# THERMAL ENERGY STORAGE: A PROCESS TO INCREASE EFFICIENCY AND TO SAVE OUR ENVIRONMENT

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**ABSTRACT**

*Thermal energy storage (TES) includes a number of different technologies. Thermal energy can be stored at temperatures from -40°C to more than 400°C as sensible heat, latent heat and chemical energy (i.e. thermo-chemical energy storage) using chemical reactions. Energy storage systems are designed to accumulate energy when production exceeds demand and to make it available at the user's request. They can help match energy supply and demand, exploit the variable production of renewable energy sources (e.g. solar and wind), increase the overall efficiency of the energy system and reduce $CO_2$ emissions.*

***Keywords: Emmisions, Chemical Reactions, Renewable Thermo-Chemical etc.***

## I. INTRODUCTION

- **Sensible Thermal Energy Storage**

The use of hot water tanks is a well known technology for thermal energy storage. Hot water tanks serve the purpose of energy saving

in water heating systems based on solar energy and in co-generation (i.e. heat and power) energy supply systems. Hot water storage systems used as buffer storage for domestic hot water (DHW) supply are usually in the range of 500 litres to several cubic meters. This technology is also used in solar thermal installations for DHW combined with building heating systems (solar-combi systems). Large hot water tanks are used for seasonal storage of solar thermal heat in combination with small heating system. An energy storage system can be described in terms of the following properties:

**Capacity:** The energy stored in the system depends on the storage process, the medium and the size of the system.

**Power:** Defines how fast the energy stored in the system can be discharged (and charged).

**Efficiency:** The ratio of the energy provided to the user to the energy needed to charge the storage system. It accounts for the energy loss during the storage period and the charging/discharging cycle.

**Storage Period**: Defines how long the energy is stored and lasts in hours to months (i.e. hours, days, weeks and months for seasonal storage).

**Charge and Discharge Time**: Defines how much time is needed to charge/discharge the system.

**Cost:** Refers to either capacity or power of the storage system and depends on the capital and operation costs of the storage equipment and its lifetime (i.e. the number of cycles). Capacity, power and discharge time are interdependent variables and in some storage systems, capacity and power can also depend on each other. For example, in TES systems, high power means enhanced heat transfer (e.g. additional fins in the heat exchanger), which, for a given volume, reduces the amount of active storage material and thereby the capacity.

A ↑

B ↑

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C 🡅

**D 🡅**

**Figure.1: Different Kinds of TES [A, B, C, D]🡅**

### ➢ Underground Thermal Energy Storage (UTES)

UTES is also a widely used storage technology, which makes use of the underground as a storage medium for both heat and cold storage. WUTES technologies include borehole storage, aquifer storage, cavern storage and pit storage. These technologies strongly depend on local geological conditions. Borehole storage: It is based on vertical heat exchangers installed underground, which ensure the transfer of thermal energy to and from the ground layers (e.g. clay, sand, rock). Ground heat exchangers are also frequently used in combination with heat pumps where the ground heat exchanger extracts low temperature heat from the soil. Aquifer storage: Its uses a natural underground water permeable layer as a storage medium. The transfer of thermal energy is achieved by mass transfer (i.e. extracting/re-injecting water from/into the underground layer). Most applications deal with the storage of winter cold to be used for the cooling of large office buildings and industrial processes in the summer. Cavern storage and pit storage: It is based on large underground water reservoirs created in the subsoil

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to serve as thermal energy storage systems. These storage options are technically feasible, but applications are limited because of the high investment costs.

### ➢ Phase Change Materials For TES

Sensible heat storage is relatively inexpensive, but its drawbacks are low energy density and variable discharging temperature. These issues can be overcome by phase change material (PCM)-based TES, which enables higher storage capacities and target oriented discharging temperatures. The change of phase could be either a solid/liquid or a solid/solid process. Melting processes involve energy densities in the order of 100 kWh/m$^3$ (e.g. ice) compared to a typical 25 kWh/m$^3$ for sensible heat storage options. Phase change materials can be used for both short term (daily) and long term (seasonal) energy storage, using a variety of techniques and materials.

## II. THERMAL ENERGY STORAGE VIA CHEMICAL REACTIONS

High energy density (i.e.300 kWh/m$^3$) TES systems can be achieved using chemical reactions (e.g. thermo-chemical storage-TCS). Thermo-chemical reactions, such as adsorption (i.e. adhesion of a substance to the surface of another solid or liquid), can be used to store heat and cold, as well as to control humidity. Typical applications involve adsorption of water vapor to silica-gel or zeolites (i.e. micro-porous crystalline alumino-silicates)of special importance for use in hot/humid climates or confined spaces with high humidity are open absorption systems based on lithium-chloride to cool water and on zeolites to control humidity.

## III. APPLICATIONS

Important fields of application for TES systems are in the building sector (e.g. domestic hot water, space heating, air-conditioning) and in the industrial sector (e.g. process heat and cold). TES systems can be installed as either centralized plants or distributed devices. Centralized plants are designed to store waste heat from large industrial processes, conventional power plants, combined heat and power plants and from renewable power plants, such as concentrated solar power (CSP). Their power capacity ranges typically from hundreds of kW to several MW (i.e. thermal power). Distributed devices are usually buffer storage systems to accumulate solar heat to be used for domestic and commercial buildings (e.g. hot water, heating, appliances). Distributed systems are mostly in the range of a few to tens of kW. Manufacturing industry (e.g.automobile industry) can also benefit significantly from TES.

## IV. COSTS OF TES SYSTEMS

Cost estimates of TES systems include storage materials, technical equipment for charging and discharging, and operation costs. TES systems for sensible heat are rather inexpensive as they consist basically of a simple tank for the storage medium and the equipment to charge/ discharge.

