# Underground Natural Gas Storage in the U.S.

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An Initiative of the IOGCC & GWPC

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## Acronyms and Abbreviations

| | |
|---|---|
| API | American Petroleum Institute |
| bcf | billion cubic feet |
| BGS | British Geological Survey |
| DOT | U.S. Department of Transportation |
| EIA | U.S. Energy Information Administration |
| FERC | Federal Energy Regulatory Commission |
| mmcf | million cubic feet |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| psig | pounds per square inch gauge |
| RP | Recommended Practice |
| tcf | trillion cubic feet |

# 1 INTRODUCTION

The U.S. economy relies upon an uninterrupted supply of energy. This energy is supplied by a variety of sources such as crude oil, natural gas, and coal. Over time, natural gas has become a vital component of the U.S. energy supply, currently comprising 29% of the total. In addition, natural gas is playing an ever-increasing role in meeting the nation's electricity demands.[1] The demand for natural gas is spread across numerous sectors of the U.S. economy and natural gas serves as an important energy source for industrial, commercial, and electrical generation sectors and also plays a vital role in residential heating.

The key characteristics making natural gas an ideal energy source are that it is clean burning, cost effective, and domestically abundant. Compared to oil and coal, natural gas is a clean-burning fuel with low air emissions, making it a popular choice for power companies seeking to comply with increasingly strict air emission standards. Additionally, over 95% of the natural gas consumed in the U.S. is produced domestically, resulting in a low-cost, stable supply that is not dependent on foreign sources that may be subject to potential instability caused by international politics.[2]

The natural gas industry relies on a complex network of transmission and distribution lines to provide the primary link from producing areas to end users; however, the storage of natural gas is an essential component of this system and is critical for maintaining its efficiency and reliability. One of the challenges with using natural gas is that it is more difficult to stockpile than other fuels, such as coal or oil. To manage this issue, natural gas is stored in underground formations that allow for the containment of large volumes of natural gas and quick withdrawal to meet the needs of the end user.

As demand for natural gas has increased over the years, the importance of underground natural gas storage (hereinafter referred to as underground gas storage) to the gas delivery network has increased proportionally. As underground gas storage regulations and demand have evolved, operations have also changed and have allowed natural gas storage to maintain its essential role in ensuring the safe and reliable supply of natural gas to the U.S.

# 2 NEED FOR NATURAL GAS STORAGE

The primary purpose of underground gas storage is to provide a buffer between a relatively constant supply and a variable demand for natural gas. Underground gas storage allows large supplies of natural gas to be stored close to end users, which reduces the need for larger transmission pipelines and allows for continuous supply of natural gas in the event of supply interruptions such as natural disaster, accidents, or acts of terror. This helps to keep prices relatively stable through seasonal peaks in demand or other disruptions. Further, in a somewhat recent development, natural gas storage may be used by marketers for price hedging.

Underground natural gas storage facilities play an essential role in reliable natural gas delivery and have been developed to ensure that natural gas is available to be delivered to the end-users on an as-needed basis. A lack of adequate gas storage could potentially result in the following:

- Black- or brown-outs during unexpectedly warm summers, resulting in a lack of electric power for items such as lights, electronics, and air conditioners.
- Lack of natural gas to heat homes in the winter.

- Lack of power generation for commercial and industrial sectors.
- Increased need for larger and more expensive transmission lines to transport the full volume of natural gas from the point of generation to the end-user.
- Increased price volatility.

# 3 UNDERGROUND STORAGE BASICS

In an underground gas storage facility, the purpose is to inject gas underground in a manner and location that causes it to stay in place until such time that it is withdrawn. To achieve this, an underground gas storage facility will employ injection/withdrawal wells that are involved in the operation of the facility. A typical storage facility will also have observation wells present within and/or around the gas storage reservoir or cavern to monitor for pressure changes or potential migration of natural gas out of the gas storage reservoir.

