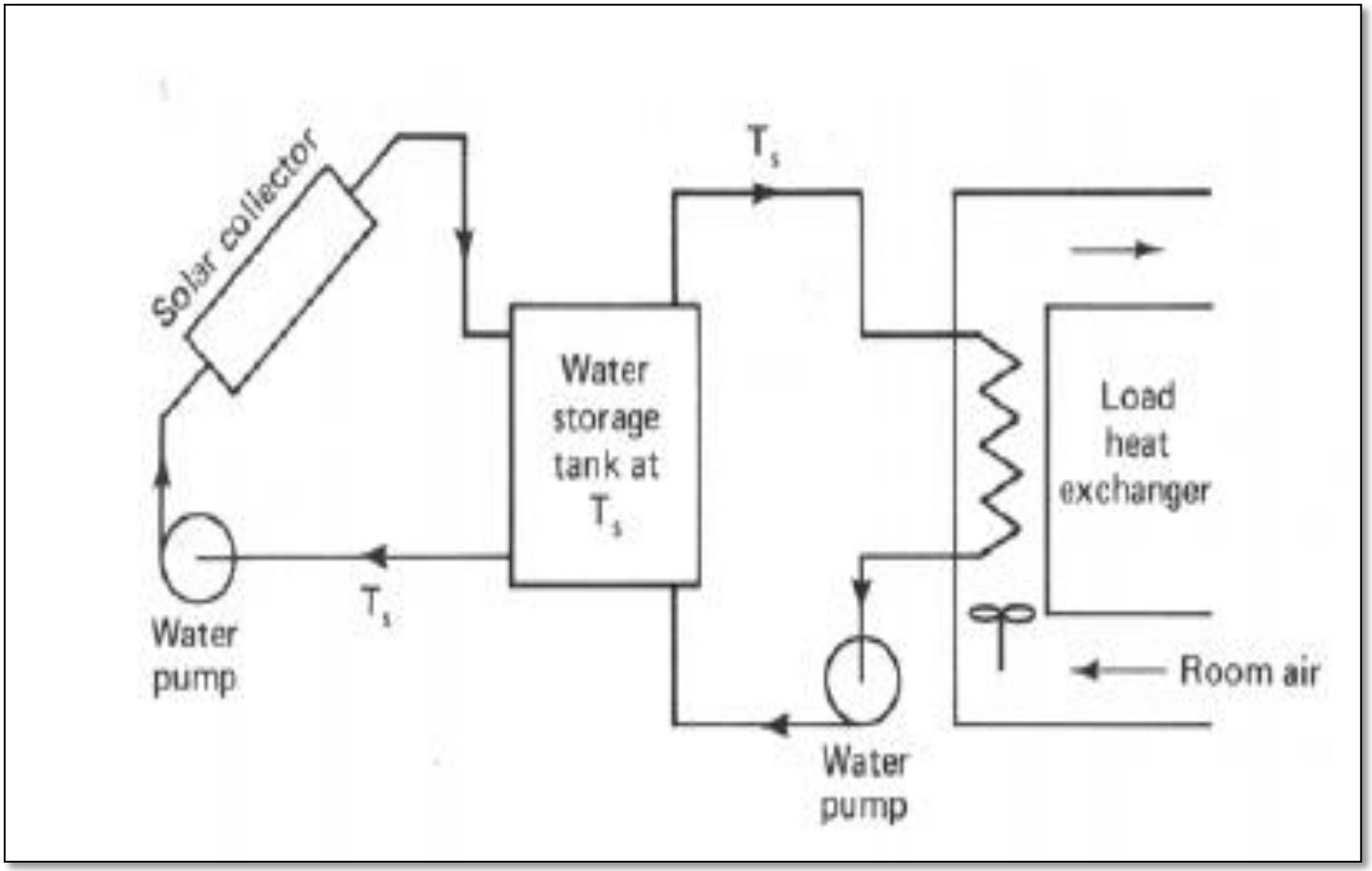
Thermal Energy Storage
Sensible Storage in Liquids

