Subsurface / Underground Compressed Air Energy Storage (CAES)

Renewable energy sources, such as solar and wind, being susceptible to short term and long term seasonal fluctuations, cannot provide energy upon demand. Energy storage at grid-scale, allows renewable energy to be supplied on demand, enabling carbon-free electricity grids 100% supplied from renewables.

Storing compressed air underground in geological formation – subsurface Compressed Air Energy Storage (CAES) – is one of the few technological options to economically store energy at grid-scale. The concept was invented in the 1950s and has developed since then.

The surface equipment of a CAES plant uses energy to drive pumps to compress air and inject it underground to store energy. When energy is demanded, the high pressure air is extracted and expanded to drive turbines to generate power. EIC's isothermal CAES minimizes the equipment necessary and energy losses during the compression and expansion phases.

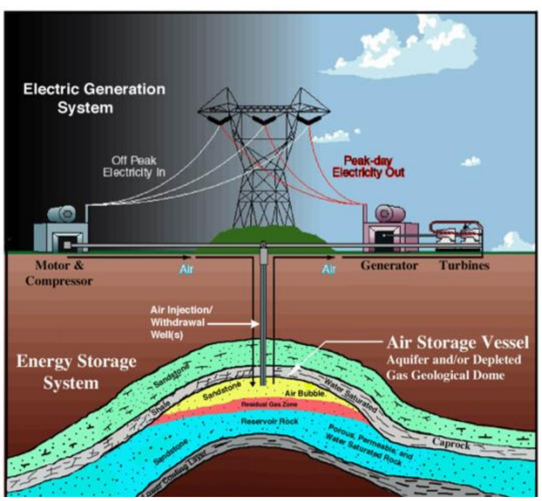

Figure 1: Underground Compressed Air Energy Storage (King/Moridis, Wiley Press, 2021)

The historical development of CAES technology has been joint application of several technologies, each of which has been used to commercial and technical success for other purposes for many years[1]. Natural Gas has been successfully stored in underground aquifers and depleted natural gas fields since the 1950s. Wells have been used to produce hydrocarbons for 150 years and to produce water for thousands of years.

Underground geological structures suitable for energy storage in the form of compressed air under pressure include:

- Solution-mined salt caverns
- Excavated mine cavities
- Aquifer water-bearing geological structures
- Depleted natural gas reservoirs

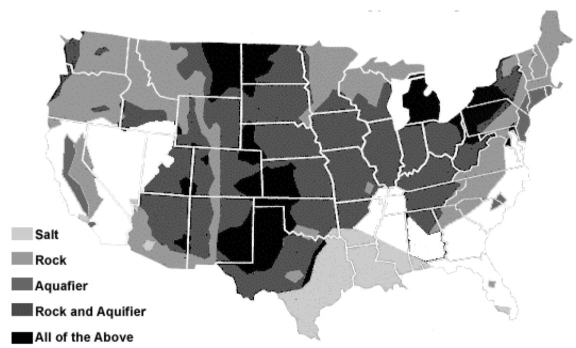

Figure 2: Underground formations potentially suitable for CAES (2003 DOE/EPRI Handbook)

Studies conducted by the US Department of Energy over 1970-1995 concluded that around 80% of the US had potentially suitable conditions for subsurface CAES, as shown in Figure 2.

The selection of suitable underground sites requires the assessment of conditions that enable the matching of operating pressure and flow rates

[1] From "Compressed Air Energy Storage" M. J. King & M. J. McGill, Encyclopedia of Engineering and Technology, 2nd Ed., 2015

to and from the underground storage to the surface equipment. Each of the types of geology: salt cavern; excavated hard rock mine cavities; aquifer rock; depleted gas reservoirs bring unique considerations for their evaluation.

For example, air and natural gas can be contained in aquifer porous media structures or in depleted gas reservoir porous rock because of multiple geologic and hydraulic barriers to migration. The air or natural gas are contained under pressure by an impermeable shale or carbonate caprock. These geological conditions allow a large volume of air, typically many times more than what is needed for a daily charge and discharge cycle for energy storage and generation, to be stored underground without any significant leakage leading to loss of pressure and energy. Thus, the underground air remains at approximately constant pressure, with daily charge and discharge being a small perturbation of the remaining cushion gas underground.

A second major consideration is the deliverability of air, i.e., the rate at which air can be withdrawn from the underground cavern to supply the surface equipment for power generation. Deliverability is influenced by the number of wells, and the permeability characteristics of the reservoir, which affect how wells are supplied with air from the large subsurface air volume.

Underground CAES is different from natural gas storage and the storage of other fluids as injecting oxygen (in the air) underground has a number of risks. All these risks are well-understood scientifically, and there are engineering measures to manage them If there are hydrocarbons present, care must be taken to ensure the oxygen/hydrocarbon mixture is not within an "ignition envelope" that would make it combustible. By careful staged injection of the air bubble, it is possible to assure that most hydrocarbons migrate to the extremities of the air bubble so that the presence of hydrocarbons in the daily charge and discharge is minimized.

In some depleted oil & gas fields, the hydrocarbon-bearing rock is below hydrocarbon-free aquifer rock by impermeable layers. It is possible to isolate the hydrocarbon zone from the upper storage aquifer pore space by placing an isolating plug in the well(s) just above the hydrocarbon-bearing zone. The existing well infrastructure can then be used to store air in the aquifer rock above the hydrocarbon zone.

Oxygen also causes corrosion in certain mineralogies. Screening mineralogy avoids sites where oxidation might compromise the long-term pressure integrity of the reservoir.

Salt caverns and excavated mines offer modest energy storage, up to 24 hours for modest plant sizes such as 100MW. Porous or aquifer rock, where water or hydrocarbons are trapped, offers the largest volumes for energy storage, adequate for the largest long duration energy storage needs at GW scale. The smallest gas reservoirs with volumes of 40 million cubic meters can easily hold Terawatt hours of storage, storing air at pressures ranging from 120-200 bar. Surface storage of such capacity would be prohibitively expensive.