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Hard Rock Caverns-Limestone and Other
SvdL March, 2011

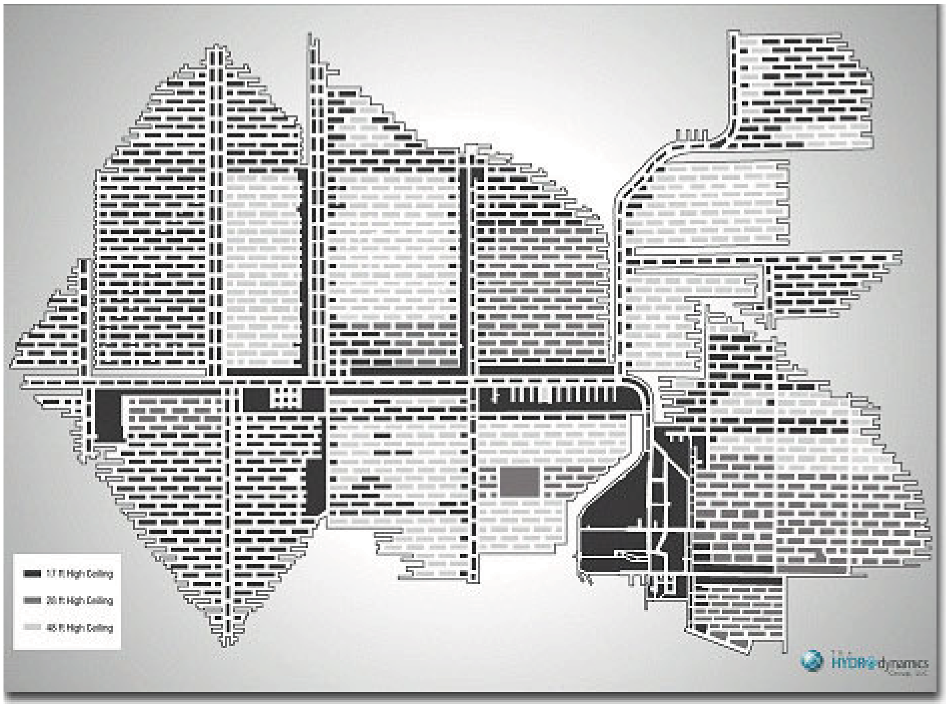
Example Cavern Limestone Mine suitable for Compressed Air storage up to 100bar.

The height is about 38 ft, very stable no seismic activity—the floor is covered with a layer of very fine limestone particles (dust)the was a concern if this were agitated with injection that the dust would enter the combustion expanders. The thought was to have a low velocity distribution header at the roof level to minimize the disturbance—the air supply would go through filtration before entering the Turbo machinery.

The Norton Mine was developed by the systematic removal of about 338 million cubic feet of limestone at a depth of about 2200 feet below the surface.

The three panel room heights of 17-, 28-, and 47- feet are control mined by splitting the limestone on 2 to 3-inch thick shale and oil shale bedding plains that are continuous over the area of the mine. Approximately 47 percent of panel rooms are 17-feet high, 21 percent are 28-feet high, and 32 percent are 47-feet high

The Norton Mine was developed by the systematic removal of about 338 million cubic feet of limestone at a depth of about 2200 feet below the surface. The mine covers an area of about 7,000 feet by 4,000 feet (7,763 acres).