- Water
- Mineral oil
- Nitrate salts
- Carbonate salts
- Liquid sodium

Thermal Energy Storage
Sensible Storage in Water

- Water is the most frequently used as storage medium for liquid systems.
- Water is standard storage medium for solar heating and cooling systems for buildings.
- Other liquids can be used for thermal storage above 100C

Thermal Energy Storage
Sensible Storage in Water



Thermal Energy Storage
Sensible Storage in Water

Advantages:

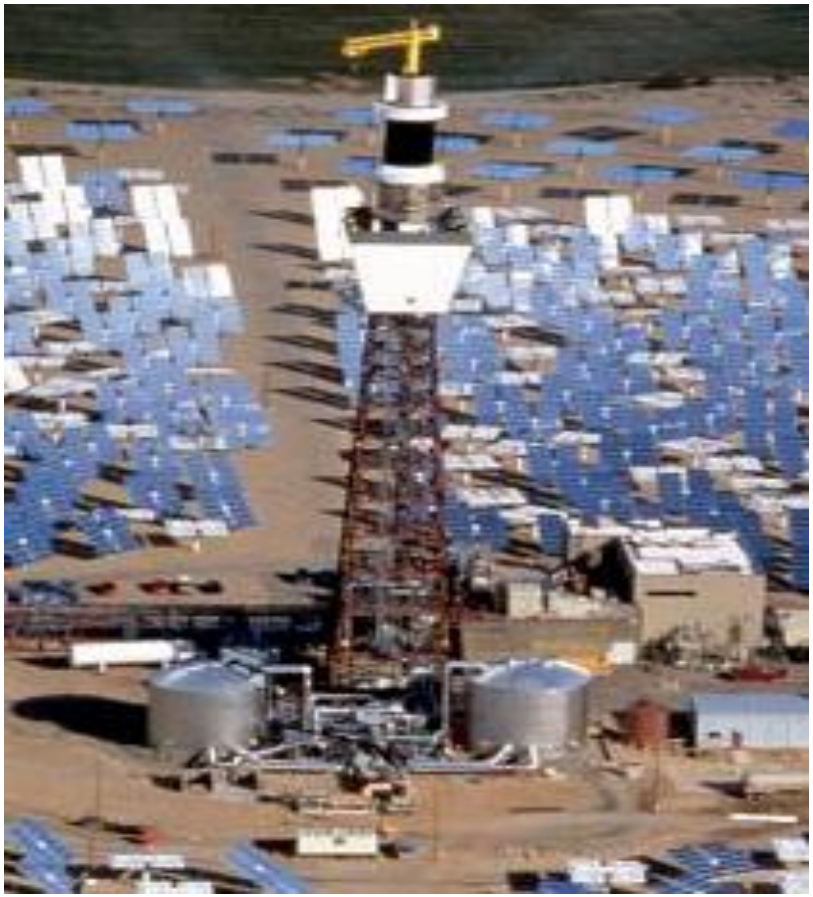
1. Abundant
2. Low cost
3. Non-toxic
4. High storage capacity
5. Easy to transport
6. Non combustible

Disadvantages:

