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)*

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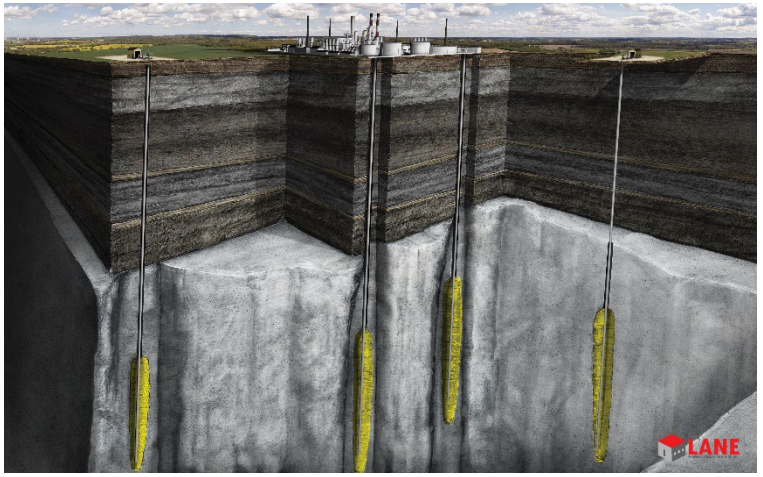
Storage Caverns Overview

- ☑ 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



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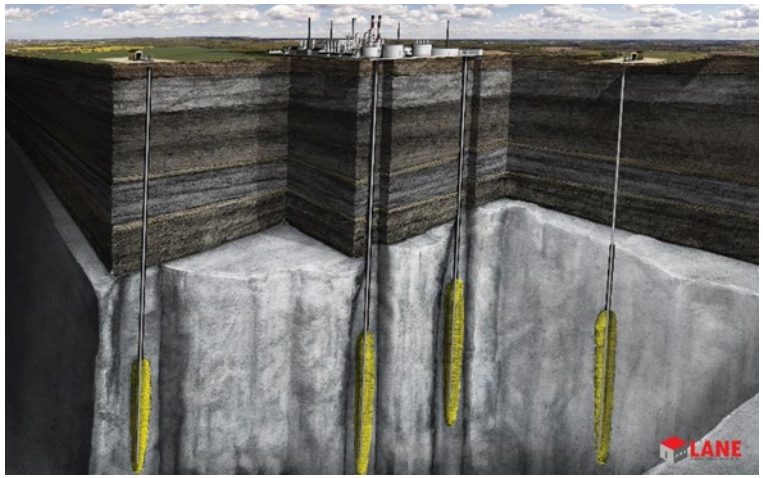
Salt Caverns: Basic Design Requirements

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



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North American Salt Deposits