The following terminology is important to understanding how a storage facility functions:

- **Cushion (base) Gas**: The volume of gas, including physically irretrievable gas, needed to provide adequate lift for the working gas and to maintain structural integrity of the storage facility.
- **Working Gas**: The volume of gas, in excess of the designed volume of cushion gas, which is injected and withdrawn in a cycle determined by the capacity of the gas storage facility and gas supply requirements being met. **Figure 1** depicts how the working gas volume fluctuates based on seasonal changes in demand.

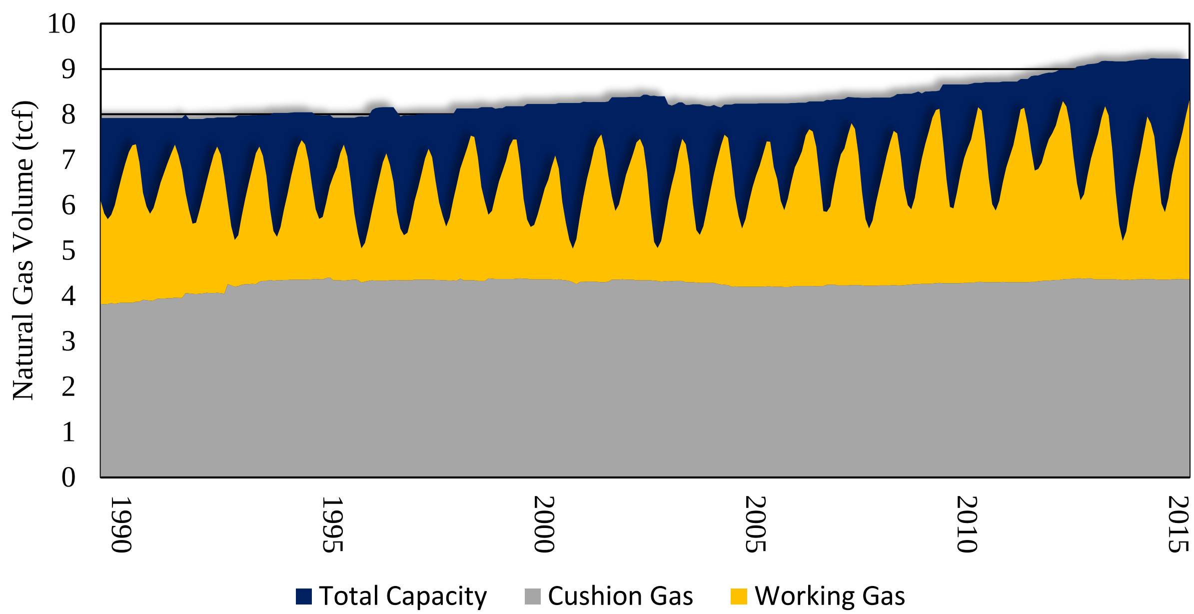


**Figure 1. Gas Storage Volumes from 1990 to 2015**
(data source: EIA[3])

- **Deliverability**: The amount of gas that can be withdrawn from a storage facility on a daily basis. The deliverability of a storage facility depends on the ability of gas to travel from the storage reservoir to the well. Deliverability rates also vary depending on how much gas, and therefore pressure, is in the storage facility at a given time.

# 4 TYPES OF UNDERGROUND STORAGE FACILITIES

Although numerous types of gas storage facilities have been attempted or experimented with, there are three basic types of underground natural gas storage facilities currently in use:

- Depleted oil and gas reservoirs,
- Salt caverns, and
- Aquifers.

## 4.1 Depleted Reservoir

Depleted reservoir storage facilities utilize oil and gas reservoirs whose hydrocarbons have already been produced and further production is no longer economically viable. In depleted reservoir storage facilities, gas is injected and stored within the pore spaces of the rock and then subsequently withdrawn as needed (**Figure 2**). With over 300 depleted reservoir facilities in operation, this is the most abundant type of storage facility in the U.S. The main reason for their abundance is that depleted oil and gas fields are readily available in many areas throughout the country and they are relatively inexpensive to develop compared to other storage types.

