Thermal heat storage

- it allows excess thermal energy to be stored and used hours, days, months later, at scales ranging from the individual process, building, multiuser-building, district, town, or region.
- The different kinds of thermal energy storage can be divided into three separate categories: **sensible heat**, **latent heat**, and **thermo-chemical** heat storage.
- Each of these has different advantages and disadvantages that determine their applications.

Sensible heat storage

- The most direct way is the storage of sensible heat.
- Sensible heat storage is based on raising the temperature of a liquid or solid to store heat and releasing it with the decrease of temperature when it is required.
- Materials used in sensible heat storage must have high heat capacity and also high boiling or melting point.
- Although this method of heat storage is currently less efficient, it is least complicated compared with latent or chemical heat and it is inexpensive.
- From thermodynamics point of view, the storage of sensible heat is based on the increase of enthalpy of the material in the store, either a liquid or a solid in most cases.
- The sensible effect is a change in temperature.

Sensible heat storage

- Heat stored can be obtained by the equation:

$$\Delta Q = m \cdot \int_{T_1}^{T_2} c_p\ (T).\, dT$$

where
ΔQ is the energy stored [J]
m is the mass of an object [kg]
c_p is the specific heat capacity [$J.kg^{-1}.K^{-1}$]
dT is the temperature difference

- Heat Capacity:
  - When a given amount of heat is added to different substances, their temperatures increase by different amounts.
  - This proportionality constant between the heat Q that the object absorbs or loses and the resulting temperature change T of the object is known as the heat capacity C of an object.

$$C = Q / \Delta T$$

Sensible heat storage

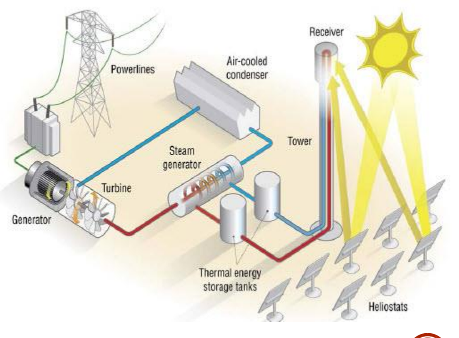
- Multiple forms are already being used and improved while new ones are being investigated actively. Some important ones are:

Molten-salt technology:

- The sensible heat of molten salt is also used for storing solar energy at a high temperature.
- Presently, this is a commercially used technology to store the heat collected by concentrated solar power.
- The heat can later be converted into superheated steam to power conventional steam turbines and generate electricity.
- Various eutectic mixtures of different salts are used (e.g., sodium nitrate, potassium nitrate and calcium nitrate).

Working principle

- ✓ The salt melts at 131 °C (268 °F) and it is kept liquid at 288 °C (550 °F) in an insulated "cold" storage tank.
- ✓ The liquid salt is pumped through panels in a solar collector where the focused sun heats it to 566 °C.
- ✓ It is then sent to a hot storage tank.
- ✓ With proper insulation of the tank the thermal energy can be usefully stored for up to a week.
- ✓ When electricity is needed, the hot molten salt is pumped to a conventional steam-generator to produce superheated steam for driving a conventional turbine/generator set as used in any coal or oil or nuclear power plant.
- ✓ A 100-megawatt turbine would need a tank of about 30 ft tall and 79 ft in diameter to drive it for four hours by this design.



Sensible heat storage

❖ **Hot silicon technology:**

- ➢ Solid or molten silicon offers much higher storage temperatures than salts with consequent greater capacity and efficiency.
- ➢ It is being researched as a possible more energy efficient storage technology.
- ➢ Silicon is able to store more than 1 MWh of energy per cubic metre at 1400 °C.
- ➢ An additional advantage is the relative abundance of silicon when compared to the salts used for the same purpose.

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Sensible heat storage

❖ **Heat storage in hot rocks or concrete**

- Water has one of the highest thermal capacities at 4.2 J/(cm3·K) whereas concrete has about one third of that.
- On the other hand, concrete can be heated to much higher temperatures (1200 °C) by for example electrical heating and therefore has a much higher overall volumetric capacity.
- Thus in the example below, an insulated cube of about 2.8 m^3 would appear to provide sufficient storage for a single house to meet 50% of heating demand.
- Siemens-Gamesa built a 130 MWh thermal storage near Hamburg with 750 °C in basalt and 1.5 MW electric output.
- A similar system is scheduled for Sorø, Denmark, with 41–58% of the stored 18 MWh heat returned for the town's district heating, and 30–41% returned as electricity.

Sensible heat storage

❖ **Molten aluminum:**

- Another medium that can store thermal energy is molten (recycled) aluminum.
- This technology was developed by the Swedish company Azelio.
- The material is heated to 600 degrees C.
- When needed, the energy is transported to a Stirling engine using a heat-transfer fluid.