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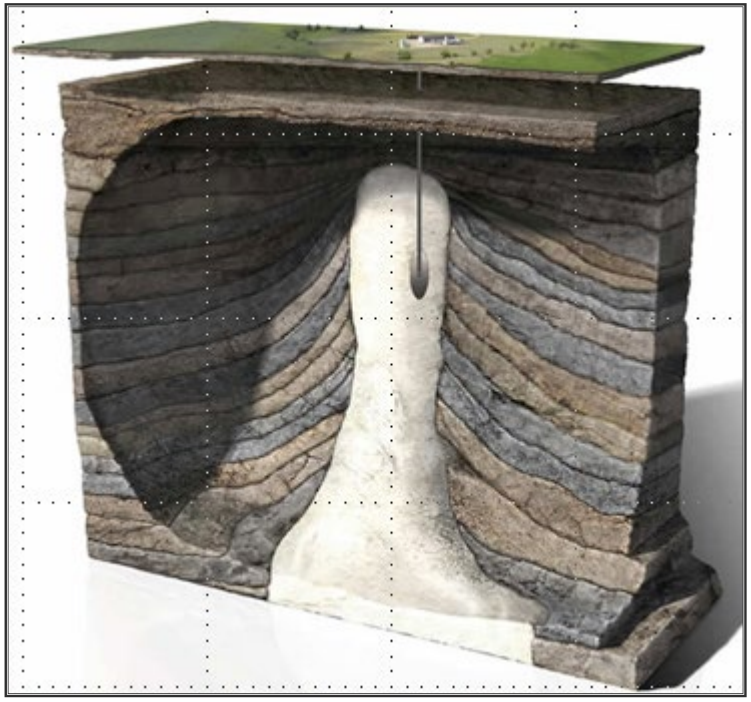
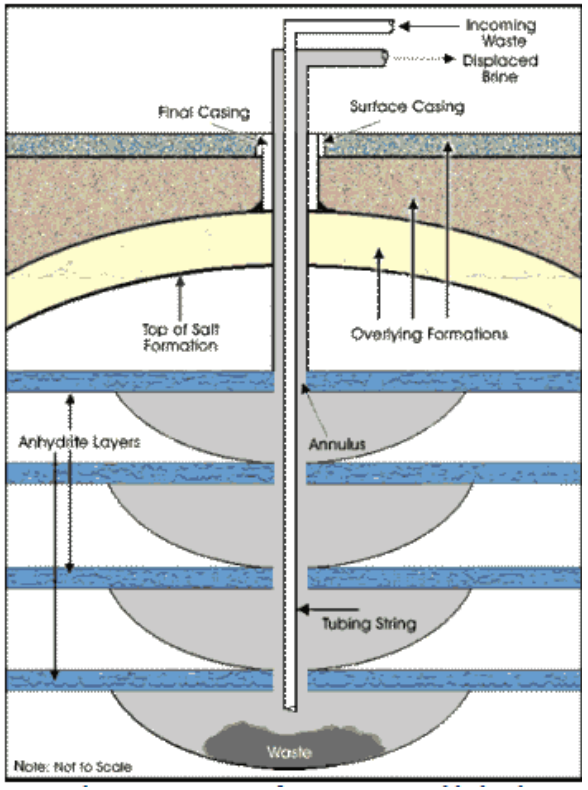
Domal & Bedded Salt Caverns

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



Bedded - Midcontinent, NE US, Canada
(100 – 1,000 KBbl)



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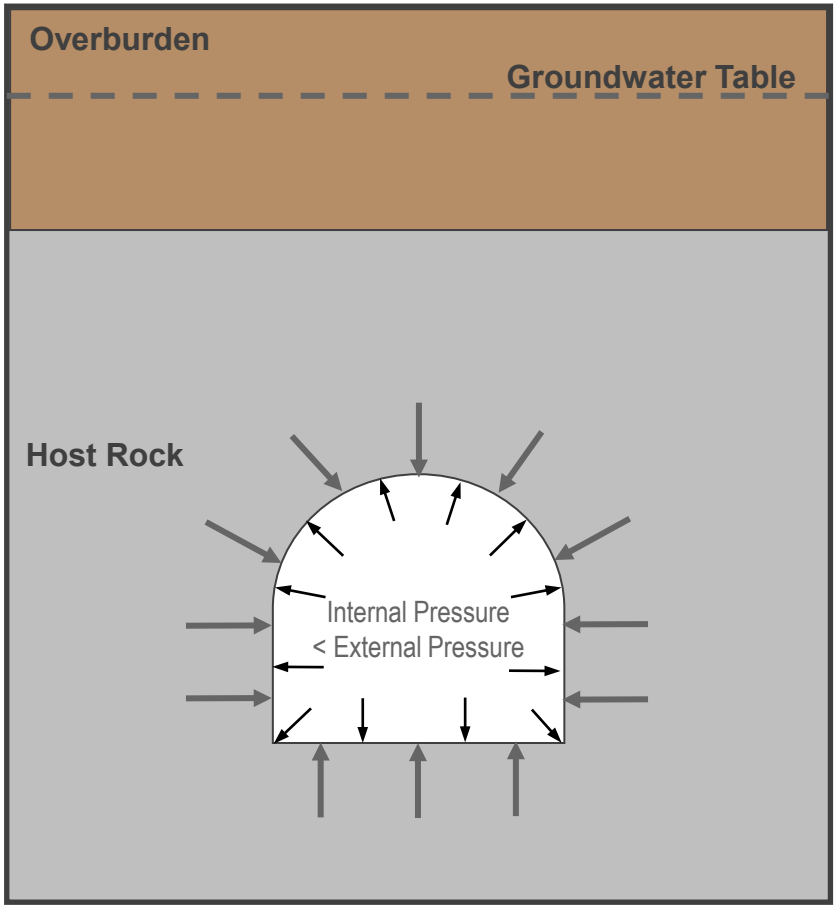
Hard Rock Caverns: Basic Design Requirements

