

UNDERGROUND HYDROCARBON STORAGE

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Underground Hydrocarbon Storage in Texas

Topics:

- Industry Overview
- Geology
- Ownership
- Regulation

Industry Overview

 Underground hydrocarbon storage has become an increasingly vital link in the Texas economy. Although a vital link, underground hydrocarbon storage reservoirs and caverns have often been treated as "step-children" of the petroleum, pipeline, and petrochemical industries.

- Historically, underground hydrocarbon storage facilities have often been regarded as just big underground "tanks."
- Unfortunately, underground hydrocarbon storage has most often received public attention from leaks, fires, or explosions:

- Mont Belvieu casing leak, explosion, and fires in the 1980s
- Brenham cavern overflow and explosion in 1992
- Moss Bluff leak and fire in 2004

All Forms Of Commercial Hydrocarbons Are Stored Underground

- Natural Gas
- Crude Oil
- NGL and LPG
- Hydrogen

In Texas, Operators Utilize Three Types Of Underground Formations For Hydrocarbon Storage

- Caverns leached in salt domes
- Caverns leached in bedded salt
- Oil and gas reservoirs, either depleted or partially depleted

Texas Underground Storage Reservoirs And Caverns Contain Huge Volumes Of Stored Hydrocarbons

- Crude Oil Hundreds of Millions of Barrels
- NGL and LPG Hundreds of Millions of Barrels
- Natural Gas *Hundreds of Bcf*

Crude Oil Underground Storage

- The Department of Energy's Strategic Petroleum Reserve stores crude oil in two Texas salt domes.
 - Bryan Mound Salt Dome in Brazoria County
 - Big Hill Salt Dome in Jefferson County

• SPR has two other storage facilities in Louisiana, and a 5th site has been selected in Mississippi.

• There are approximately 35 active crude oil storage caverns at these 2 domes.

Strategic Petroleum Reserve Texas Locations



- SPR was established after the oil embargo in 1973-74 to provide for emergency crude oil supplies.
- Current SPR crude oil capacity at all its facilities is 727 million barrels.
- Planned expansions are expected to increase capacity to 1 billion barrels.

- Currently, crude storage is at about 700 million barrels.
- This stored volume equates to about 56 days of "import protection" at current import volumes.
- Drawdown capability for production out of SPR is about 4.4 million barrels per day.

- SPR has withdrawn oil for sale on the open market three times:
 - In 1985, DOE conducted a test sale of facilities and procedures.
 - In 1990 and 1991, SPR crude was produced to offset shortages during the Desert Shield/Desert Storm operations in Iraq.
 - In 2005, SPR was tapped to offset supply shortages resulting from Hurricane Katrina.

(Additionally, there have been about a dozen crude oil exchanges to assist with minor supply disruptions.)

NGL/LPG Underground Storage

- Most Texas salt cavern storage is utilized for natural gas liquids.
- NGL and LPG are stored in both bedded salts and salt domes.
- There are approximately 250 active NGL/LPG caverns in Texas.

SALT CAVERN NGL/LPG STORAGE **Active Locations**

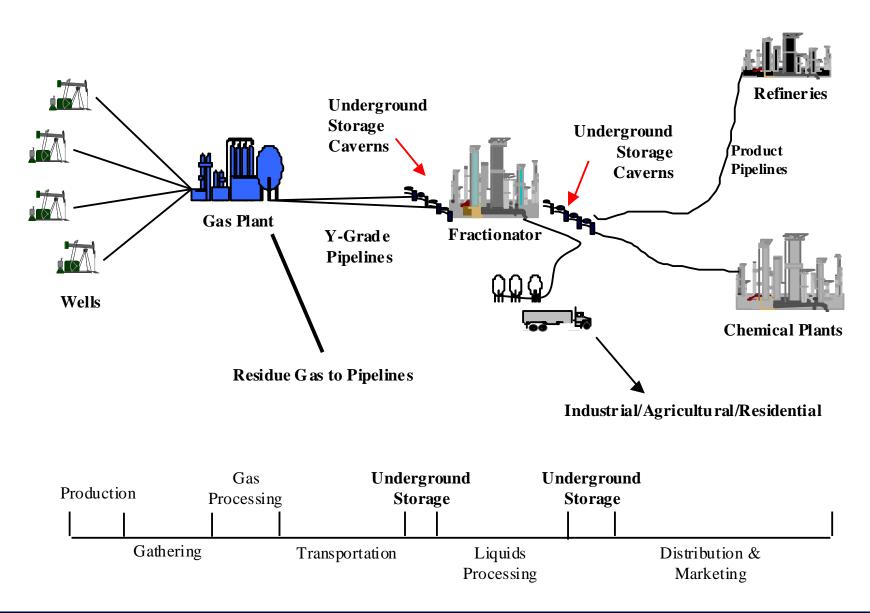


SALT DOME

Salt cavern storage of natural gas liquids is an integral part of the oil and gas production process.

