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Overview of the Subsurface Challenges for Compressed Air Energy Storage

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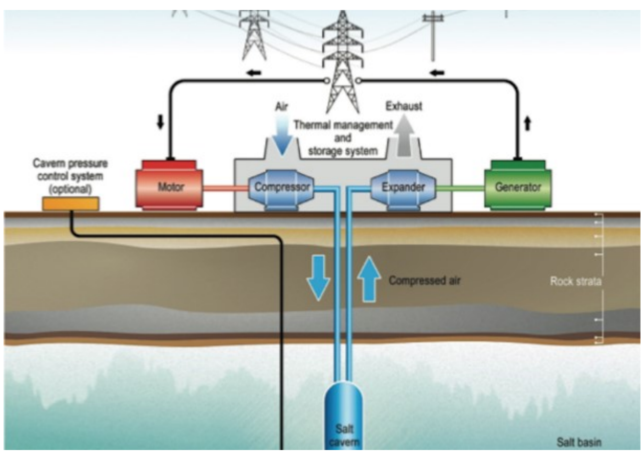
Compressed Air Energy Storage (CAES) is a proven and mature technology. Two projects that have been in operation for decades are in Huntorf, Germany and McIntosh, Alabama. Ample information is available from existing projects, studies, and researches; however, the technology did not show a widespread deployment due to economic and technical risks associated with the projects.

The basic idea of CAES is compressing a large volume of air to store in a subsurface geologic formation when the electricity price is low (Off-peak hours). During on-peak hours, when the electricity price is high, the stored air is released back to the surface to run a gas turbine and generate electricity. As the gas turbine is operated with compressed air, the fuel required to produce a unit of electricity is a third of that of a conventional gas turbine[1]. Lower fuel requirement reduces carbon emissions by 40-60%[2]. Figure 1 shows the basic CAES system.

Figure 1: CAES System



Source: Storelectric.

There are two types of underground formations that can be utilized to implement CAES: 1) salt caverns, and 2) porous formations.

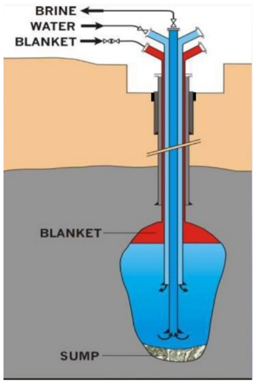
Salt caverns are the most desired of the two CAES applications. The two existing CAES projects are implemented in salt caverns. Moreover, salt caverns have been used for decades to store hydrocarbons in North America. There are hundreds of caverns used for commodity storage in Canada. Usually, those caverns are located close to oilfields and refineries, because most salt formations were discovered in Canada during oil and gas exploration and development in the mid-90s. Porous formation for CAES applications has been studied at length. Porous formations have the advantage of widespread availability of suitable geological formations (same as oil and gas deposits) that gives more options when choosing a CAES location. However, implementing CAES in porous formations has many technical and economic challenges that hinder its deployment. This article presents information regarding the status and associated technical and financial risks associated with CAES.

Salt Caverns

Salt layers were discovered in Canada in the 1900s and since then salt production increased exponentially[3]. There are two methods for salt extraction[4]. The most common one that resembles surface mining operations is the conventional rock salt mining method which accounts for roughly 92% of total salt production. The second method is known as solution mining or brining[3]. Solution mining is a method that creates underground caverns.

Solution mining operations are done by drilling a well to reach the top of a salt formation. The well usually has three completion conduits (pathways) designed to pump fresh water into a well, pump brine out of a well, and inject special fluid known as blanket (such as diesel) to cover the bottom part of the well and the casing, to protect the cavern's roof by ensuring that water does not wash salts around the casing at the top of the cavern. Figure 2 shows an example of a solution mining cavern.

