Non-chemical storage technologies

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Non-chemical and Thermal Energy Storage

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Options

- Advanced compressed air energy storage (ACAES)
- Thermal and pumped thermal energy storage, Carnot Batteries
- Liquid air energy storage
- Thermochemical heat storage
- Gravitational energy storage
- Storage to provide heat

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ACAES

Three grid-connected ACAES plants using caverns now in operation in China, e.g.

- 50 MW_e /300 MWh_e plant (operating since May 2022)

- air stored in a salt cavern, heat in thermal oil
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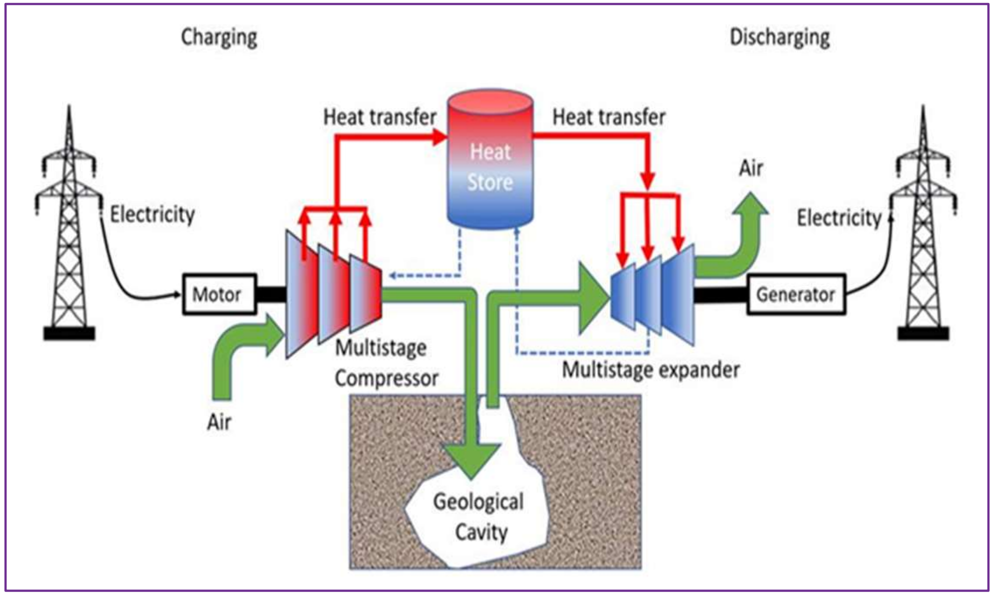
- 100 MW_e /300 MWh_e plant (operating since September 2022)

- air stored in a mined cavern, heat in supercritical water



- 10 MW_e/100 MWh_e plant (operating since September 2021)

- air stored in a salt cavern, heat in supercritical water

Cannot give generic cost: depends on several factors

- **pressure range** (~ determined by depth, unless in solid rock or container)
- **design:** number of stages of compression and expansion,

(*heat stores most of the energy: compressed air mainly stores exergy*)

assumed multistage compression → limits temperature rise → store heat of compression in water (much cheaper than high temperature molten salt storage)