• Gas from the lease goes to gas processing plant where natural gas liquids are removed.

- Natural gas liquids extracted at gas processing plant are sent as Y-Grade for fractionation.
- Underground storage holds Y-Grade until it can be sent for fractionation.
- Underground storage holds the "product" resulting from fractionation for use as fuel and feedstock.

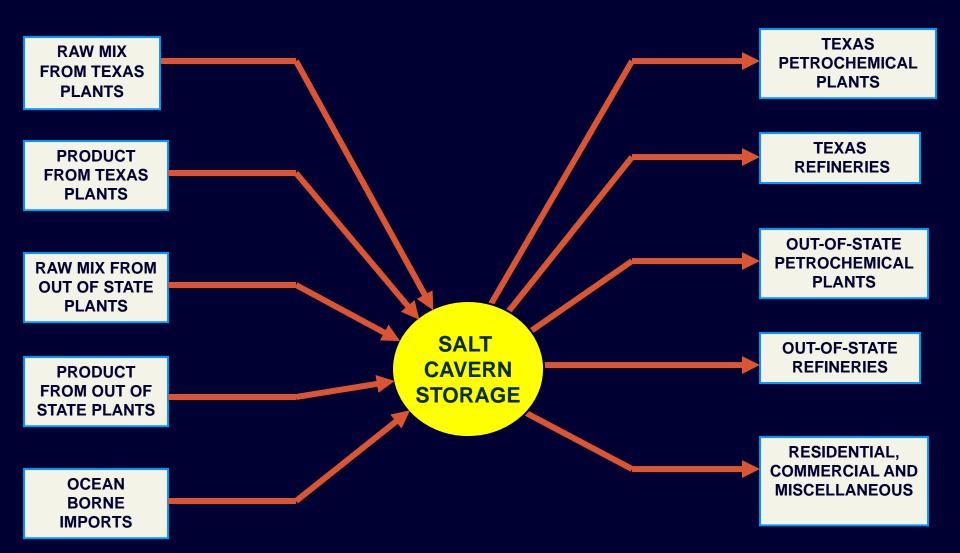


Commercial NGL and LPG Stored in Underground Caverns:

- Butane Commercial
- Butane Normal
- Butane/Butylenes Mix
- Butane/Gasoline Mix
- Condensate
- Ethane/Propane Mix
- Ethanol
- Ethylene
- Iso Octane

- Iso Octene
- Isobutane
- Isobutylene
- Methanol
- Naphtha
- Natural Gasoline
- Propane
- Y-Grade

- Salt cavern storage provides the link between "upstream" and "downstream."
- Upstream storage helps prevent shut in of wells producing into gas plants.
- Downstream storage provides fuels and feedstock for plants, refineries, and end users.



Natural Gas Underground Storage

Important benefits from underground storage of natural gas:

• Provides a "cushion" for supply and demand for natural gas.

- Provides swing capacity to meet seasonal variations in demand.
 - During warmer months when supply exceeds demand, natural gas is injected into underground storage reservoirs.
 - During cold weather months when demand exceeds supply, injected gas is withdrawn from storage.

- Provides high deliverability gas in close proximity to end-users.
- Facilitates price hedging.

Texas Has Two Types Of Underground Natural Gas Storage

- Reservoir gas storage
- Salt cavern gas storage

Reservoir Gas Storage Is By Far The Most Common

- Typically, reservoir gas storage is in a relatively shallow "depleted" oil or gas field with high deliverability.
- Most Texas reservoir gas storage projects are located near municipalities or industrial areas.

Depleted Reservoir Gas Storage Active Locations



In 1949, the Railroad Commission issued the first Texas permit for gas storage in a depleted reservoir in the Withers, North Field in Wharton County.

- A total of 38 reservoir gas storage projects have been permitted.
- But only 13 of these projects are currently active.
- Active depleted reservoir storage projects have a current capacity slightly over 500 Bcf.

- In October 2006, active reservoir gas storage inventory was 311 Bcf.
- Deliverability from active reservoir gas storage is about 4.7 Bcf per day.

What Are The Advantages Of Storing Gas In Depleted Reservoirs?

- Producing fields have existing wellbores and gathering facilities.
- Typically, existing pipelines are nearby.
- Usually, the geologic configuration of the reservoir is well-known.

What Are The Disadvantages Of Gas Storage In Depleted Reservoirs?

- Limited well deliverability.
- High base gas to working gas ratio.
- Usually limited to only a single storage cycle per season.
- There can be legal ownership issues.

SALT CAVERN GAS STORAGE Active Locations

Although a few salt cavern gas storage facilities in Texas utilize bedded salt; most are in salt domes.





In 1973, the Railroad Commission issued the first Texas permit for gas storage in a solution mined salt cavern at the Bethel Salt Dome in Anderson County.