- ➢ Storage media (e.g. water, soil, rocks, concrete or molten salts) are usually relatively cheap. However, the container of the storage material requires effective thermal insulation, which may be an important element of the TES cost. Most systems consist of a 5,000-10,000 m$^3$ water container with energy content between 70-90 kWh/m$^3$ and investment costs between 50-200 EURO/m$^3$ of water equivalent, thus translating into a specific investment cost from 0.5-3.0 EURO per kWh.

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- In the case of UTES systems, boreholes and heat exchangers to activate the underground storage are the most important cost elements. Specific costs range from 0.1-10 EURO per kWh and depend heavily on local conditions.
- Phase change material (PCM) storage and TCS systems are significantly more complex and expensive than the storage systems for sensible heat. In most cases (e.g. thermo-chemical reactors), they use enhanced heat and mass transfer technologies to achieve the required performance in terms of storage capacity and power, and the cost of the equipment is much higher than the cost for the storage material. In general, the cost of a PCM system ranges between 10 and 50 EURO per kWh. The difference between the pure PCM and the complete TES system is even higher for active PCM installations.
- Materials for TCS are also expensive as they have to be prepared (e.g. pelletized or layered over supporting structures). Containers and the auxiliary TCS equipment are expensive also for both heat and mass transfer during energy charging and discharging. TCS systems can be operated as either open systems (i.e. basically packed beds of pellets at ambient pressure) or closed systems. Open systems are often the cheapest option while closed systems need sophisticated heat exchangers. The TCS cost ranges from 8-100 EURO per kWh. The overall economic evaluation of a TES system depends significantly on the specific application and operation needs, including the number and frequency of storage cycles.

## V. POTENTIAL AND BARRIERS

TES technologies face some barriers to market entry and cost is a key issue. TES market development and penetration varies considerably, depending on the application fields and regions. Penetration in the building sector is comparably slow in Europe where the construction of new buildings is around 1.3 percent per year and the renovation rate is around 1.5 percent; of course, the integration of TES systems is easier during construction. The estimate of the European potential is based on a 5 percent implementation rate of TES systems in buildings. Penetration could be much higher in emerging economies with their high rates of new building construction. TES potential for co-generation and district heating in Europe is also associated with the building stock. The implementation rate of co-generation is 10.2 percent, while the implementation of TES in these systems is assumed to be 15 percent. As far as TES for power applications is concerned, a driving sector is the concentrating solar power (CSP) where almost all new power plants in operation or under construction are equipped with TES systems, mostly based on molten salt. This is perhaps the most important development field for large, centralized TES installations. In the industrial sector, about 5 per cent of the final energy consumption is assumed to be used by TES installations. In particular, the use of industrial waste heat is expected to grow since the price of fossil fuels will rise and energy efficiency will be the key to competitiveness. Other barriers relate to material properties and stability, in particular for TCS. Each storage application needs a specific TES design to fit specific boundary conditions and requirements. Research and development activities focus on all TES technologies. Most of such efforts deal with materials (i.e. storage media for different temperature ranges), containers and thermal insulation development. More complex systems (i.e.PCM,TCS)require research and development efforts to improve reacting materials, as well as a better understanding of system integration and process parameters.

## VI. APPLICATION OF THERMAL ENERGY IN HARNESSING SOLAR ENERGY

Thermal applications are drawing increasing attention in the solar energy research field, due to their high performance in energy storage density and energy conversion efficiency. In these applications, solar collectors and thermal energy storage systems are the two core components. Concentrating solar thermal power, more commonly referred to as CSP, is unique among renewable energy generators because even though it is variable, like solar PV and wind, it can easily be coupled with TES as well as conventional fuels, making it highly dispatchable. A multitude of advancements have taken place in recent years in an effort to make CSP more cost effective.

Ongoing research efforts are in the areas of reflector and collector design and materials, heat absorption and transport, power production and thermal storage. The availability of storage capacity is expected to CSP plants by electrical utilities. By coupling TES with a CSP plant, the thermal energy can be stored for later use to drive a heat engine. TES has several advantages when compared to mechanical or chemical storage technologies. TES generally has lower capital costs as compared to other storage technologies, as well as very high operating efficiencies.

A TES prototype system that was incorporated into the Solar Two project in Daggett, California demonstrated a round-trip efficiency greater than 97 percent and which was defined as the ratio of the energy discharged to the energy stored in the TES system. Several studies showed that addition of a TES system would result in the following:

- By taking into account the efficiencies of all plant components, TES can improve the annual solar-to electric efficiency (13.2 v/s 12.4 percent), though it slightly lowers the steam cycle efficiency (37.5 v/s 37.9 percent) due to the lower steam temperatures that occur while TES is in use. The two main reasons for the increased annual efficiency were
- much reduced need to dump energy during very high insolation periods and
- Lower turbine start-up losses due to buffering of the intermittent periods.
- The annual Levelized Cost of Energy (LCOE) is reduced by 10 per cent because of the higher capacity factor.
- Slight increases in the thermal losses in the receiver because of the higher HTF return temperature to the solar field.
- Two types of losses occur: thermal losses from the TES storage system, and losses when the storage system is full and the power plant cannot accept more energy because it is already at maximum load.
- Requires a larger solar field compared to the one without storage.
- Increases the capital cost but produces more energy resulting in a lower cost of electricity.
- Electric parasitics are slightly lower with TES because of the higher annual generation and lower percentage of off-line parasitic consumption.
- Turbine start-up becomes a smaller fraction of total energy use since it is operated for more hours with fewer starts.

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