Compensated Hard Rock Air Storage Cavern

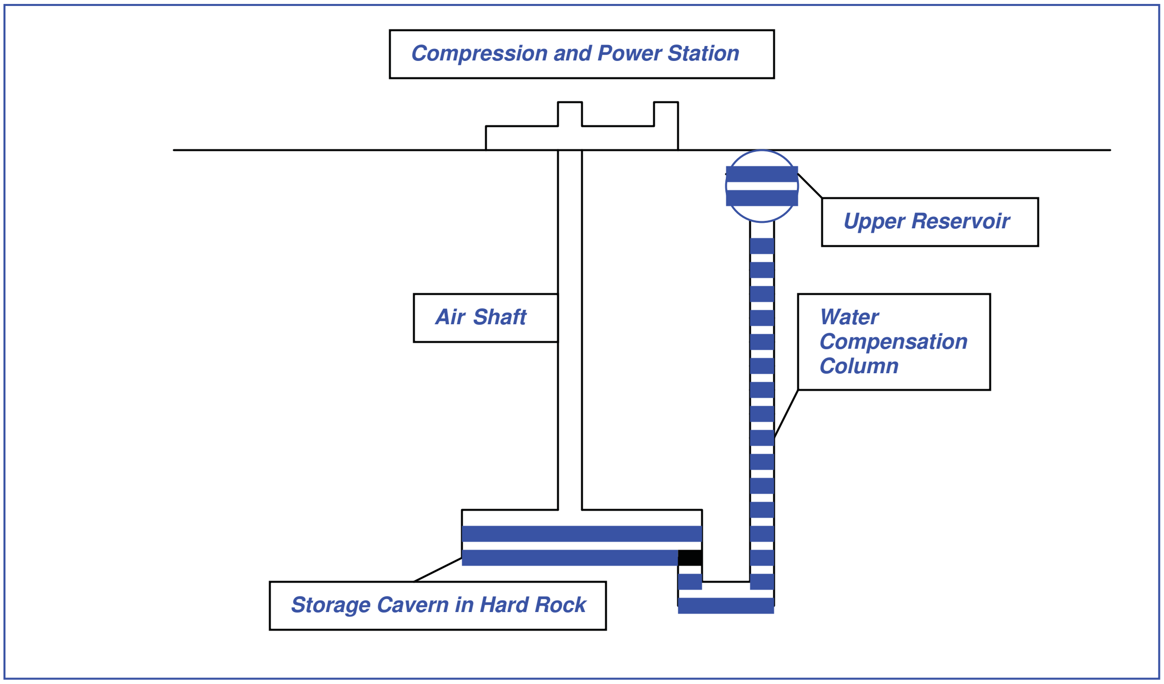
Hard Rock Caverns are used to store hydro carbon fuels and potentially the most abundant storage media in the USA.

Hard Rock caverns are more expensive, though modern techniques for shaft and Cavern excavations have progressed dramatically from 2o years ago.

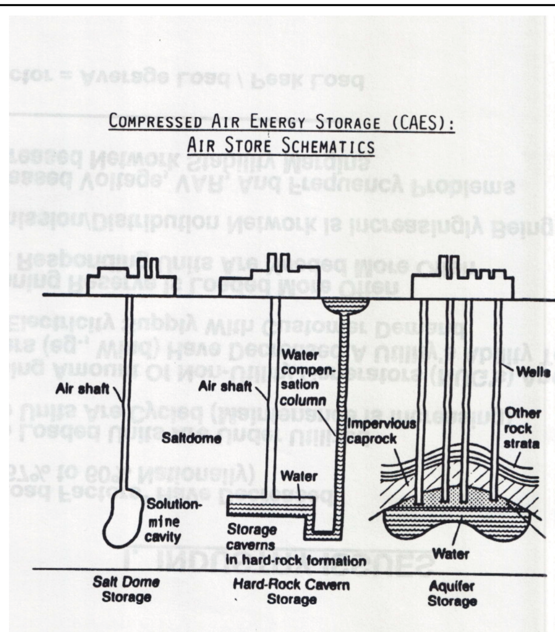
To keep the costs down, it is desirable to keep the cavern small and maintain the air at a constant pressure by means of a water compensation system.

Water –compensated rock cavern can store about 5 times as much energy as an uncompensated cavern of the same volume.

A vertical shaft connects the underground chamber with a surface lake. As air is injected into the chamber, the column of water is pushed up; as air is released, the water fills the void, the same principle as Pneumatic /Hydraulic accumulator.