- Over 55 salt caverns have been permitted for gas storage.
- But only 35 salt caverns are actively storing gas today.
- The Texas active salt cavern gas storage capacity is approximately 200 Bcf.

- In October 2006, active Texas salt cavern facilities held 68.6 Bcf.
- Deliverability from active salt cavern gas storage is reported at about 6.2 Bcf per day.

What Are The Advantages Of Storing Gas In Salt Caverns?

- High deliverability
- Low ratio of base gas to working gas
- Multiple storage cycles per year
- Geologically sealed

What Are The Disadvantages Of Gas Storage In Salt Caverns?

- High initial start up cost
- Long lead time to create storage
- Locations limited to Gulf Coast areas

GEOLOGY

Salt Formations

The properties of underground salt make it ideal for hydrocarbon storage.

- Salt is inert to hydrocarbons.
- As a rock formation, salt can be extremely strong, hard, and dense, with a compressive strength similar to concrete in formations used for storage.

- When relatively pure and not interbedded with other rocks, salt can have permeability and porosity so low that it is impermeable to hydrocarbons.
- These characteristics make underground rock salt an excellent container for gas, oil, and petroleum products.

Salt Dissolves In Water

- Therefore, water can be injected into a salt formation to dissolve or "leach" caverns for storage.
- This process, referred to as "solution mining," makes creation of large storage caverns in underground salt economically feasible.

Salt is "Plastic"

- When rock salt is subjected to the pressure and temperature caused by the weight of the overburden it becomes "plastic" and flows or moves.
- As a consequence of this inherent characteristic, a cavern created in underground salt has the tendency to close up slowly over time, a phenomenon called "salt creep."

- Additionally, any fractures or fissures in salt have a tendency to close and "heal" over time.
- This results in a self-sealing quality that makes underground salt an excellent choice for safe and secure storage of hydrocarbons.

Salt Occurs Naturally In Formations That Are Relatively Shallow

- These shallow depths are economically accessible by wells.
- Shallow depths also result in temperatures and pressures that are ideal for storage operations involving a variety of commercial hydrocarbons, both gas and liquid.

Two Different Salt Formations Are Utilized For Underground Hydrocarbon Storage

• Bedded Salt

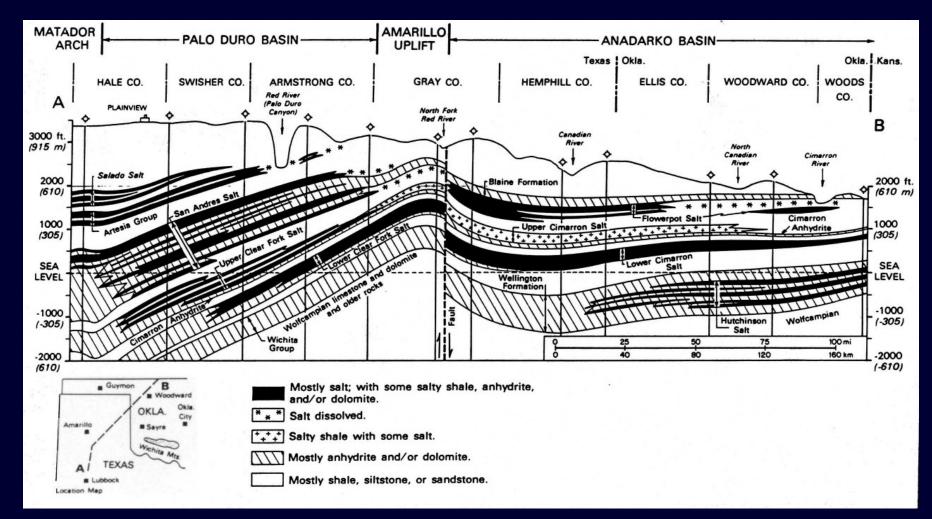
• Salt Dome Salt

Bedded Salt Geology

- Bedded salt occurs in underground layers beneath much of Texas.
- As ancient seas evaporated, the salt was deposited into thick layers.

- Over geologic time, these layers were slowly covered and buried by other sediments.
- Under the weight of this overburden, the salt formations took on the dense impermeable qualities that make it ideal for storage caverns.