- ☑ 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

Hydrostatic Design Principle

- ☑ 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



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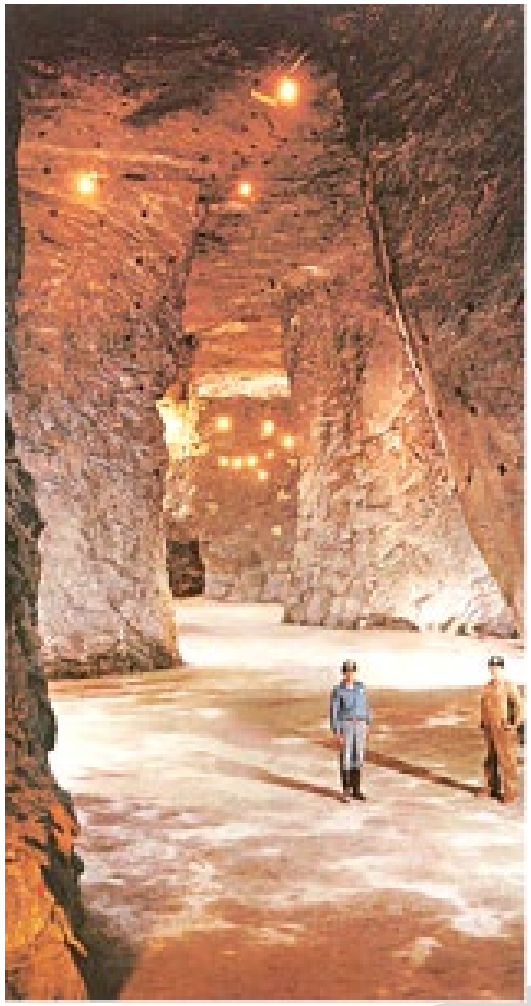
Global Hard Rock Cavern Inventory

- ☑ US:
  - 83 constructed
  - 60 in service (LPG)
- ☑ Northern Europe:
  - 75 commercial (crude & LPG)
- ☑ Asia:
  - 24 strategic (crude & LPG)
  - 13 commercial (crude, light oil & LPG)



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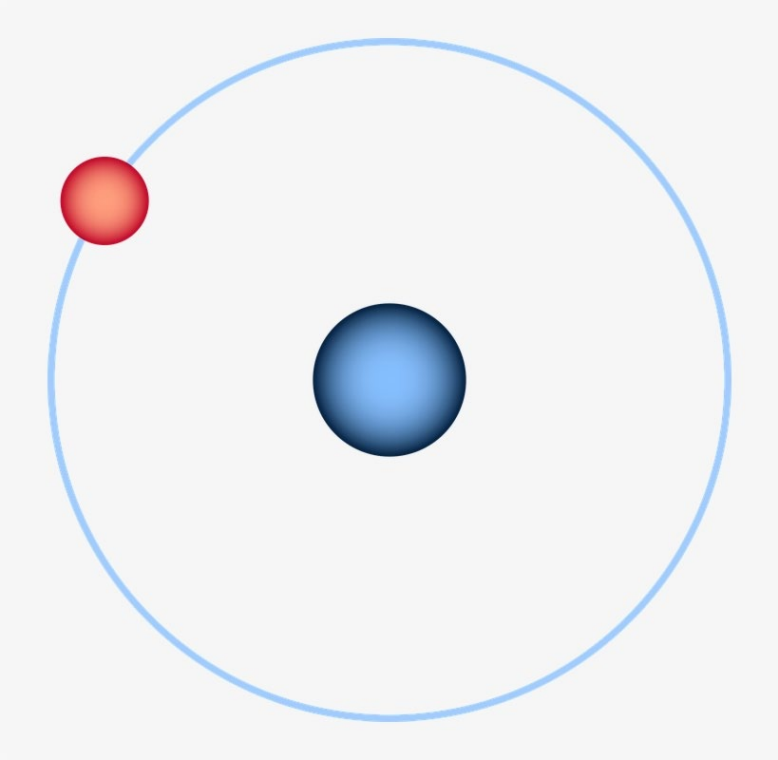
Existing H_2 Caverns/Conversion Potential