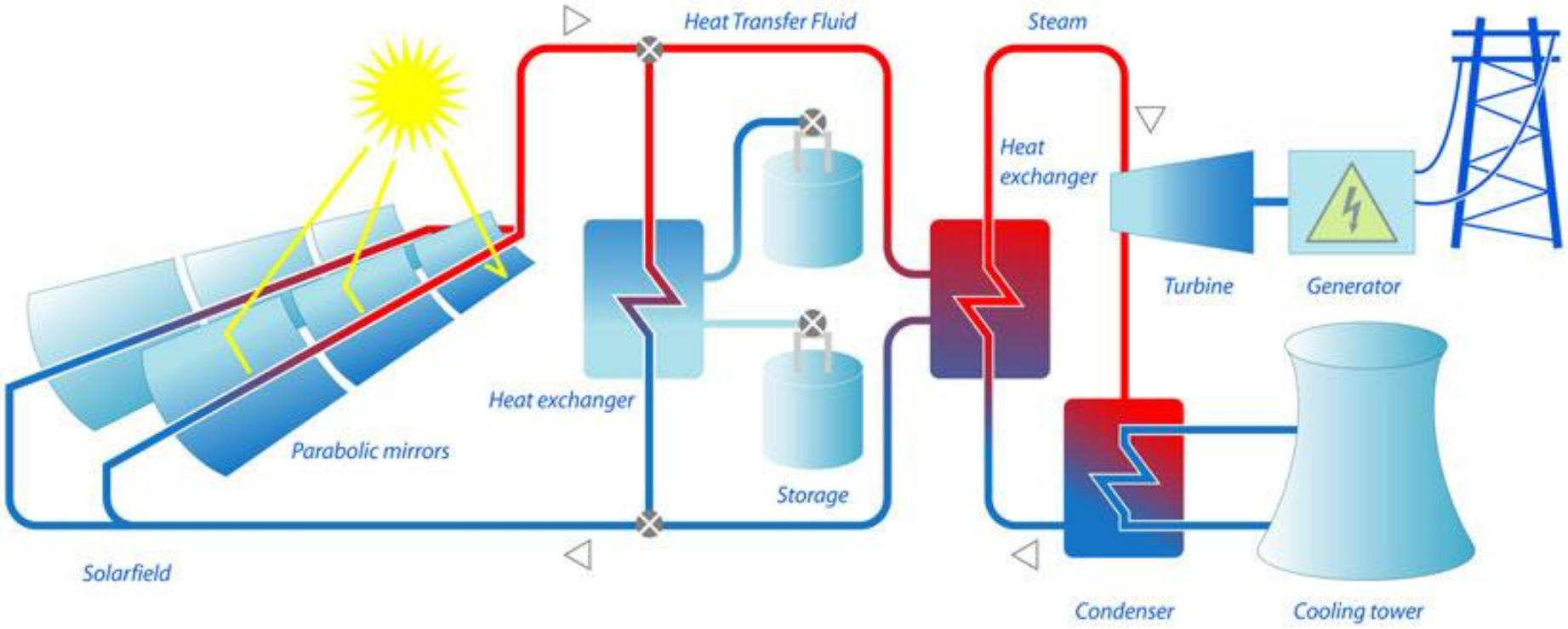
1. High vapor pressure
2. Corrosive medium
3. Destructive expansion
4. Non isothermal energy delivery

Thermal Energy Storage
Sensible Storage in Molten Salt

- Most common composition: Eutectic mixture of $NaNO_3$ (60%) and KNO_3 (40%)
- Fusion temperature: 221 °C
- Maximum Operating Temperature: 565 °C
- Usually two tanks (cold and hot) are used