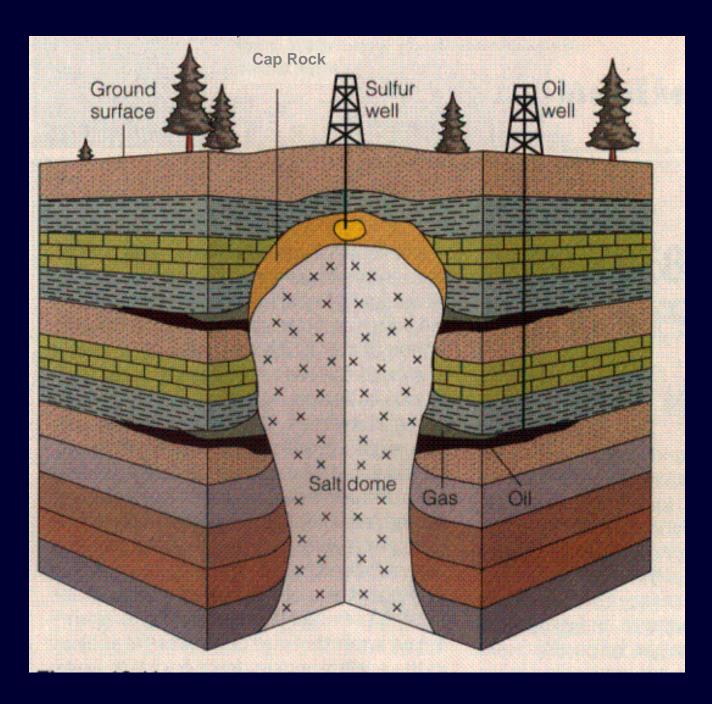
Cross Section Showing Salt Intervals



Salt Domes

- Salt domes are large, broad underground columns or pillars of rock salt found along the Gulf Coast.
 - These large salt columns are extrusions or fingers of salt that extend up to near the surface from a deep bedded salt layer known as the Louann salt.
 - Surrounded by sediments and often topped by a caprock, salt domes have formed the traps for many prolific commercial accumulations of oil, gas, and sulfur.

- For underground storage, it is the salt within the salt dome that is the valuable resource.
 - Salt dome salt often extends over an area that is miles wide.
 - Salt domes extend deep into the ground providing a thick salt interval.
 - This width and thickness allows creation of large groupings of tall cylindrical caverns.



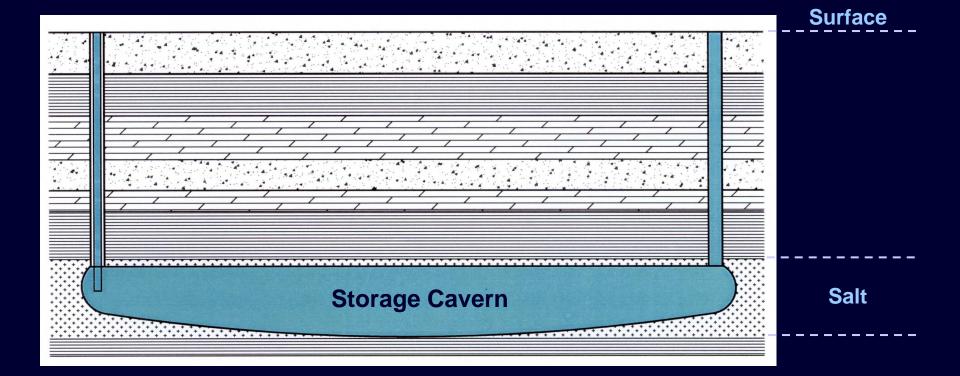
Solution Mining in Salt

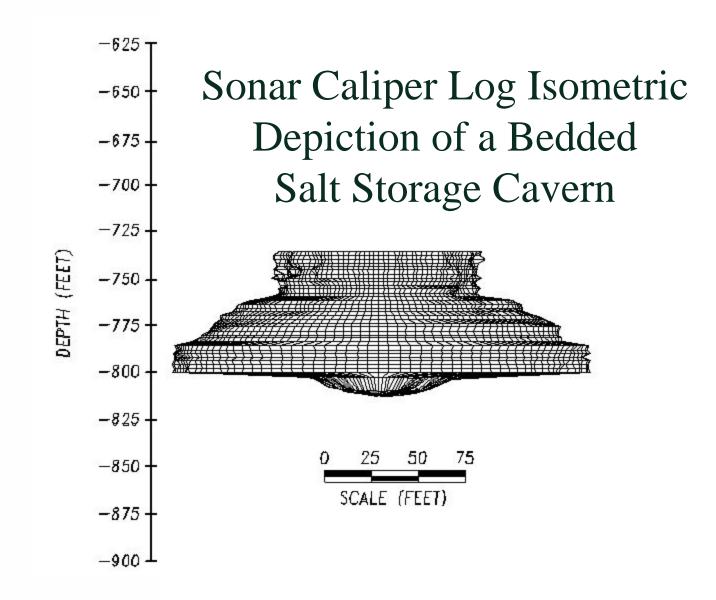
- In either bedded or domal salt, the operator injects water using the solution mining process to "leach" or dissolve a cavern.
 - A well is drilled into the salt formation.
 - Large quantities of fresh water are injected.
 - The water dissolves the rock salt to create a cavern.
 - The depths and rates of water injection are varied to control the shape and size of the cavern.

- Stored hydrocarbons can then be injected into the cavern as brine is removed.
- For gas storage in salt caverns, the cavern is "de-watered" with most of the water removed so that gas at the surface can be compressed and injected down into the cavern.