- ☑ Existing H_2 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

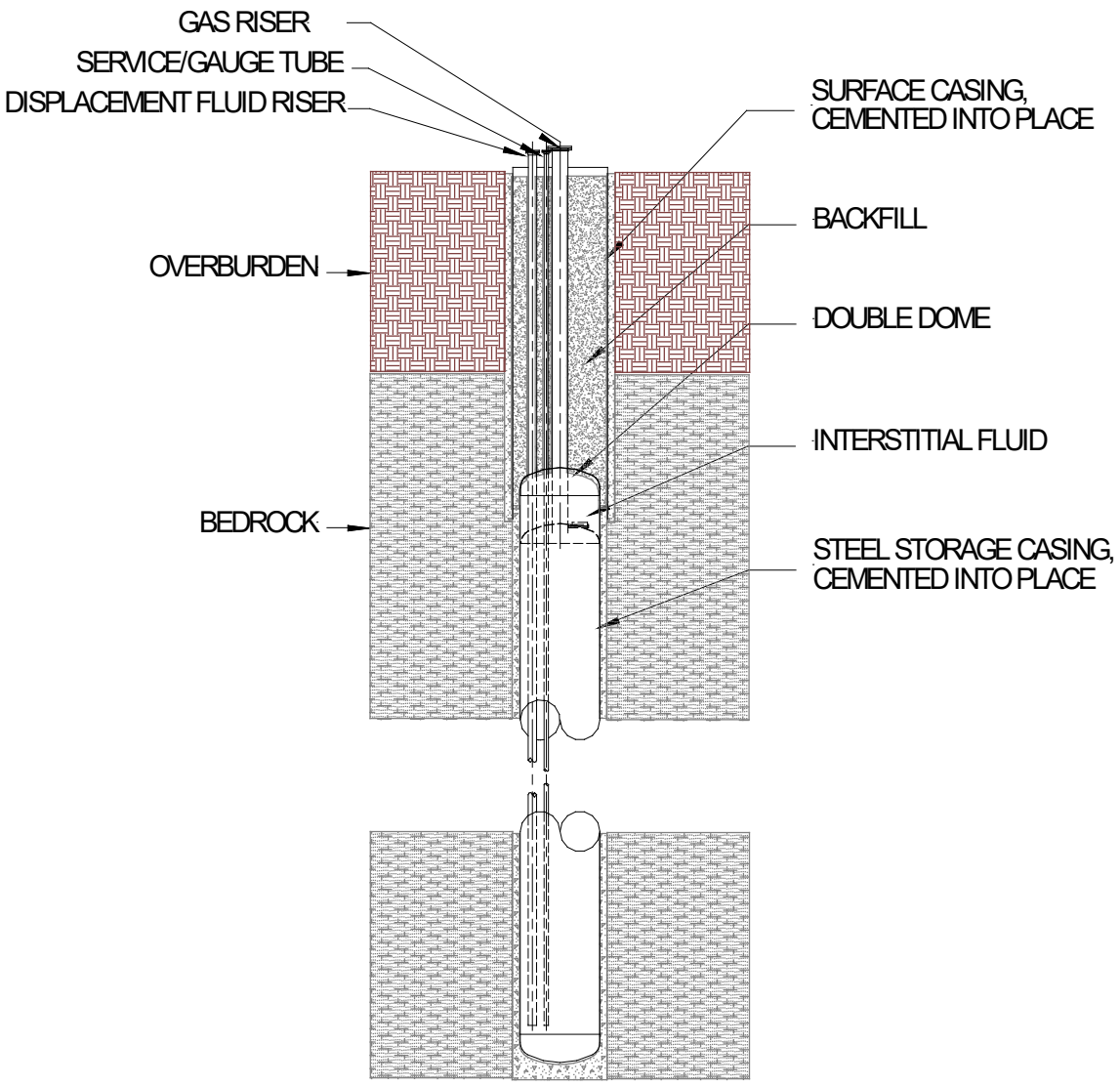
ROM Cavern CAPEX

- 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.

