Advanced thermal storages - towards higher energy densities, long term storage and broader operating ranges

As the share of renewables in energy production grows so does the role for thermal energy storage. The wide range of applications for thermal energy storage presents a broad range of development conditions for advanced thermal storage technologies to supplement the existing, widely used water-based heat storage technologies. Thermal energy storage could reveal itself as a real game-changer, allowing for a notable decrease in primary energy demand, thus reducing the energy footprint. It could also support the widespread acceptance and use of renewable energy as well as the efficient use of fluctuating energy sources.

A few specific thermal storage concepts are already part of our daily life. For example, in many district heating networks water storages are being used to decouple the electricity and heat generation in cogeneration plants. Another example is concentrating solar power plants that are creating dispatchable solar electricity by using state-of-the-art two-tank molten salt storages technology.

Why do we need advanced thermal storages?

Although several success stories like the ones mentioned above can be told, the current portfolio of storage technologies cannot serve all possible thermal energy storage (TES) applications. For example, industrial applications call for high temperatures, particularly when dealing with steam, in a very narrow temperature range. And, cooling and heating applications can be hampered by space restrictions and therefore demand higher energy densities of the storage. An overview of such applications and their main driver for development is given in the table below.

In particular, phase change materials (PCM) and thermochemical materials (TCM) comply with higher energy storage densities and offer the perspective of nearly loss-free long term storage. The advantages of higher material energy density and loss-free storage are well known, but the implementation of actual storage systems continue to be challenging. SHC Task 58 /ECES Annex 33: Material and Component Development for Thermal Energy Storage is addressing the challenge and has made significant progress in standardized measurement protocols, materials and component development and system concepts for specific use-cases.

Industrial waste heat utilization, process optimization & solar process heating

Apart from preheating cases, integration of solar heating in industrial processes calls for storages operating at temperatures above 150°C to deliver the required process heat or steam. At these temperatures, water storage reaches its limit and, with increasing temperature, direct steam storage also becomes challenging due to the high-pressure levels and related high costs. When process steam is required, the heat should be delivered in a very narrow temperature range, calling for PCMs and TCMs, which offer the advantage of high storage capacity at nearly constant temperature level.

Similar requirements apply for the recuperation of waste heat either as heat or electricity in combination with a power cycle, as well as the integration of storages to improve process efficiency.

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Temperature level	Application	Driver
Charge T unrestricted	**Power-to-Heat / Process steam**	**Energy density**
10°C	Solar Cooling	High energy density, low temperature
60- 110 °C	Climatization in Cars	High energy density
60 - 120°C	Solar Heating	High energy density Seasonal storage
> 150°C	Solar Process Heat / Steam	Higher temperatures
> 200°C	High T Waste heat recuperation	Higher temperatures
250-400°C	Industrial CHP	Higher temperatures
> 600°C	Concentrated solar power	Higher temperatures, higher storage densities

In this context, thermochemical storage systems based on reversible chemical reactions using, for example, SrBr2, MgO or CaO enable both the upgrading and transporting of the recovered heat. When combined with power-to-heat, the storages provide an alternative to simultaneously generate process steam and store renewable electricity for later use as heat and/or electricity.[1]

Solar heating and cooling

In this sector, water and ice storage in district heating networks have seen increased usage and been used successfully to improve efficiency and reduce the size of the generation plant. However, about 80% of dwellings in Europe are not connected to district heating, so decentralized solutions on both the community and building level are required. These applications face very stringent space restrictions and hence require storages with a substantially increased energy density compared to current sensible storage systems. In this application range, TES based on sorption materials like zeolites[2], aluminum phosphates or salt-hydrates are just a few exciting examples of applications, where energy density and compactness are fundamental properties.

With increasing penetration of renewables, longer term storage becomes increasingly important to bridge the time and location gap between heat/cold generation and use.

Mobile and transportable heating

In the field of mobility, thermal energy storage will play an important role. In electric cars, for example, thermal storages will be a key element to ensure energy efficient climate inside vehicles. Storages are in this case subjected to very stringent space and weight restrictions.

For waste heat recovery an energy dense and efficient storage is required to allow for the cost-effective transportation of waste heat to the consumer site. As projects in Germany have shown, the costs for transporting waste heat are currently dominated by labor costs. However, in a future with autonomous driving cars this will no longer be the case; thus high energy density heat transport might become an interesting option supporting the decarbonization of the industry.

Flexibility in the power grid

As previously discussed, cogeneration combined with energy storages allows for more flexible electricity generation while ensuring that the heat demand is met. In district heating, stratified water storages are state-of-the-art. In industrial cogeneration, high temperature storages are required. Depending on the power and capacity requirements for this application both PCM (high power[3]) or TCM (longer storage periods) using e.g. CaO or MgO[4,5], being developed.