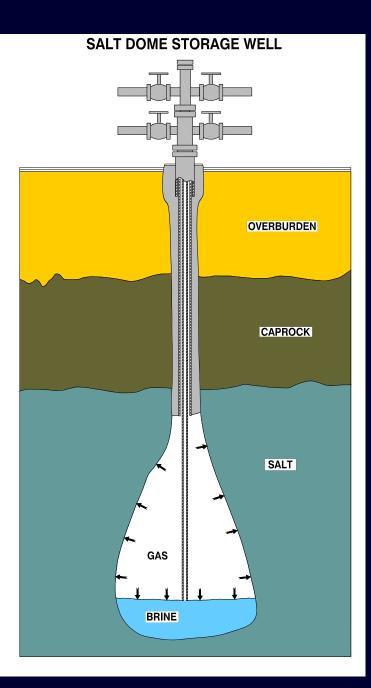
• For caverns storing crude oil or liquids, saturated brine is moved in and out of the storage cavern to displace the hydrocarbons, so that the cavern is always filled with liquid, either brine or hydrocarbons or both.

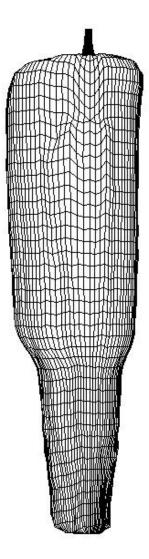
Solution-Mined Cavern in Bedded Salt



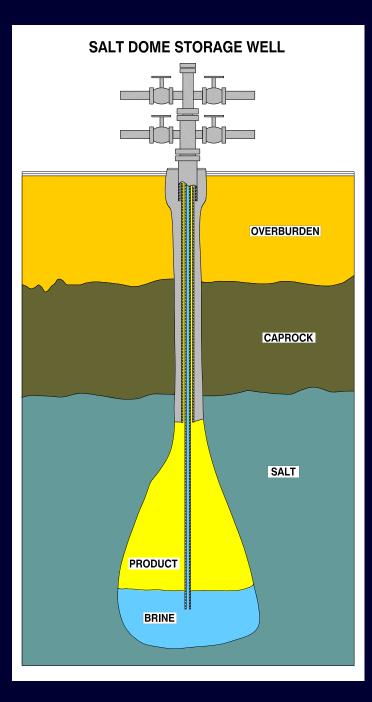


Solution-Mined Salt Dome Gas Storage Cavern

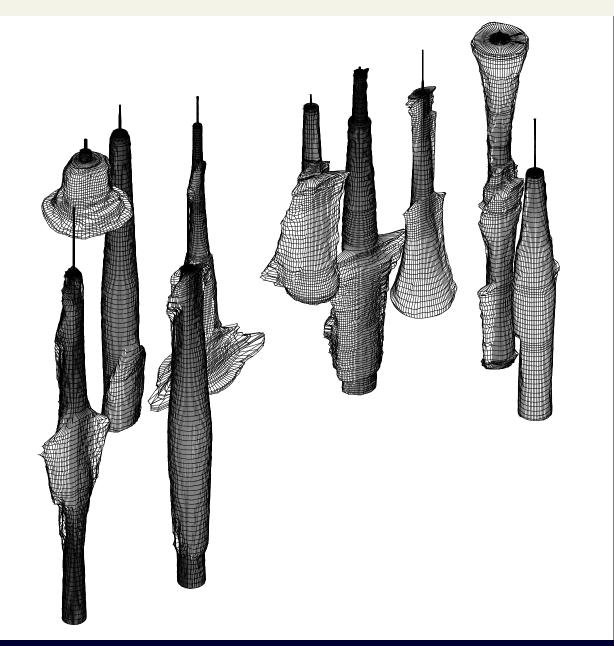




Sonar Caliper Log Isometric Depiction of Salt Dome Gas Storage Cavern Solution-Mined Salt Dome NGL/LPG Storage Cavern