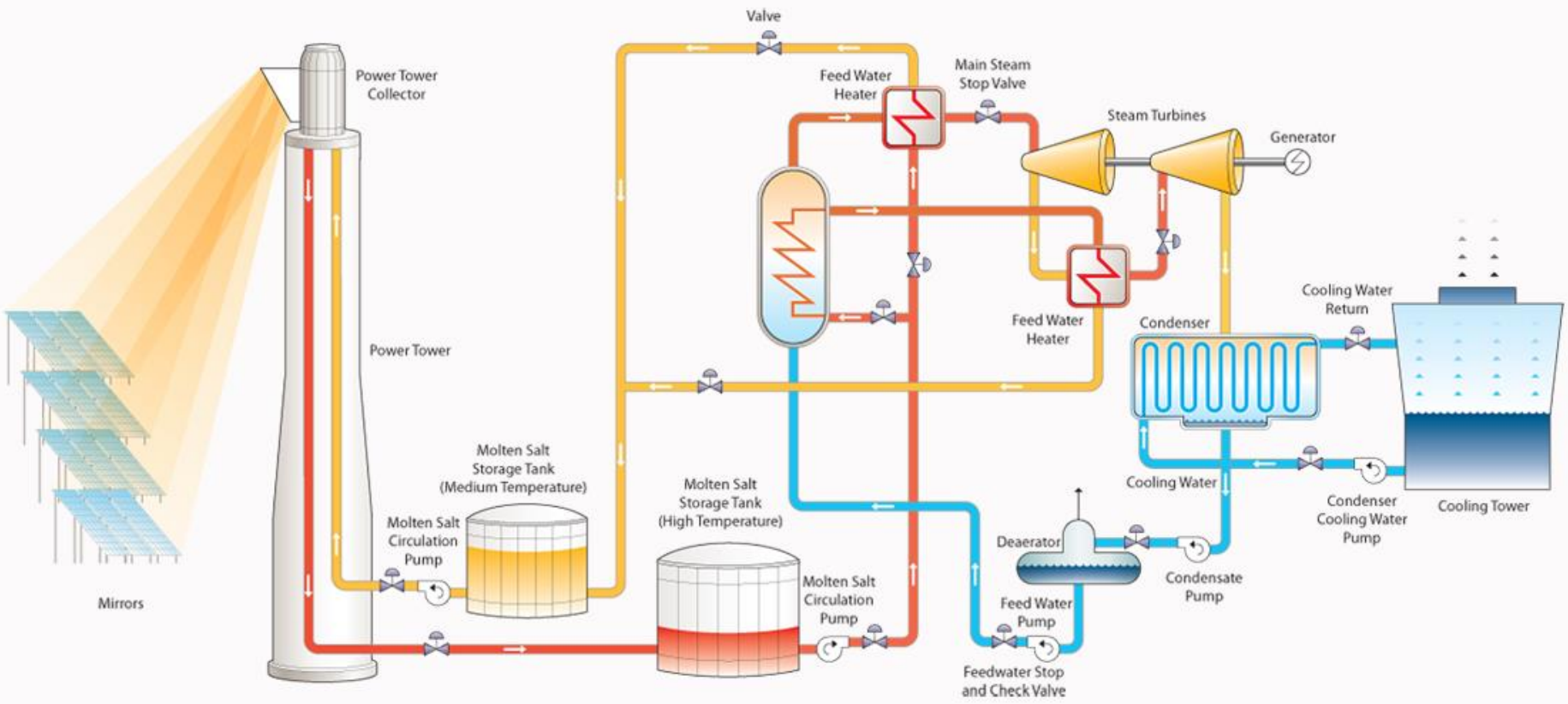
Thermal Energy Storage
Sensible Storage in Molten Salt



Thermal Energy Storage
Sensible Storage in Molten Salt

- **Storage Capacity**: 7.5 hours @ 50 MW. 1,010 MWh.
- **Thermal Storage Description**: 28,500 tons of molten salt
- **Tanks size**: 14 m high, 36 m diameter.
- **Cold tank temperature**: 292 ºC
- **Hot tank temperature**: 386 ºC

Thermal Energy Storage
Sensible Storage in Molten Salt



Thermal Energy Storage
Sensible Storage in Liquids

$$Q_s = (mC_p)_s \ \Delta T_s$$

Q_s is the total heat capacity for a cycle operating through the temperature range ΔT_s and m is the mass of liquid in the unit