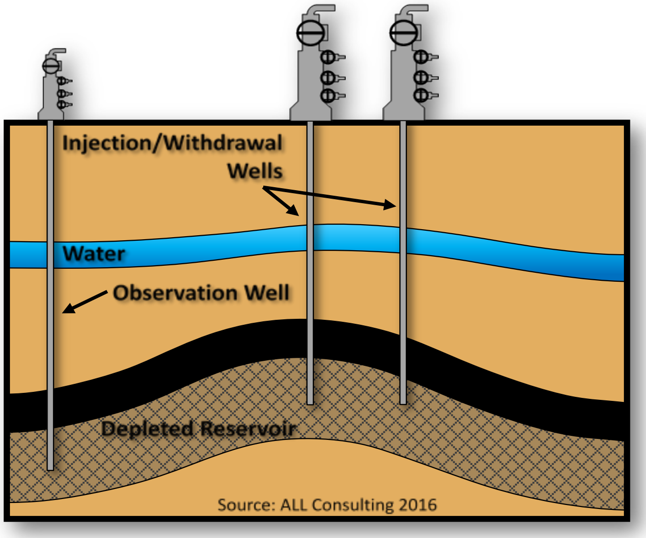


**Figure 2. Example of Depleted Reservoir Storage**

Depleted reservoirs are more cost effective than other storage types because they have the ability to use the existing infrastructure (wells and pipelines) and require that less cushion gas be injected prior to withdrawal since a certain amount of gas remained in place after production operations ceased. Additionally, there is less capital investment required for geologic characterization of depleted reservoirs since much of the geology is already known from the production operations and since the reservoir was able to contain its previous hydrocarbon contents for millions of years.

Depleted reservoir storage has a long cycle time, generally 200-250 days for injection and 100-150 days for withdrawal.[4] This longer cycle time is due to the storage gas having to be injected and withdrawn through the pore spaces of the reservoir rock. Because of this long cycle time, depleted fields are generally used for base load capacity to serve anticipated seasonal demand needs (**Table 1**).

**Table 1. Gas Storage Facility Characteristics**
(source: FERC[5])

| Storage Type | Depleted Reservoir | Aquifer | Salt Cavern |
|---|---|---|---|
| **Cushion Gas** | 50% | 50-80% | 20-30% |
| **Injection Time** | 200-250 | 200-250 | 20-40 |
| **Withdrawal Time** | 100-150 | 100-150 | 10-20 |
| **Relative Cost** | Low | Moderate | High |

## 4.2 Aquifers

Aquifer gas storage is similar to storage in depleted reservoirs in that the gas is being injected into, stored within, and withdrawn through pore spaces in a porous reservoir resulting in similarly long cycle times and low deliverability, making them most useful for base gas demand (**Figure 3**).