Figure 2: Typical Example of a Salt Cavern with Solution Mining Operation



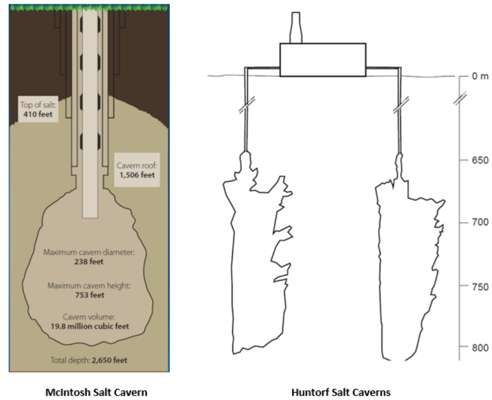
Source: Atlas BA

Once drilling and completion periods are finished, fresh water is pumped downhole to wash and dissolve salts. This process is called leaching. The fluid is pumped out of a well as a brine with high salinity, which could be turned into salt by evaporation or disposed of according to environmental regulations.

In Canada, solution mining for salt extraction purposes began in nine locations: Nappan in Nova Scotia; Goderich, Sarnia, Sandwich, Watford, and Amherstburg in Ontario; Neepawa in Manitoba; Unity in Saskatchewan; and Lindbergh in Alberta[3]. Some of the locations became major hubs for hydrocarbon and chemical storage, as oilfields and oil discoveries revealed salt formations that led to a revolution in the salt extraction. It is important to note that the above-mentioned provinces would be the reasonable options for CAES in salt caverns in Canada.

Usually, it takes up to three years to drill and create a cavern with an average volume of 100,000 m^3[5],[6]. Around 6-8 m^3 of fresh water are required to dissolve salt and create a 1 m^3 cavern[7]. The leaching process eventually creates the cavern with a pear-shaped profile[6]. It is important to note that bigger caverns can take a longer time for development. For example, the volume of a cavern at the McIntosh Power Plant is 538,000 m^3 to produce 110 MW[8], while the size of the Huntorf plant cavern (two caverns) is 310,000 m^3 to produce 290 MW[8]. Figure 3 shows the caverns shape in the two current CAES projects – McIntosh (left side) and Huntorf (right side).

Figure 3: CAES Salt Caverns



Source: Powersouth & Crotogino et al.

There is a difference between creating a cavern for salt extraction and for commodity storage such as a hydrocarbon. For optimum salt extraction, the operator would create many wells and develop two or more caverns in the same proximity, so caverns can connect at the subsurface and create a larger compartment, which is known as a gallery[9]. However, caverns for commodity storage rely on one cavern[6].

There are risks associated with underground storage such as leakage, ground subsidence, and cavern failure due to roof collapse[10]. Caverns can shrink due to salt creep or grow due to washes. Regulators in Canada[11],[12] follow the Canadian Standards Association (CSA) Standard Z341: Storage of Hydrocarbons in Underground Formations to ensure proper design, construction, operation, and abandonment for caverns and associated wells[13].

The standards are designed by experts in the field with the latest version being released in 2018. CAES, or air as a stored substance, is not in the scope of this standard. However, the standard covers natural gas, which is more hazardous than the air. The standard has reasonable safety factors to ensure safe practice to protect the public and the environment.

It is important to note that CAES operation is different from hydrocarbon storage and they cannot be compared. In hydrocarbon storage operation, fluids are pumped in and out by fluid displacement (no compression/decompression), which allows the operator to maintain a constant pressure at controlled flow rates below the maximum allowable pressure. The injection and withdrawal are done per season, which does not cause a major disturbance in the cavern. There are hundreds of caverns in Canada used for underground storage with no issues.

CAES exposes the cavern daily to high pressure during compression and dramatic decreases in pressure during withdrawal. Pressure and temperature would fluctuate during daily cycles which could be as many as needed per day to meet the power generation requirements. There are no guarantees that a cavern would be stable throughout the project's life span. Rock mechanic studies, along with thermodynamic simulations, would be required to predict cavern stability.