	Depth (ft)	Max Pressure (psig)	Cavern Volume (Bbl)	Working Mass (mt)	Capex $M
Hard Rock	2,000	800	1,000,000	626	$133
	2,000	800	2,000,000	1,251	$203
	750	300	1,000,000	223	$109
	750	300	2,000,000	447	$179
Gulf Coast Salt	4,000	3,400	1,000,000	1,997	$79
	4,000	3,400	2,000,000	3,995	$81
Appa-lachia Salt	5,000	3,400	1,000,000	1,846	$82
	5,000	3,400	2,000,000	3,692	$127

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)



2 - 20 METRIC TON HYDROGEN STORAGE CAPACITY
DIAMETER AND DEPTH TO SUIT REQUIREMENTS

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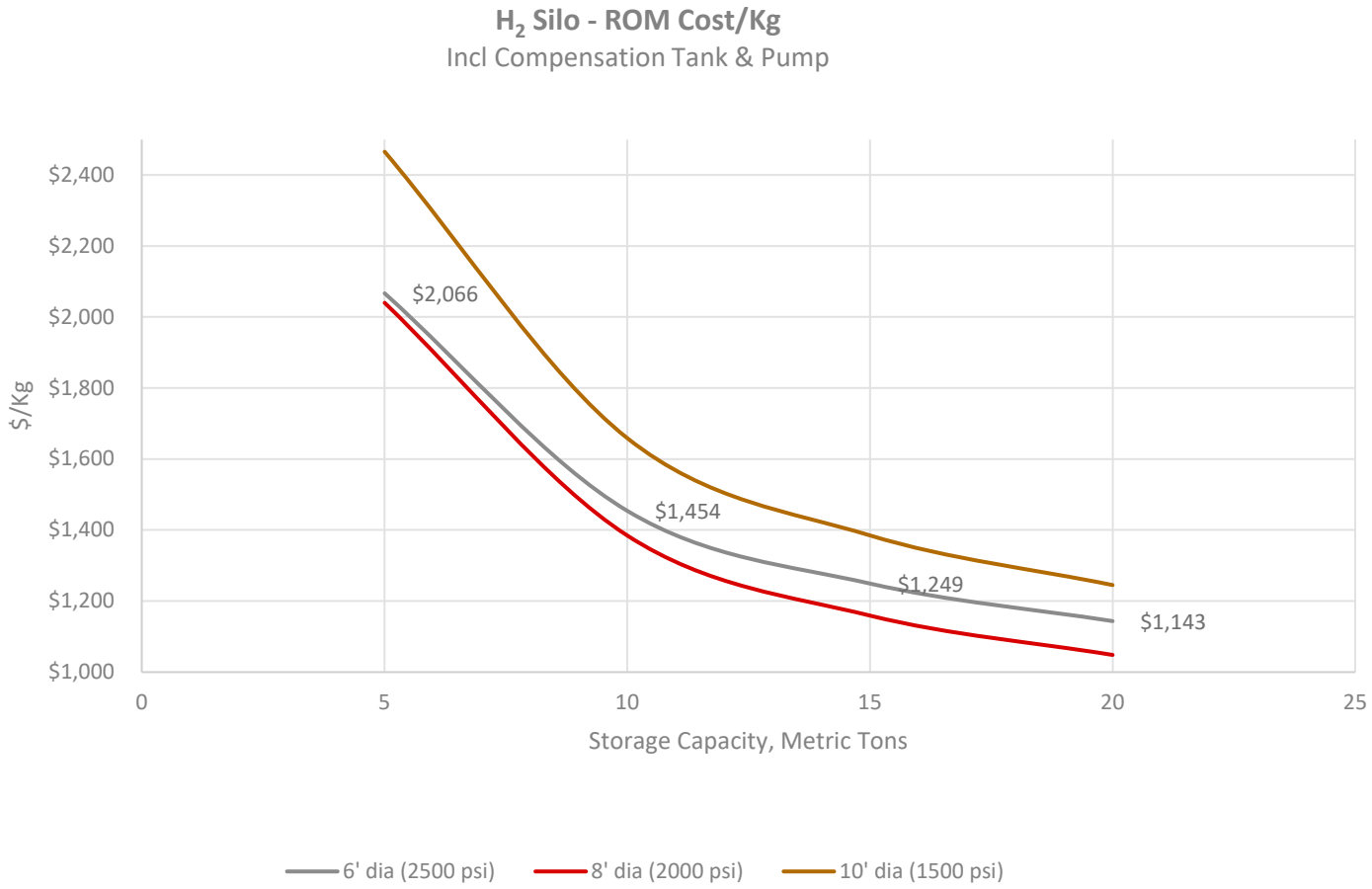
ROM Cost – Compensated H2 Silo System



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