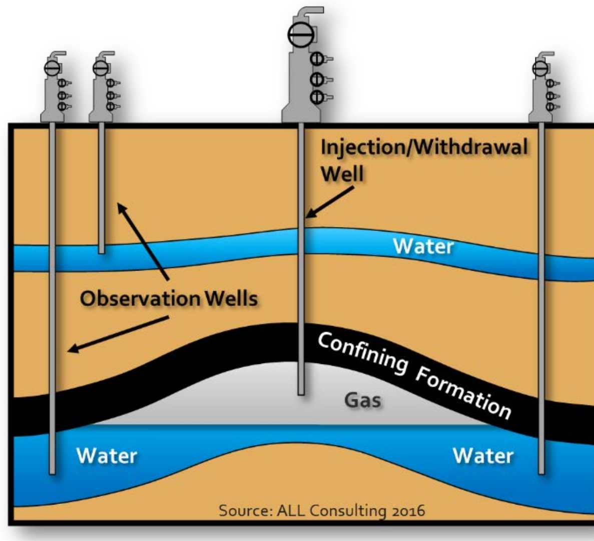


**Figure 3. Example of Aquifer Gas Storage**

Although similar in some respects to storage in a depleted reservoir, aquifer gas storage takes place in water-bearing reservoirs that use the existing water for both lateral and lower confinement of the gas. Additionally, aquifer gas storage facilities are more expensive because of infrastructure and cushion gas requirements. At an aquifer gas storage facility, there is a need to install new injection/withdrawal wells, observation wells, and pipelines to operate the facility. Further, aquifer gas storage facilities have a high cushion gas requirement of 50-80%, all of which must be injected, resulting in additional capital expenditures (see **Table 1**).[6]

## 4.3 Salt Caverns

Gas storage in salt caverns is fundamentally different than storage in either depleted reservoir or aquifers since the storage occurs in an empty void as opposed to pore spaces. To create the voids, either salt domes or bedded salts are solution-mined to form the cavern in the salt deposit in which gas is to be stored (**Figure 4**). The need to solution mine the salt deposits to form the caverns, disposal costs, and the need for full geologic characterization and infrastructure development, makes salt cavern storage the most expensive type of storage available.

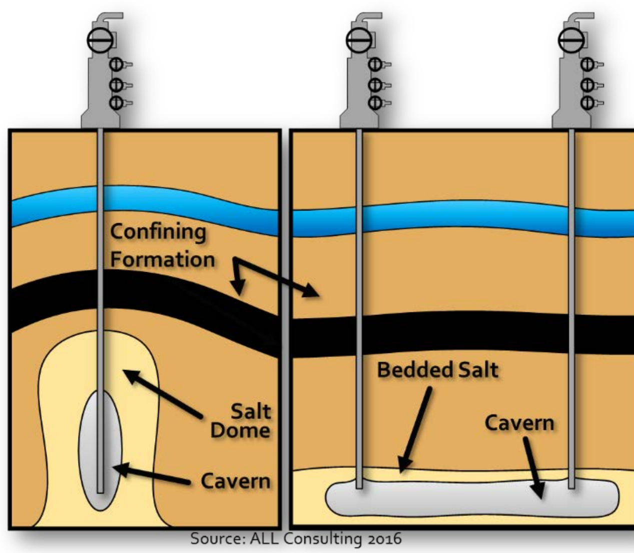


**Figure 4. Example of Salt Cavern Gas Storage**

Since the gas in salt cavern storage is stored in a void, it doesn't need to travel through pore spaces during injection or withdrawal, resulting in short cycle times. Because of this, salt cavern storage facilities are high-deliverability facilities that are best used for peak demand in which a large volume of gas needs to be withdrawn within a short period of time. The high deliverability of salt cavern storage facilities also makes them the desired type of storage for use by marketers for price hedging.

These caverns rely on the salt formation, which has very low permeability, to provide confinement of the gas. Since there are no pore spaces to be filled, there is a very low cushion gas requirement (20-30%), although a certain amount of cushion gas is still required to provide lift for the working gas and to prevent salt creep, which has the potential to reduce overall cavern size and storage capacity (see **Table 1**).[7]

# 5 HISTORY OF GAS STORAGE IN THE U.S.

The need to store large volumes of natural gas to provide a leveling buffer between supply and demand has been recognized since natural gas transmission pipelines were initially being built in the late 1890s. Seeing the need for and importance of a reliable supply of natural gas, in 1909, the U.S. Geological Survey recommended that surplus natural gas be stored in underground reservoirs.[8] The first underground natural gas storage project was in 1915 in a gas field in Ontario, Canada. The following year, the first underground gas storage project was initiated in the U.S. in a depleted gas field to serve peak demands of the City of Buffalo, New York.[9,10] This storage field is still in operation and is the longest operating underground storage project in the world.[11] As demand for natural gas continued to grow, there was an associated increase in natural gas storage capacity, and by the 1930s, there were nine underground gas storage projects located across six states.[12] See the underground gas storage timeline in **Figure 5**.