As stated earlier, the two operations are different. However, complying with CSA standard's is essential since there are many guidelines designed to protect the environment such as the required distances from other wells and properties, mechanical integrity testing (MIT), hydraulic control monitoring, sonar surveys, subsidence monitoring, annual examination, and abandonment[13].

It is important to note that when air leaks, it will not cause direct damage to the environment. The main issue is that it can create a pathway to other reservoir compartments and affect their integrity. For example, if air leaked to a hydrocarbon or solution mining project, they will leak back to the CAES site and both projects will be a threat to the environment. Enough distance from other activities is required; the minimum distance may vary, depending on the jurisdiction. For example, in Ontario, a space of 1.6 km is required from any gas storage area designated by the Ontario Energy Board[11],[14].

In summary, salt caverns are suitable for CAES projects. However, it is important to conduct comprehensive studies and address risks during the planning stages of a project as it requires very careful evaluation regarding subsurface issues.

CAES in Porous Formations

Regardless of various studies over many years, developing CAES in porous formations[15]-[17] is still undergoing further assessment. Apparently, it looks possible because this type of formation is used to store hydrocarbons. However, CAES is different because the operation requires the immediate release of air to run turbines during on-peak hours. This compression and release operation cycle could be done several times per day, whereas the natural gas storage takes place a few times per season, over several days, from different wells.

A porous formation has many challenges that could restrict airflow during injection and withdrawal due to a variation in permeability and porosity (reservoir heterogeneity). The most notable case was the Iowa Stored Energy Park (ISEP), which was designed to store electricity at a rate of 270 MW. After eight years in development, the project was terminated due to the site's geological limitations[17],[18]. Nonetheless, the idea still interests many companies in that field. A new research project in California is being conducted by the Pacific Gas and Electric Company (PG&E) to explore the viability of starting new projects in a porous rock formation in the US[16].

Porous formations could be in an aquifer or former hydrocarbon depleted reservoir. There are safety concerns[19] related to former oil and gas reservoirs as there is a possibility of detonation due to the existence of air, heat, and fuel. There are different reasons for ignition, however, the adiabatic heat during compression is a concern and could be a source of ignition. Studies[16],[20] would recommend purging the formation from hydrocarbon and perform air quality tests before commencing CAES operations.

There is a high possibility of financial loss and project cancellation for CAES in porous formations. As stated earlier, the porous formation is not deployed on a large scale and still undergoing further study. However, it is important to learn from other cases.

For example, the ISEP CAES project was proposed to produce 240 MW, the total project cost was $400 million. Even though the location was very good for wind projects; the subsurface geology was not suitable for the CAES application. The project was cancelled after spending $8.6 million, where most of the funds were provided by the Department of Energy (DOE) Energy Storage Program [18].

There is a recent study by Pacific Gas and Electric – which was awarded $25 million funding from a DOE grant, $24 million from the California Public Utilities Commission and $1 million from the California Energy Commission – to determine the feasibility of a 300 MW CAES[16].

The CSA group held a workshop in October 2018[21] to facilitate a discussion about CAES in porous rock reservoirs and potential existing national or international standards that may offer suitable technical approaches. Three areas that have been addressed that are not in the scope of CSA Z341 for hydrocarbon storage:

- Technical feasibility: Address the potential for fires and explosions, areas such as gas/air mixtures will need additional research. There may also be unique corrosion environments due to the formation of fluids and well design.
- Research and modelling: Proponents need to prepare reservoir models that simulate CAES operation before field tests.
- Pilots: Lab and pilot tests to be done after simulation and before any field operations to minimize potential safety and environmental risks.

In conclusion, CAES projects in porous formations are still undergoing further assessment and significant investments are required to develop a demonstration project.

References:

[1] B. Elmegaard and W. Brix, "Efficiency of Compressed Air Energy Storage," p. 13, 2011.

[2] Energy Storage Association, "Compressed Air Energy Storage (CAES)" 2019.

[3] R. K. Collings, "SALT, AND THE CANADIAN SALT INDUSTRY," DEPARTMENT OF MINES AND TECHNICAL