Technology: Compressed Air Energy Storage

GENERAL DESCRIPTION

Mode of energy intake and output

Power-to-power

Summary of the storage process

In compressed air energy storages (CAES), electricity is used to compress air to high pressure and store it in a cavern or pressure vessel. During compression, the air is cooled to improve the efficiency of the process and, in case of underground storage, to reach temperatures comparable to the temperature at storage depth. To (re-) generate electricity, the compressed air is expanded in an adapted gas turbine which is coupled to a generator. Before or during this expansion, the air must be heated to prevent it from cooling to sub-zero temperatures and to improve the efficiency of the conversion. Adiabatic CAES systems use the heat generated during compression for this, temporarily storing it in a thermal storage. Diabatic systems do not store the heat from compression. Instead, they use natural gas or or other fuels to heat up the air during expansion.

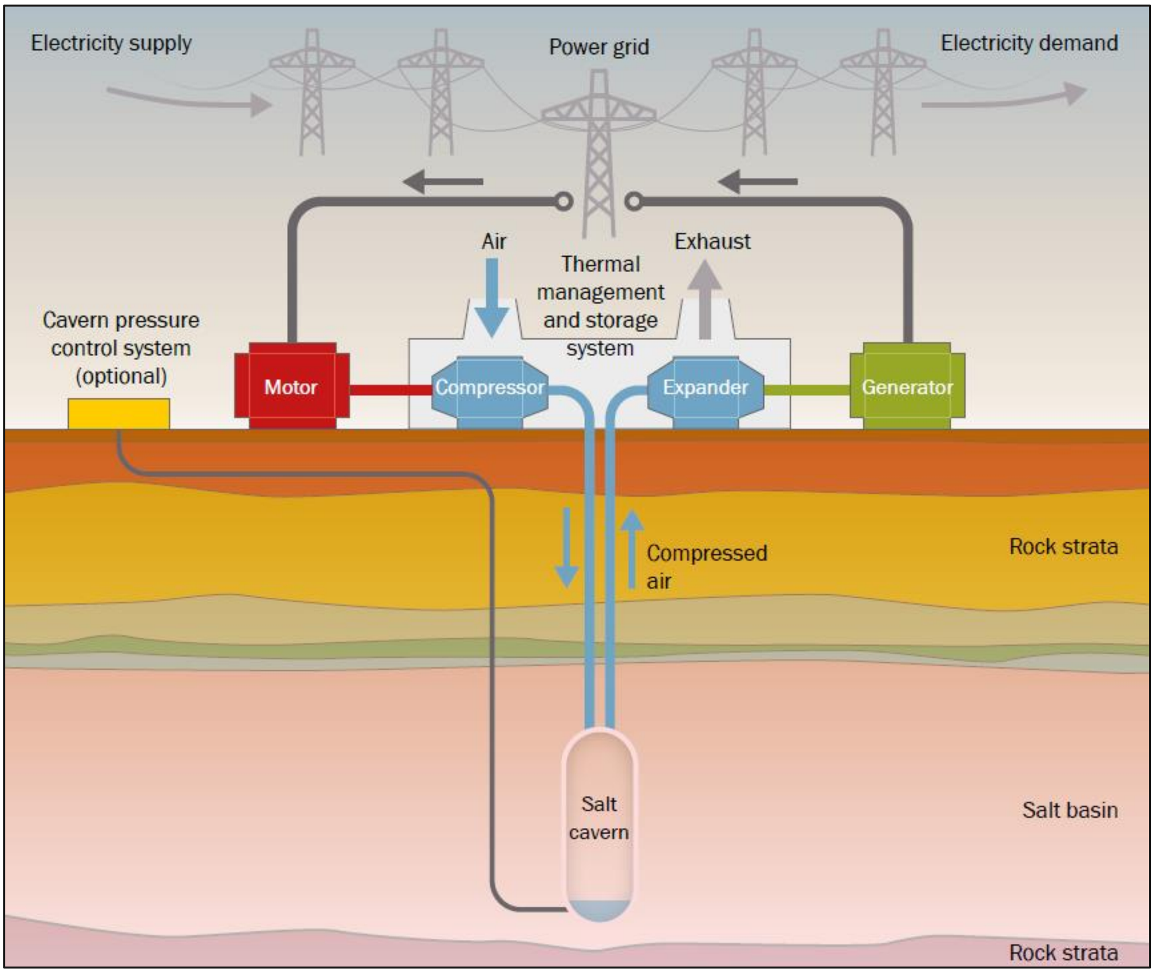

Figure 1: Schematic of CAES, taken from: Groenenberg et al., *Large-scale energy storage in salt caverns and depleted fields (LSES) – project findings*, TNO Report R12006, 2020.

System Design

Typical system capacities range between 100 and 500 MW_{el}. Most commonly, the air is stored in man-made salt caverns of several 100,000 m^3, built into subsurface salt formations. Suitable salt formations can be found in northwest Europe (Germany, the Netherlands, and Denmark), on the Iberian Peninsula, in southeast France, parts of Great Britain, and in the United States. Small-scale systems may also use pressurised cylinders or tanks for above-ground storage.