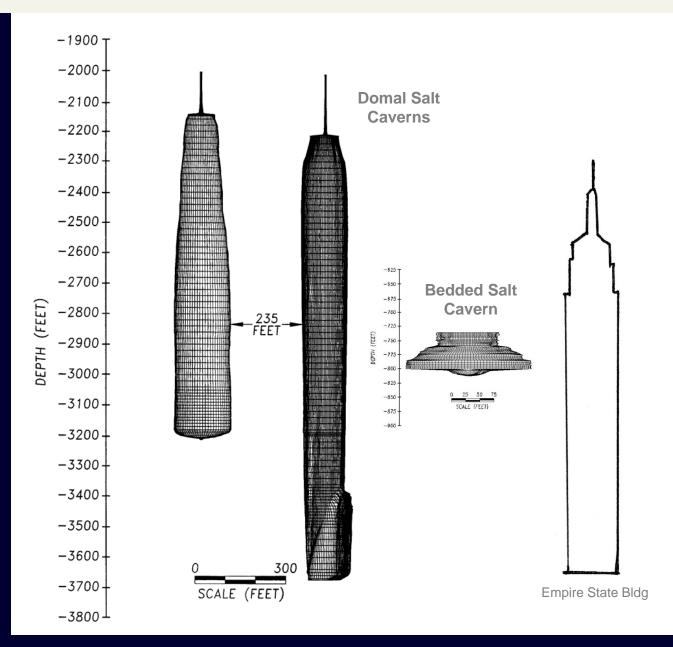


Salt Dome NGL/LPG Storage Caverns



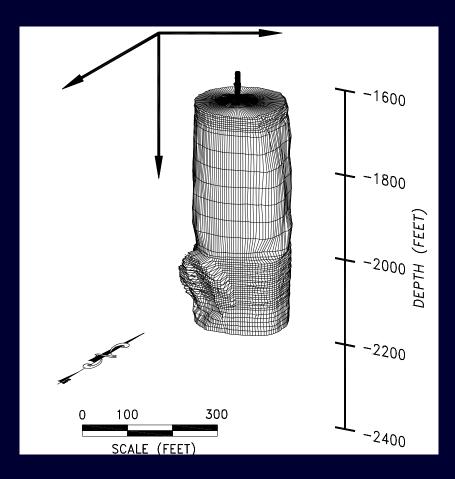
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Comparison of Salt Dome Caverns with Bedded Salt Cavern



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Salt Dome Crude Oil Storage Cavern



Depleted Reservoir Geology

• Depleted reservoirs in many geologic formations are candidates for gas storage projects.

- Necessary reservoir characteristics are:
 - Known reservoir confinement and boundaries
 - Defensible mappings/estimates of native gas volumes by tract
 - Excellent gas porosity
 - Excellent gas permeability

OWNERSHIP

Fee Simple Ownership

- Ideally, underground storage properties should be owned in fee simple.
- Anything other than fee simple title may present difficult ownership issues.
- Fee simple ownership, however, is often not possible.

Prior Ownership and Development Issues

• The typical underground storage facility site will also be the location of other mineral exploration and development activities, both past and current.

- Many salt storage properties will be leased for oil, gas, or for other minerals.
 - Salt deposits have been the site of oil and gas exploration for a hundred years.
 - Salt domes have been mined for sulfur.
 - Many salt deposits have been mined for salt or for brine.

• Depleted reservoirs will be leased for oil and gas.

• Some oil and gas leases will likely remain in effect.

• Other leases may have terminated.

Other Ownership Issues

- Mineral ownership is often divided or severed.
- Surface facilities, and resources normally associated with the surface estate, including water, will be needed for storage operations.
- The right to store hydrocarbons might not be granted by some leases or conveyances.

Ownership of Salt

- Since first considered by Texas courts in 1884, salt has been held to be a mineral:
 - "It is apprehended that by no one in any way familiar with the elementary principles of chemistry and mineralogy, would salt be classed otherwise than as a mineral substance. So far as we are informed it is so regarded by all classes the common people as well as those having special learning upon the subject."

State v. Parker, 61 Tex. 265 (1884).

Salt has been held to be a "mineral" under an oil, gas, and mineral lease. *Cain v*. *Neumann*, 316 S.W.2d 915 (Tex. Civ. App. – San Antonio 1958, no writ).

Ownership of Salt Water

• The Texas Supreme Court has held that salt water produced in oil and gas operations and injected in secondary recovery operations is not a mineral under an oil, gas, and mineral lease, but in reaching this decision, the Court indicated that salt in solution might require a different result under the same circumstances: • "If a mineral in solution or suspension were of such value or character as to justify production of the water for the extraction and use of the mineral content, we would have a different case. The substance extracted might well be the property of the mineral owner, and he might be entitled to use the water for purposes of production of the mineral."

Robinson v. Robbins Petroleum Corp., Inc., 501 S.W.2d 865 (Tex. 1973).

Ownership Issues in Depleted Reservoirs

- Who owns native gas?
- Who owns stored gas?
- What if stored gas and native gas are mixed and produced together?
- What if an offset production well captures and produces stored gas?

Who Owns Native Gas?

- This is a standard mineral title question.
- If wells still produce under an oil and gas lease, the lessee likely owns the native gas, subject to the obligation to pay royalty.

• If the last well on a tract is plugged and abandoned and lease is terminated, or if a tract was never leased or never produced, the unleased mineral owner likely owns the native gas.

Who Owns Stored Gas?

• Stored gas is personal property.

"once severed from the realty, gas and oil, like other minerals, become personal property ... title to natural gas once having been reduced to possession is not lost by the injection of such gas into a natural reservoir for storage purposes."