The Illustration below provides the three established Air Storage concepts and quick comparison for consideration when geological facilities are investigated



1`) Salt Cavern Constant Volume/ Variable pressure. Large Vol.

2) Hard Rock Cavern/ water compensated 5 x less Vol. Higher Cost

3) Aquifer lower cost constant pressure needs good cap rock

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The McIntosh Salt Cavern;

Top of this solution mined salt cavern is located 1,500 feet underground. The Bottom of the cavern is 2,500 feet underground. The air storage volume is 19-million cubic feet (19.6 oft quoted as 20 million) 200 ft in diameter and 1,000 feet tall. The Cavern walls do not move due to the pressure changes and have the strength 50 times that of the maximum pressure produced for the CAES plant.

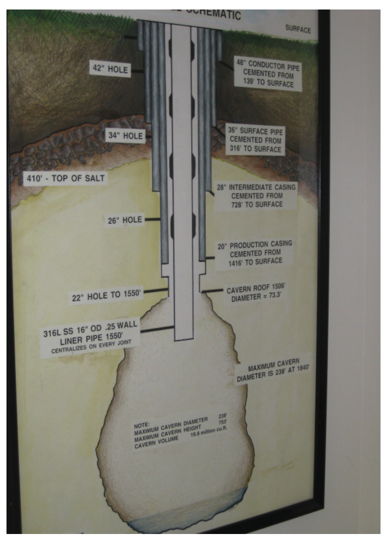
At full charge, the cavern pressure is 1,100 psig, at full discharge the pressure is 650 psig, the Delta P is the working volume. The air is with drawn at a rate of 340 #/sec (as fast as a wide bodied jet engine) or 1,224,000 lbs/hr delivering 110,000 kW. Air recharging system is designed to compress for 1.7 hrs/1 .0 hr/Generation.

The cavern volume sustains the Power unit for 26 hrs continuous operation before requiring a full recharge—the equivalent of 44 hrs of compression at 200#/sec.Reducing the operating pressure by 40 psia reduces the unit to 100 MW for 28 hrs of operation. Tests demonstrated 2600MW/hrs and 29,512,000 lbs/air.

The cavern air pressure is regulated to the WHRU at 715 psia increasing the temp from 95 oF to 546 oF to the HP combustor where NG fuel is added to increase the HP Expander inlet temperature to 1000 oF at an inlet pressure of 620psia.The HP expander outlet temp. to the LP Combustor where the air mass is reheated to 1600 oF to match the LP inlet pressure of 227 psia and expanded to 15 psia at a temperature of 700 oF to the WHRU to heat the incoming cavern air from 95 oF to 546 oF.

Cavern Casing Details

- Solution Mining the Cavern
- • 56” hole with 48” conductor
- pipe cemented from 139’ to
- surface
- • 42” hole with 36” surface
- pipe cemented from 316’ to
- surface
- • 34” hole with 28” intermediate
- casing cemented from 728’ to
- surface
- • 26” hole with 20” production
- casing cemented from 1416’ to
- surface
- • 22” hole to 1550’
- • 13.375” blanket casing at 1702’
- • 17.5” hole to 1750’
- • 8.625” wash casing at 2633’
- • 315’ to top of caprock
- • 410’ to top of salt
- • 2650’ total depth



Cycle optimization determines the operating hours vs. cavern volume and available charging hours available during the night (low cost hrs) and during the low demand on the week-end.

The current design rating of 135 MW has an air flow of 400#/sec with a required pressure of 700psia at the HP combustor flange, this approx. 23 5 increase is achieved with no increase at HP combustor temperature to the HP expander.

Knowing the air flow requirements of the fixed design, the working cavern volume can be established based in the daily/ weekly mission hours of power delivery. If the cavern pressure is established at 1350 psia, the regulated pressure of 840psia to the WHRU inlet flange is required. The Delta pressure is the stored energy available for power generation. Higher Expander inlet pressures can be considered within current design issues at 850 psia at HP combustor