Thermal Energy Storage
Sensible Storage in Liquids

$$(mC_p)_s \frac{dT_s}{dt} = Q_u - \dot{L}_s - (UA)_s(T_s - T_a')$$

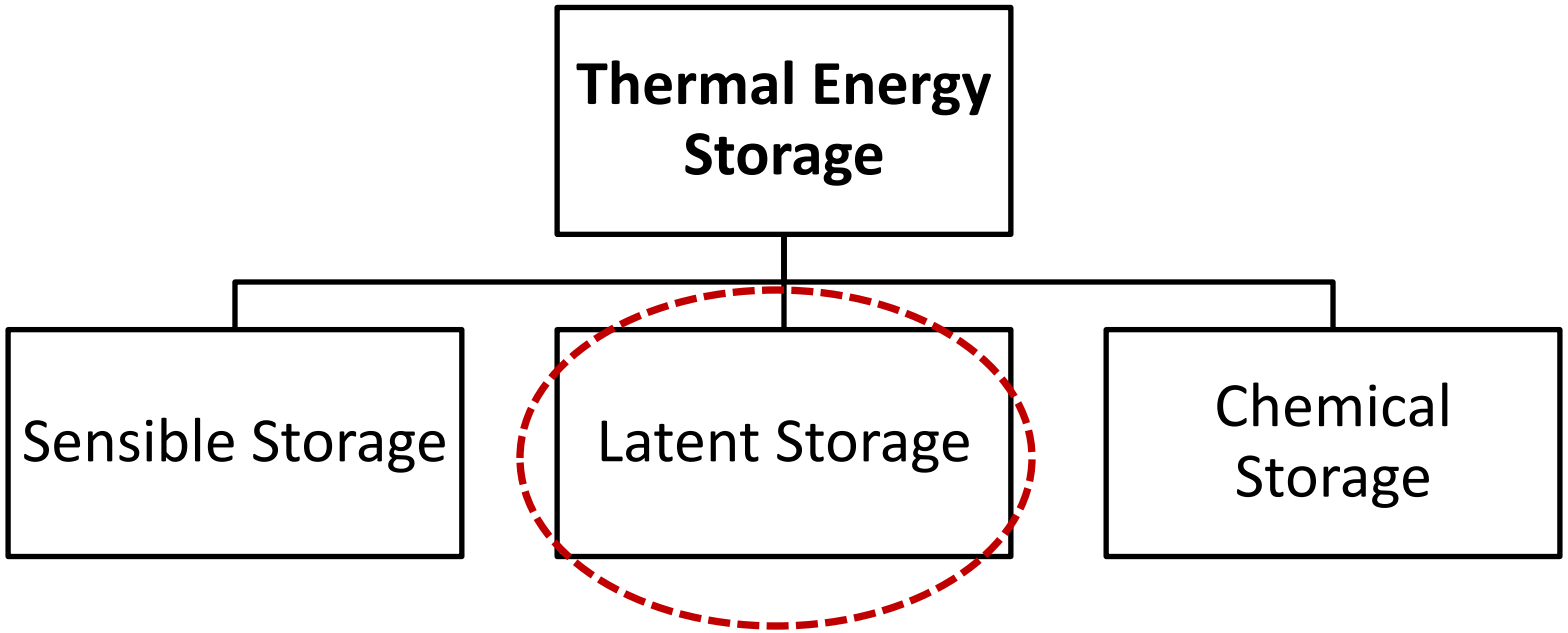
- Q_u and $\dot{L}_s$ are rates of addition or removal of energy from the collector and to the load
- T'_a is the ambient temperature for the tank (which may not be the same as that for a collector supplying energy to the tank).

Thermal Energy Storage
Sensible Storage in Liquids

Numerical Solution

$$T_s^+ = T_s + \frac{\Delta t}{(mC_p)_s}\left[Q_u - L_s - (UA)_s(T_s - T_a')\right]$$