Lone Star Gas Co. v. Murchison, 353 S.W.2d 870 (Tex.Civ.App.-Dallas 1962, writ ref'd n.r.e.) quoting with approval White v. New York State Natural Gas Corp. et al, 190 F.Supp. 342 (W.D.Pa.1960).

Who Owns Commingled Gas?

- Commingling of stored and native gases
 - In Humble Oil and Refining Co. v. West, the Texas Supreme Court applied the confusion of goods doctrine, placing the burden on the storage operator to identify the shares of produced gas according to the ratio of native gas to stored gas:

• "As a general rule, the confusion of goods theory" attaches only when the commingled goods of different parties are so confused that the property of each cannot be distinguished. Where the mixture is homogeneous, the goods being similar in nature and value, and if the portion of each may be properly shown, each party may claim his aliquot share of the mass. . . . Additionally, the burden is on the one commingling the goods to properly identify the aliquot share of each owner; thus, if goods are so confused as to render the mixture incapable of proper division according to the pre-existing rights of the parties, the loss must fall on the one who occasioned the mixture."

Humble Oil and Refining Co. v. West, 508 S.W.2d 812, 815 (Tex. 1974) 84

Who Owns Offset Well Production?

• In Lone Star Gas Co. v. Murchison, 353 S.W.2d 870 (Tex. Civ. App. – Dallas 1962, writ ref'd n.r.e.), a storage operator sued a neighboring operator who was alleged to have produced stored gas from a well drilled on a tract offset to a gas storage reservoir. The Court of Civil Appeals held that the storage operator stated a cause of action for conversion.

Who Owns The Right To Store?

• The Texas Supreme Court decision in *Humble Oil and Refining Co. v. West* contains language that hints at the complexities that can be involved in determining who has the right to store: - "Humble . . . owns the lands in fee simple, and this includes not only the surface and mineral estates, but also the matrix of the underlying earth, i.e., the reservoir storage space, subject only to the reserved right of the Wests to the payment of royalties on minerals that are produced and saved." Humble Oil and Refining Co. v. West, 508 S.W.2d 812, 815 (Tex. 1974) • If the storage reservoir is not owned in fee, the right to store is potentially divided among all the various estates and interests:

- Mineral Estate Ownership:
 - Mineral Owner, if unleased
 - Lessee, if leased for oil and gas.
 - Lessor, if leased for oil and gas.

- Surface Estate Owner
- Obviously, the goals and interests of these owners may not coincide.

Suggested Solutions

- Identify each tract within the proposed storage facility to avoid offset issues.
- Acquire fee simple ownership of proposed storage tracts.

• If without fee simple ownership:

 Identify all potential owners, both mineral and surface estates.

 Acquire existing leases and other rights to develop oil, gas, and other minerals.

- Acquire the right to store hydrocarbons.

Additional Suggestions for Depleted Reservoir Storage

- Enter into agreement for gas storage that includes:
 - unitization for gas injection and storage operations
 - agreement on native gas volumes and production of native gas

• Obtain RRC Special Field Rules to limit production of stored gas by offset wells or by wells drilled through the storage reservoir to deeper zones. In these situations, special rules can require:

- that no allowable will be assigned to the offset well until the RRC determines the amount of native gas attributable to the well.
- that wells drilled through the storage reservoir must be cased and cemented above and below the storage reservoir to prevent escape of stored gas.

Condemnation for Depleted Gas Reservoir Storage Projects

 A gas utility can invoke eminent domain to condemn property interests necessary to the operation of a gas storage facility. TEX. NAT. RES. CODE Sec. 91.171 - 91.184. • Condemnation is available only if the storage operator has acquired at least 66-2/3 percent of the working interest and royalty interest in the storage project reservoir area and has failed, after a good faith effort, to obtain the property interests to be condemned.

• Before initiating eminent domain proceedings in the county where the property is located, the utility must first obtain a Railroad Commission order with specific findings:

- that the formation to be used for storage is classified as a gas reservoir
- that the gas reservoir is suitable for storage of natural gas
- that the proposed storage is necessary to provide adequate service to the public and is in the public interest
- that use of the formation as a storage facility will not harm water resources

• The RRC order must determine the horizontal limits of the reservoir expected to be penetrated by displaced or injected gas.

The RRC must also find either:

• that the formation does not contain native gas producible in paying quantities

or

 that 75% of the original recoverable native gas has been produced <u>and</u> that the formation has greater value to the consuming public as a storage facility than the value of the remaining native gas production has to the consuming public. Since 1979 when this eminent domain authority was enacted, the RRC has entered eminent domain findings for each of the depleted reservoir gas storage projects it has approved. REGULATION

The Railroad Commission has adopted three Statewide Rules to regulate underground hydrocarbon storage in Texas:

- Rule 95 for storage of liquid hydrocarbons (crude, NGL, and LPG) in salt caverns
- Rule 96 for storage of natural gas in depleted reservoirs
- Rule 97 for storage of natural gas in salt caverns

Regulatory Standards

- The rules require that underground storage be created, operated, and maintained in a manner that will prevent:
- waste of stored hydrocarbons
- uncontrolled escape of stored hydrocarbons
- pollution of fresh water
- danger to life or property

Permit Required

- The operator or owner must obtain an RRC permit for each underground hydrocarbon storage facility.
- Specific permit authority must be obtained for each type of storage. For example, a salt dome facility storing both NGL and natural gas requires permits under both Rule 95 and Rule 97.