The necessary heat storage in adiabatic systems can be provided in different ways and at different temperature levels. Single-stage processes run at temperatures of around 600 °C, for which fixed-bed storages (cf. fact sheet on sensible high-temperature storages) are a suitable technology. Multi-stage processes can use lower storage temperatures, which may be achieved using different storage media, such as thermal oil, molten salts, or even water.

Focus on provision of power or energy

Energy

Suitable fields of application

Power-to-power storage for hourly to weekly balancing, provision of control energy (tertiary, partly secondary)

State of development/commercial availability

Adiabatic systems are still under development (TRL 5).

Diabatic systems, which store air in underground salt caverns and co-fire natural gas in the CAES turbine, are commercially available (TRL 9). Worldwide, two systems have been implemented: the Huntorf plant in Germany, which can output 321 MW_{el} over 2 hours at full load, and the McIntosh plant in the USA, which outputs 110 MW_{el} over a time span of 26 hours.

TECHNICAL SPECIFICATIONS

Specific energy storage density	kWh/m³	kWh/t
	2-25	Not relevant
Specific power density	kW/m³	kW/t
	Not relevant	Not relevant
Typical/feasible storage size	MWh_{out}	MW_{out}
	50-27,000	100-500
System efficiency	40-60 %	
Storage duration	Hours-years	
Response time	Minutes	
Service life (maximum)	Cycles	Years
	-	30-40
Loss per time in %	0.5-1 %/d for adiabatic, 0% for diabatic	

NOTES

The system's loss originates almost exclusively from the heat storage tank. The losses that occur in pressure vessels and salt caverns are negligible.

ECONOMIC SPECIFICATIONS

Investment cost per kW

1,000-1,500 € (700-1,000 € expected for 2030)

Investment cost per kWh

12-18 €

Operating and maintenance cost (based on investment/kW and kWh)

For adiabatic systems:	2-3 % of total investment per year
For diabatic systems:	2-3 % of total investment per year plus fuel cost

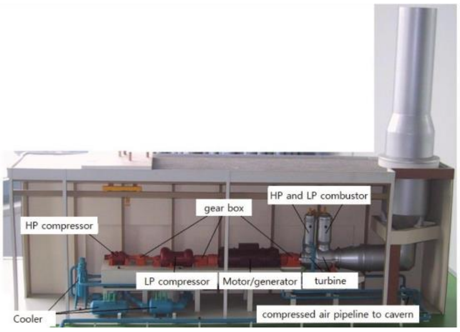

Figure 2: Model of CAES Huntorf (© Wikipedia)

Figure 3: CAES plant in Huntorf, Germany (© E.ON Kraftwerke GmbH)