Phase-change storage

- Latent Heat Storage (LHS) is associated with a phase transition, the general term for the associated media is Phase-Change Material (PCM).
- During these transitions, heat can be added or extracted without affecting the material's temperature, giving it an advantage over SHS-technologies.
- Storage capacities are often higher as well.
- There are a multitude of PCMs available, including but not limited to salts, polymers, gels, paraffin waxes and metal alloys, each with different properties.
- This allows for a more target-oriented system design.
- As the process is isothermal at the PCM's melting point, the material can be picked to have the desired temperature range.
- Desirable qualities include high latent heat and thermal conductivity.
- Furthermore, the storage unit can be more compact if volume changes during the phase transition are small.

Phase-change storage

- PCMs are further subdivided into organic, inorganic and eutectic materials.
- Compared to organic PCMs, inorganic materials are less flammable, cheaper and more widely available.
- They also have higher storage capacity and thermal conductivity.
- Organic PCMs, on the other hand, are less corrosive and not as prone to phase-separation.
- Eutectic materials, as they are mixtures, are more easily adjusted to obtain specific properties, but have low latent and specific heat capacities.
- Another important factor in LHS is the encapsulation of the PCM.
- Some materials are more prone to erosion and leakage than others.
- The system must be carefully designed in order to avoid unnecessary loss of heat.

Advantages and disadvantages of PCM use compared to conventional water storage

Thermo-chemical storage

- Thermo-chemical heat storage (TCS) involves some kind of reversible exotherm/endotherm chemical reaction with thermo-chemical materials (TCM).
- Depending on the reactants, this method can allow for an even higher storage capacity than LHS.
- In one type of TCS, heat is applied to decompose certain molecules.
- The reaction products are then separated, and mixed again when required, resulting in a release of energy.
- Some examples are the decomposition of potassium oxide (over a range of 300-800 degrees C, with a heat decomposition of 2.1 MJ/kg), lead oxide (300-350 degrees C, 0.26 MJ/kg) and calcium hydroxide (above 450 degrees C, where the reaction rates can be increased by adding zinc or aluminum).
- The photochemical decomposition of nitrosyl chloride can also be used and, since it needs photons to occur, works especially well when paired with solar energy

Thermo-chemical storage

- **Adsorption (or Sorption) solar heating and storage:**
- ✓ It can be used to not only store thermal energy, but also control air humidity.
- ✓ Zeolites (microporous crystalline alumina-silicates) and silica gels are well suited for this purpose.
- ✓ The low cost ($200/ton) and high cycle rate (2,000X) of synthetic zeolites such as Linde 13X with water adsorbate has garnered much academic and commercial interest recently for use for thermal energy storage (TES)
- ✓ Typically, hot dry air from flat plate solar collectors is made to flow through a bed of zeolite such that any water adsorbate present is driven off.
- ✓ When heat is called for during the night, or sunless hours, or winter, humidified air flows through the zeolite.
- ✓ As the humidity is adsorbed by the zeolite, heat is released to the air and subsequently to the building space.

Thermo-chemical storage

- **Salt hydrate technology:**
- ✓ The system uses the reaction energy created when salts are hydrated or dehydrated.
- ✓ It works by storing heat in a container containing 50% sodium hydroxide (NaOH) solution. Heat (e.g. from using a solar collector) is stored by evaporating the water in an endothermic reaction.
- ✓ When water is added again, heat is released in an exothermic reaction at 50 °C (120 °F).
- ✓ Current systems operate at 60% efficiency.
- ✓ The system is especially advantageous for seasonal thermal energy storage, because the dried salt can be stored at room temperature for prolonged times, without energy loss.
- ✓ The containers with the dehydrated salt can even be transported to a different location.
- ✓ The system has a higher energy density than heat stored in water and the capacity of the system can be designed to store energy from a few months to years.

Thermo-chemical storage

- **Molecular Solar Thermal-system' (MOST):**
- ❖ With this approach a molecule is converted by photoisomerization into a higher-energy isomer.
- ❖ Photoisomerization is a process in which one isomer is converted into another by light (solar energy).
- ❖ This isomer is capable of storing the solar energy until the energy is released by a heat trigger or catalyst (than converted into its original isomer).
- ❖ A promising candidate for such a MOST are Norbornadienes (NBD).
- ❖ Because it has a high energy difference of approximately 96 kJ/mol.
- ✓ The donor-acceptor substitutions provide an effective means for redshifting the longest-wavelength absorption, improves the solar spectrum match.
- ➢ A crucial challenge for a useful MOST system is to acquire a satisfactory high energy storage density.
- ➢ Another challenge of a MOST system is that to harvest light in the visible region.

Two or more compounds with the same formula but a different arrangement of atoms in the molecule and different properties

Thermo-chemical storage

- **Molecular bonds:**
- ✓ Storing energy in molecular bonds is being investigated.
- ✓ Energy densities equivalent to lithium-ion batteries have been achieved.
- ✓ This has been done by a DSPEC (dys-sensitized photoelectrosythesis cell).
- ✓ The DSPEC generates hydrogen fuel by making use of the acquired solar energy to split water molecules into its elements.
- ✓ As the result of this split, the hydrogen is isolated and the oxygen is released into the air.
- ✓ This sounds easier than it actually is.
- ✓ Four electrons of the water molecules need to be separated and transported elsewhere.
- ✓ Another difficult part is the process of merging the two separate hydrogen molecules.