When grid flexibility is needed, power-to-heat and power-to-cold are gaining interest. On a national level, both options provide an efficient way to integrate renewable peak electricity generation, thereby providing flexibility in the electricity grid and simultaneously substituting gas in the heating sector. Even on the local level, power-to-heat offers a compact alternative for solar thermal systems to

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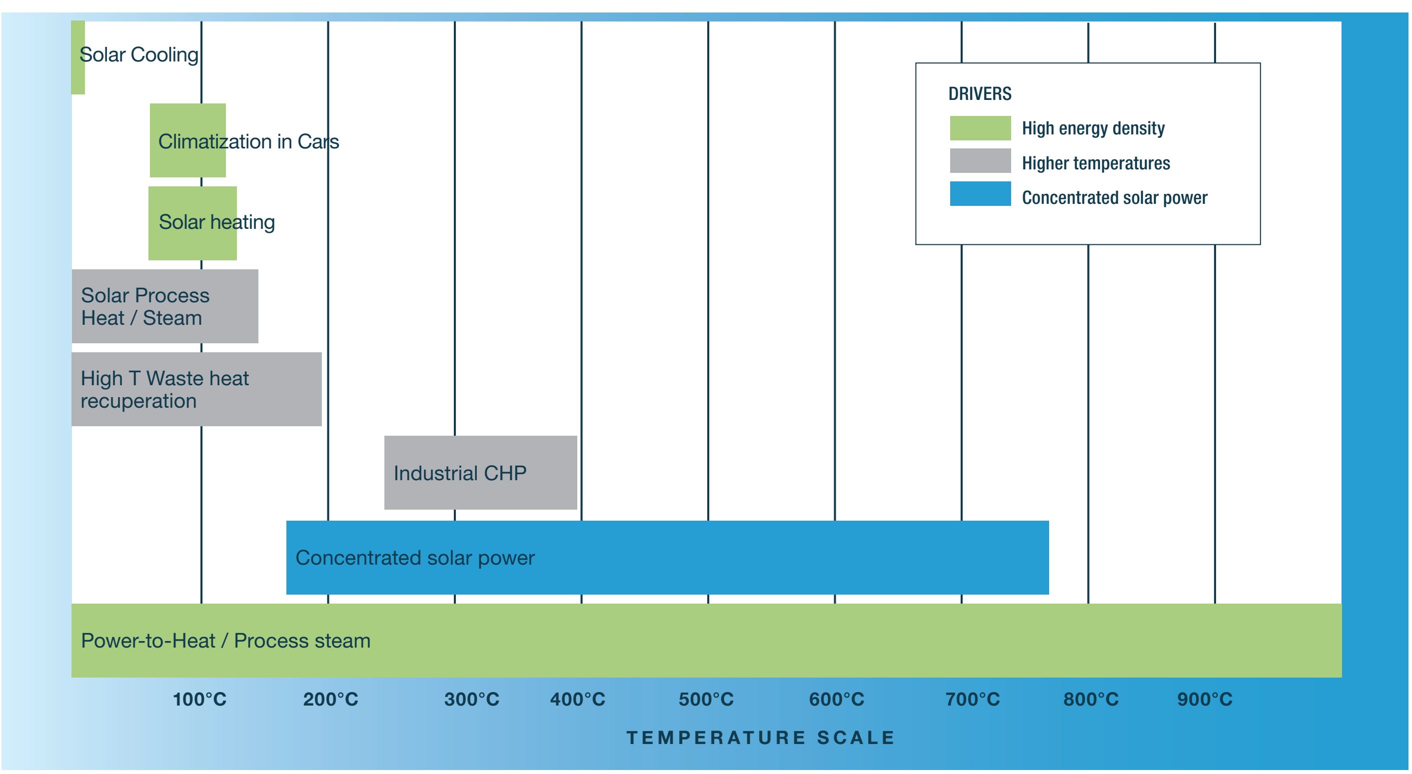

provide space heating, as well as process steam. The technological options in this regard range from simple heating rods and electro-boilers to heat pumps or compression chillers, driven by wind or solar energy.

Conclusion

Thermal storages are an essential component of a highly efficient and renewable energy future. They allow for the cost-effective integration of renewable energy not only in the heating and cooling sector but also in the electricity sector. However, the application cases discussed above show that no single storage solution can serve all applications. To unlock their full potential, further developments are required to develop storages meeting the specific requirements of a particular application. The main drivers in this development are the need for application temperatures beyond the working range of water, higher energy densities, energy charging and discharging in narrow temperature ranges, and low energy losses enabling long term heat storage while guaranteeing a cost-effective application. In particular, advanced systems based on PCM and TCM provide very promising solutions and require an international, long term research and development initiative.

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