Permit Modification, Cancellation or Suspension

- After notice and hearing, the RRC can modify, cancel, or suspend a permit for:
 - Material change in conditions or material deviations from information furnished with application.
 - (To be "material" the change must affect either safe operation or the ability to operate without causing waste or pollution.)

-Likely pollution of fresh water

Material violations of the Permit or RRC regulations

Misrepresentations during the application process

• RRC can suspend permit immediately without hearing if there is an imminent danger to life or property or imminent waste of hydrocarbons, uncontrolled escape of hydrocarbons, or pollution of fresh water.

Permit Transfer

- For salt cavern facilities under Rules 95 and 97, permits can be transferred only after approval by the RRC.
- For depleted reservoir gas storage facilities under Rule 96, the RRC has 15 days to object to transfer of a permit.

Application for Permit

• The applicant is required to submit technical data and information to establish that the proposed storage facility will comply with the rules.

• The applicant must submit information to:

Designate and describe the reservoir or salt formation.

 Demonstrate that the proposed reservoir or cavern is suitable for underground storage.

Describe the planned operation of the proposed facility.

 Show planned compliance with a list of strict safety requirements.

 Show planned compliance with specified underground injection well requirements, providing detailed data on all wellbores in the surrounding area. For depleted reservoir storage permits, the applicant must demonstrate the amount of native gas remaining in the reservoir.

 For depleted reservoir storage permits, if condemnation is planned, the applicant must provide information to establish the specific findings required for eminent domain authority.

Notification

- The applicant must notify:
 - Mineral Interest Owners in the proposed storage facility

 Leaseholders above, below, and offsetting the proposed storage facility Surface Owners overlying the proposed storage facility

- County Clerk

-City Clerk

• The applicant must also publish notice in a newspaper of general circulation in the county.

Public Hearing

• Under Rules 95 and 97, a public hearing is required for each new salt cavern storage permit, but is not required for amended permits unless there is a protest by an affected party or unless the RRC staff, in its discretion, declines to approve the amendment without a hearing.

• Under Rule 96, although a public hearing is not necessarily required for a new permit, as a practical matter, because most applications will request condemnation findings, a hearing will be required to obtain a Commission order with those findings. • Under all three rules, a hearing is required if there is a protest by an affected party or if the RRC staff, in its discretion, declines to approve the amendment without a hearing.

Mechanical Integrity Testing

- Operators must perform periodic mechanical integrity testing of each storage well.
- These pressure tests are designed to prove that the storage well or cavern does not leak.
- The MIT must be done before initial storage operations and thereafter once every five years.

Casing and Wellhead Inspections for Salt Cavern Wells

• Each new salt cavern well must have two strings of casing cemented into the salt.

• Salt cavern wellheads and casing must be inspected periodically for corrosion, cracks, or deformations.

- Rule 95 requires inspection for hydrocarbon liquid caverns once every 10 years.
- Rule 97 requires inspection for gas caverns once every 15 years.
- This inspection usually requires that the well be taken out of service so that cavern inventory can be emptied.

Emergency Shutdown Valves Required

• All salt caverns must be equipped with failclose emergency shut down valves.

• Each ESV must be tested regularly.

• Piping to and from each ESV must be designed to carry escaped product in case of an upset.

Salt Cavern Capacity and Configuration Requirements

 Sonar caliper surveys of each salt cavern must be performed before initial storage operation and thereafter once every 10 years.

• Salt caverns will continue to leach if less than saturated brine is utilized to move product.

• Sonar caliper surveys are designed to reveal the size and shape of the salt cavern.

• Sonar surveys can also be used to determine the location of cavern walls with regard to property boundaries, other caverns, and salt formation limits.

- Some salt formations have zones of preferential dissolution so that caverns can have less than perfect shapes.
- Some caverns are subject to roof falls or salt falls.

Permits issued under Rules 95 and 97 set a permitted cavern capacity for each salt cavern.

 If the sonar caliper (or any other information) indicates that a salt cavern has exceeded the permitted cavern capacity by 20% or more, the operator must notify the RRC, and an amended permit may be required.

Safety Requirements

The rules mandate storage facility safety requirements, including:

- Operating limits and pressures
- Well monitoring and reporting
- Piping integrity
- Testing and maintenance

- Leak detection
- Gas and fire detectors
- Fire suppression
- Records and data retention
- Employee and contractor safety training
- Vehicle barriers
- Emergency response planning and notification