Comparison among sensible, latent and thermo-chemical heat storage system

Chapter 4
Silicon Solar Cells

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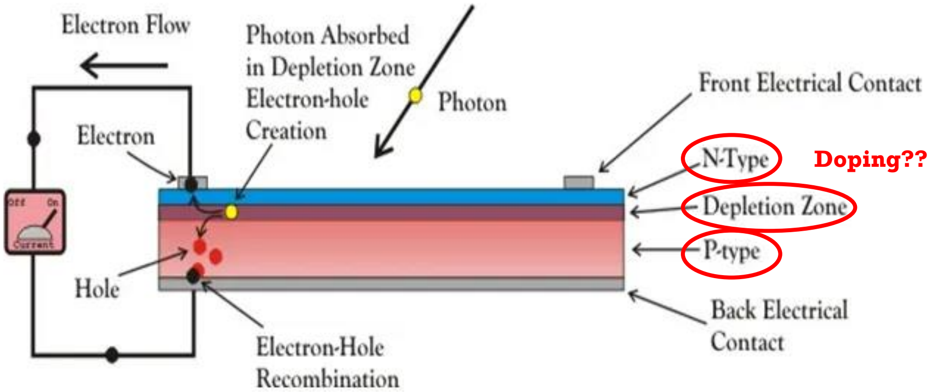
Basic Principle



Basic Principle

- Photovoltaic modules, commonly called solar modules, are the key components used to convert sunlight into electricity.
- Solar modules are made of semiconductors that are very similar to those used to create integrated circuits for electronic equipment.
- The most common type of semiconductor currently in use is made of silicon crystal.
- Silicon crystals are laminated into n-type and p-type layers, stacked on top of each other.
- Light striking the crystals induces the "photovoltaic effect," which generates electricity.
- The electricity produced is called direct current (DC) and can be used immediately or stored in a battery.
- A device called an inverter changes the electricity into alternating current (AC), the standard power used in residential homes.

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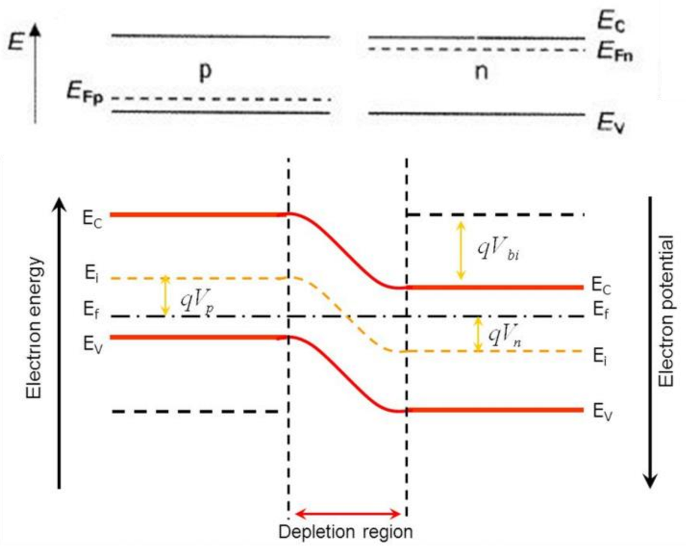
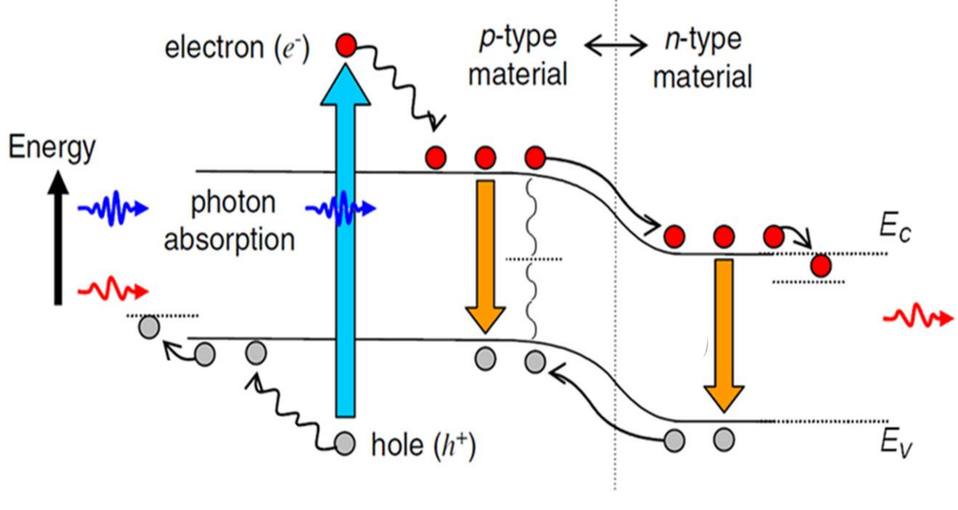
Working Principle



Energy band?
Energy level?
Fermi-energy level?
Intrinsic fermi-energy?
Energy gap?
Shallow level doping?
Deep level doping?

Working Principle



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