Types of Thermal Energy Storage



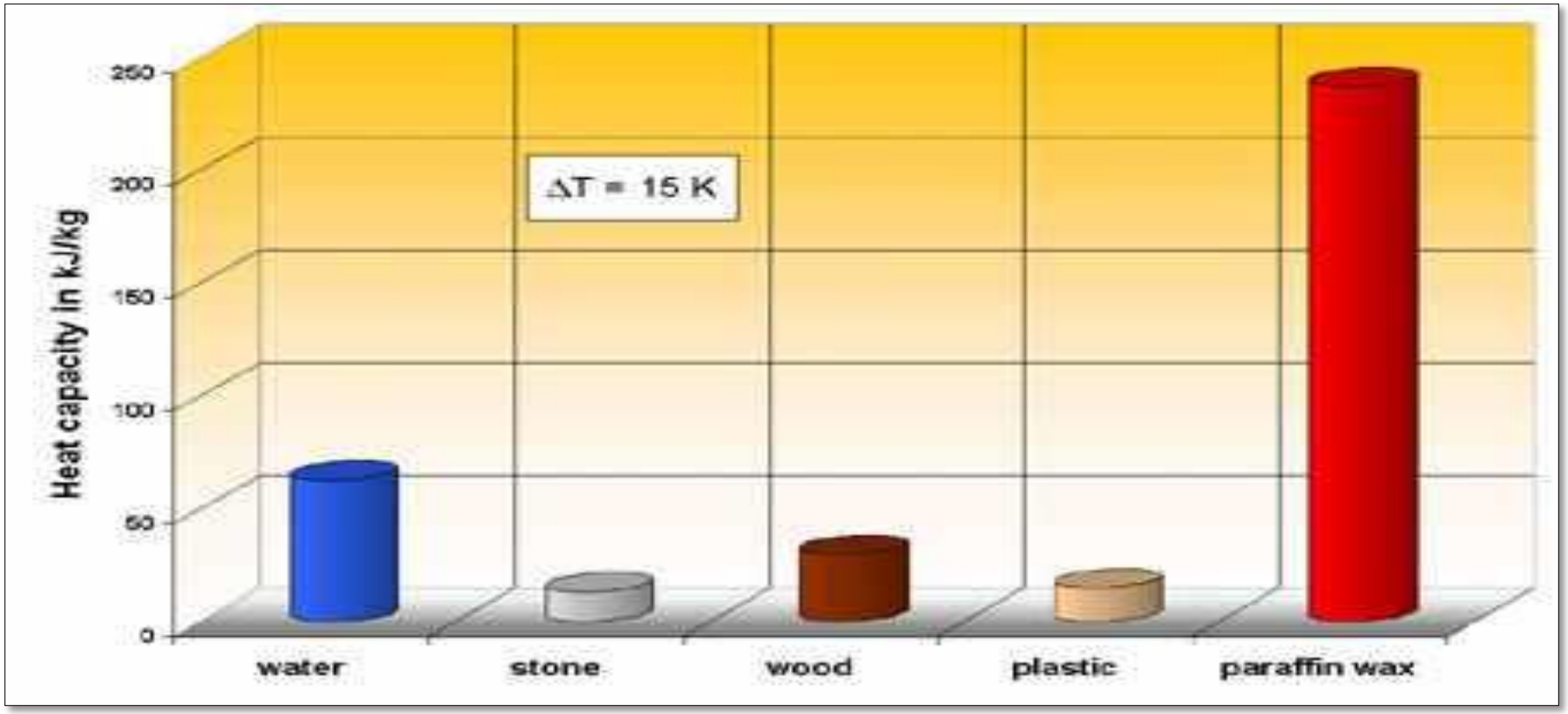
Thermal Energy Storage
Latent (Phase Change) Storage

- Latent heat is the energy required to change the state of a unit mass of material from solid to liquid or liquid to gas without a change in temperature.
- Used when thermal energy storage systems have limited space.
- Used for specific applications in building systems, or specific processes in the agricultural and industrial sector.

Thermal Energy Storage
Latent (Phase Change) Storage

Group	PCM type	Transition temperature (°C)	Latent heat (Wh/kg)	Thermal conductivity, liquid / solid (W/mK)
Inorganic salt hydrates	Calcium chloride	27-30	47-53	0.54[a] / 1.09[b]
	Sodium sulfate (Glauber's salt)	32	70	-
	Zinc nitrate	36	41	0.46[c] / -
	Magnesium nitrate	89	45	0.49d / 0.61e
Organics	Polyglycol E400	8	28	0.19[f] / -
	Polyglycol E600	22	35	0.19[f] / -
	Octadecane	28	68	-
	Ecosane	37	69	-
	Paraffin 116 (paraffin wax)	48	58	-
	Paraffin 6403 (paraffin wax)	62-64	48-53	0.17[g] / 0.35[h]
Fatty acids	Palmatic acid	63	52	0.16[i] / -
	Capric acid	32	42	0.15[j] / -
Organic/inorganic mixes (Eutectics)	Mystiric acid (mainly inorg.)	54	52	-
Aromatics	Naphtalene	80		0.13[k] / 0.34[l]

Thermal Energy Storage
Latent (Phase Change) Storage



Thermal Energy Storage
Latent (Phase Change) Storage
Technical Requirements

1. High energy of phase change
2. Negligible corrosion
3. Negligible expansion
4. Good repeatability of freeze-thaw temperature
5. Must be resistant to chemical or physical change resulting from thermal cycling.