- **size of compressors:** rule of thumb → cost ~ $(\text{power rating})^{0.6}$

Underground capacity in GB

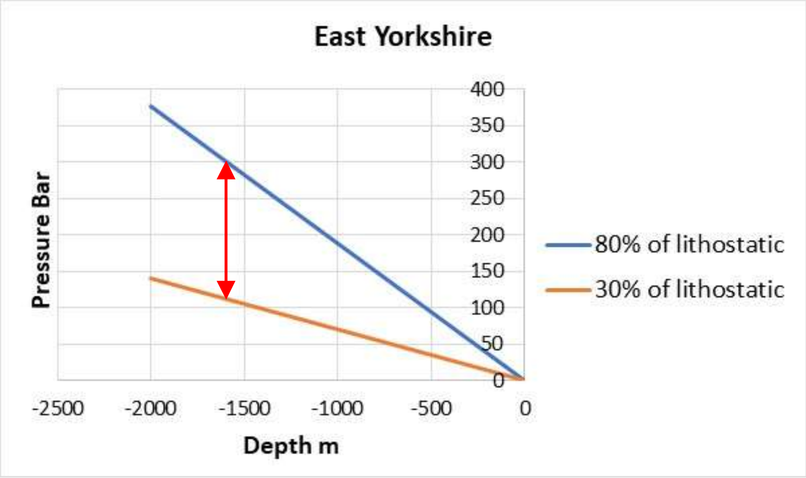
Perhaps sufficient for ACAES that would deliver 20 TWh_e storage– but this would start to encroach on other needs for underground storage

Requires 2000 caverns assuming $10GWh_e$ storage capacity

ACAES – Modelling and Cost Assumptions

Modelled 300,000 m³ (H21) **caverns at 1000 m & 1700 m depth**

Assumed average: each cavern absorbs 10 GWh work of compression in 6 stages. Expansion in 6 stages, supported by 7.5 GWh of thermal storage can deliver 6.8 GWh_e



Costs estimated based on

- **1.5 x H21 cost for clusters of caverns**, without specific H_2 related costs
- **Water pit storage**: based on actual (full) costs from Denmark
- **Compressors/expanders**: have quotes from suppliers of $200/$kW_e$ for complete/crated 1 MW_e systems (but not for UK safety standards)

But want costs (which will fall when manufactured at scale) for six-stage ~ 60 MW systems, including cost of buying/preparing site, installation, share of management costs,...

- **Assumed £(100-500*)/kW for ~ 60 MW**

  **conservative if 0.6 law holds – for very different systems, over range 1 to 60 MW*

+ 4%/year O&M

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Indicative costs:

- A cluster of 10 caverns of 300,000m^3 capacity £188.1M
- Heat storage, 10 pit stores at 140,000m^3 capacity, £70M
- Cost per kWh storage 2.6£/kWh_e stored
- 233MW compressors and expanders for 10 Caverns at £500 kW each including site preparation, installation etc. £233M
- O&M costs, 4 % of capital costs per year.

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Thermal Energy Storage

Andasol 1 Heat Storage: Molten salt

- $NaNO_3/KNO_3$ (60:40)
- Capacity around 1000 MWh thermal
- Operational store temperatures :-
  hot store 390ºC
  cold store 290ºC
- Approximately 14,000 m^3 of storage

Storage provides 7.5 hours output at $50MW_e$, $375MWh_e$

Operational temperature range could be increased to 550 ºC yielding $975MWh_e$ storage equivalent.

Larger stores have proportionately lower heat losses.

Packed bed thermal energy storage

- Low-cost materials, igneous rock with stable properties at temperature of operation. (600°C +)
- Storage capacity increases with store volume, heat losses increase with store surface area. Favours large stores.
- High conversion efficiency of electricity to heat for charging.
- Heat to electrical conversion efficiency 45%+ possible.
- If low temperature heat can also be used for other applications, district heating, higher energy efficiency can be achieved.
- Large stores with capacities of 10's of GWh_e can potentially achieve low costs per KWh_e storage. ($1-4 for modelled low and high-cost scenarios)

Concluding Remarks

Different approaches for energy storage are possible that are scalable to the multi GWh capacity with potentially low costs.

ACAES: round trip efficiencies of approximately 68 % were obtained from modelling with cost per kWh_e storage 2.6£/kWh_e

Heat: round trip efficiencies depend on temperature of storage, higher temperatures lead to higher efficiencies, 45-55% should be possible. Low costs per KWh_e are possible for large packed bed thermal stores using low cost abundant materials.

Provision of multiple services, heat/coolth in addition to electricity can increase total efficiencies to high levels.