Hydrogen Storage in Salt and Hard Rock Caverns

PREPARED BY:
LANE POWER & ENERGY SOLUTIONS, INC
Caverns are Our Core EPC Business

Team Experience

☑️ Hard Rock Caverns
  - EPC of 13.5 MBbl in nine caverns
  - Delivered the only hard rock caverns constructed in US in the last 35 years
  - Reactivated two abandoned caverns for NGL service
  - Converted 73 MBbl mine to crude oil storage (USDOE)

☑️ Salt Caverns
  - 100+ salt cavern projects
  - 25+ leach plants
  - One Hydrogen cavern (2015)
Storage Caverns Overview

- **Fluids stored**
  - Gas & liquid hydrocarbons
  - Compressed air
  - Hydrogen
  - Ammonia

- **Solution mined salt caverns**
  - 60+ year operational history
  - 2000+ caverns worldwide
  - Six in H2 service

- **Hard rock caverns**
  - 60+ year operational history
  - 200+ caverns worldwide
  - Demonstrated performance to 800 psi (at 1800’ depth)
  - None presently in H2 service
Salt is physically and chemically inert and is effectively impermeable.

- Ample raw water source, e.g:
  - Wells
  - Surface waters
  - Plant effluent

- Competent salt
  - Adequate depth, thickness & lateral setback
  - Minimal anomalies (e.g. shear zones, insoluble interbeds)

- Brine disposal means
  - Subsurface wells
  - Offshore waters
  - Plant feedstock
North American Salt Deposits

[Map of North American salt deposits with various markers indicating major salt deposits and production sites.]
Domal & Bedded Salt Caverns

Domal - US Gulf Coast
(1-10 MMBbl & Larger)

Bedded - Midcontinent, NE US, Canada
(100 – 1,000 KBl)
Hard Rock Caverns: Basic Design Requirements

- **Competent rock**
  - Adequate structural strength
  - Minimal faulting and fracturing
  - Low permeability (e.g. shale, granite, gneiss, limestone, dolomite, sandstone, chalk)

- **Favorable and stable groundwater conditions**
  - Adequate hydrostatic head
  - Ample groundwater recharge (natural or artificial)

- **Physically and chemically inert to stored fluid**
External groundwater pressure is greater than internal storage pressure

Leakage mechanism is inwards into the cavern, rather than outwards from the cavern

Applicable to both ‘dry’ and ‘wet’ caverns
Global Hard Rock Cavern Inventory

- **US:**
  - 83 constructed
  - 60 in service (LPG)

- **Northern Europe:**
  - 75 commercial (crude & LPG)

- **Asia:**
  - 24 strategic (crude & LPG)
  - 13 commercial (crude, light oil & LPG)
Existing H₂ Caverns/Conversion Potential

- **Existing H₂ caverns**
  - Teeside, UK. (3) - brine compensated salt caverns
  - Texas. (3) - domal salt caverns

- **Convert existing salt caverns?**
  - Well casings not suitable
  - Requires installing well liner or drilling a new well
Accuracy is +/- 30%.

Solution mining rates:
- Appalachia - 250 gpm
- Gulf coast – 2,000 gpm.

Storage wells:
- Appalachia – 3/MMBbl
- Gulf Coast - 1.

Estimates exclude hydrogen surface infrastructure, include solution mining facility.

Brine ponds are not necessary for dry gas storage.

<table>
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<th></th>
<th>Depth (ft)</th>
<th>Max Pressure (psig)</th>
<th>Cavern Volume (Bbl)</th>
<th>Working Mass (mt)</th>
<th>Capex $M</th>
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Hydrogen Storage Silo

- Dry or water-compensated storage
- Steel-lined, vertical shaft, 750 – 2000’ deep
- Double dome head in bedrock
- Pressurized interstitial fluid
- Diameter, depth and number to suit volume requirements
- Water compensation offers 100% H2 withdrawal (no base gas)
ROM Cost – Compensated H2 Silo System

H₂ Silo - ROM Cost/Kg
Incl Compensation Tank & Pump

Storage Capacity, Metric Tons

$/Kg

- $2,066
- $2,000
- $1,900
- $1,800
- $1,700
- $1,600
- $1,500
- $1,400
- $1,300
- $1,200
- $1,100
- $1,000

0 5 10 15 20 25

6' dia (2500 psi) 8' dia (2000 psi) 10' dia (1500 psi)