Thermal Energy Storage
Latent (Phase Change) Storage

Advantages

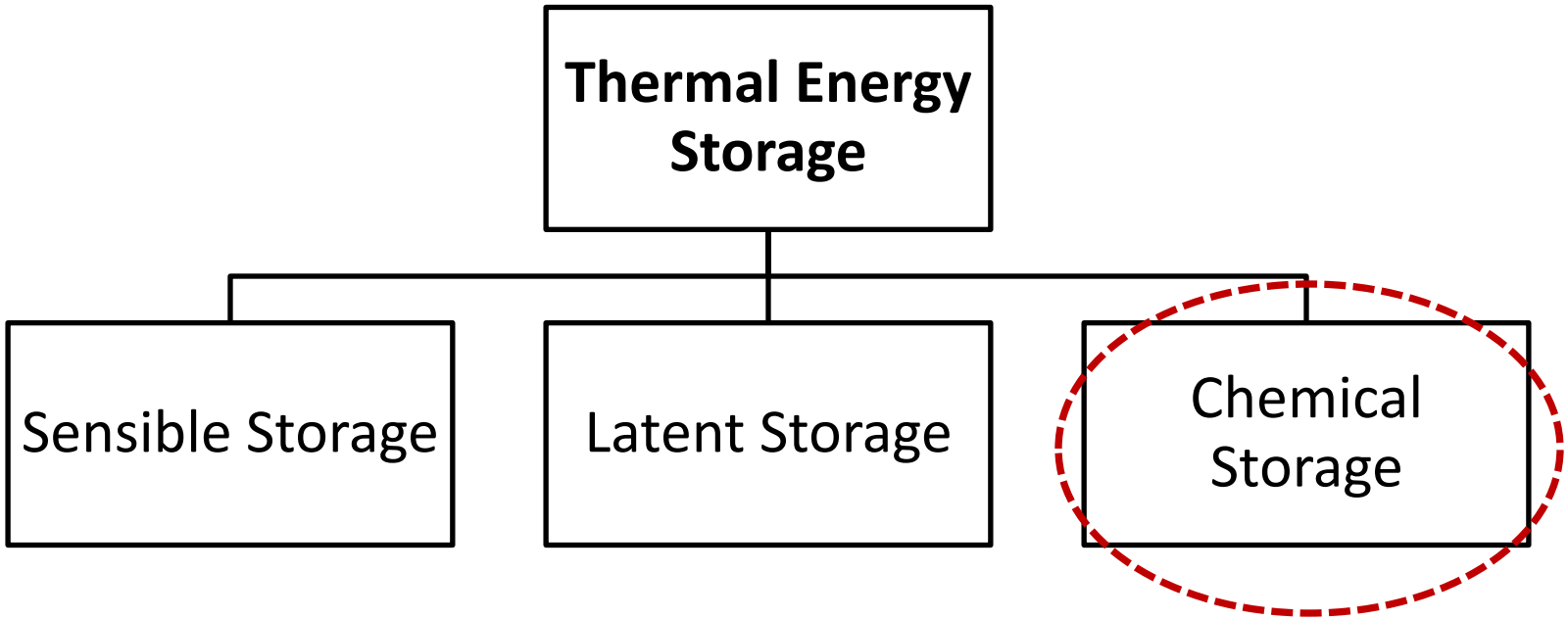
- Store energy at the temperature of process application
- Allows higher thermal energy storage capacity per unit weight or material without change in temperature
- Smaller required storage size
- Relatively constant temperature during charging and discharging.

Thermal Energy Storage
Latent (Phase Change) Storage

Disadvantages

- Higher investment costs
- Peak power during discharge is limited due to limited heat conduction in the solid state of the material.
- Limited experience with long-term operation of many thousands of charge-discharge cycles.
- Risks of loss of stability

Types of Thermal Energy Storage



Thermal Energy Storage
Chemical Storage