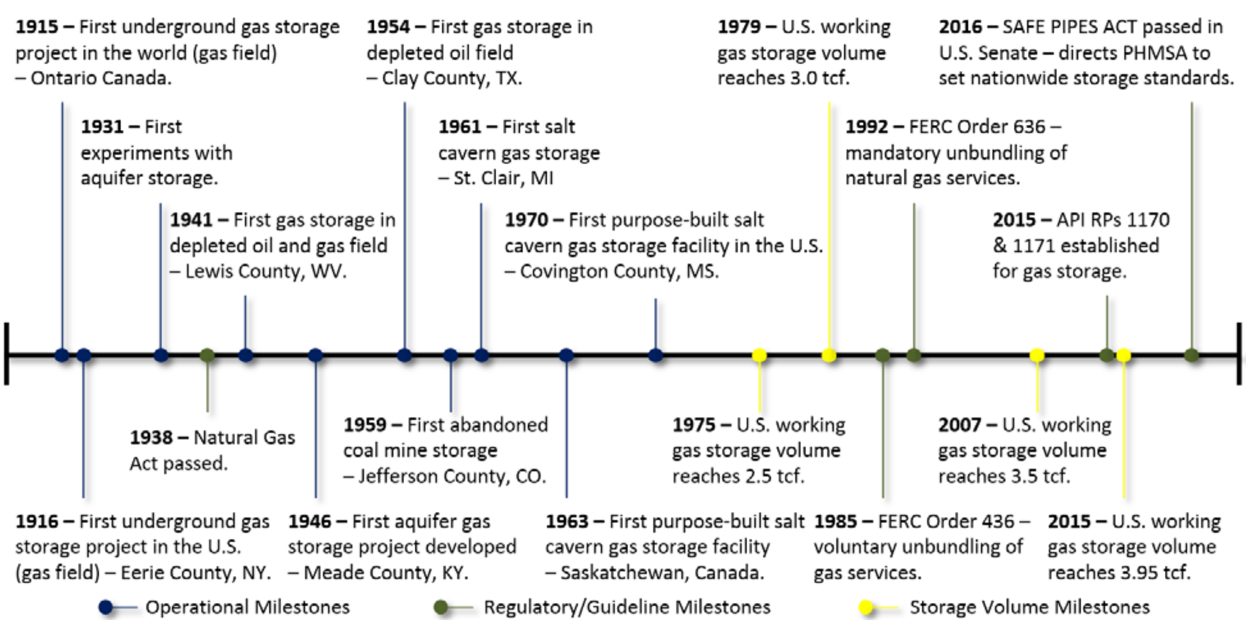


**Figure 5. Underground Gas Storage Timeline**

Until the 1930s, underground gas storage in the U.S. had generally been conducted in depleted gas reservoirs; however, with the U.S.'s continued reliance on natural gas, there was an associated need for additional storage capacity throughout the nation, which necessitated additional types of gas storage be used where depleted gas fields were not available. To meet this need, experiments began with underground gas storage in different types of storage structures, including depleted oil and gas fields and aquifers. Expanding on the use of depleted hydrocarbon reservoirs for gas storage, the first gas storage project in a depleted oil and gas field was conducted in 1941 in West Virginia and the first storage in a depleted oil field was completed in 1954 in Texas. Early gas storage projects in oil fields were initially conducted to enhance oil recovery but the fields were converted to gas storage once the oil resources were depleted. The presence of oil in the storage reservoirs led to several complications, including enrichment of the gas and oil condensing out of the gas once it entered the pipeline, along with difficulties in assessing gas volumes in the reservoir due to large amounts of gas going into solution with the oil.[13] Since not all regions of the U.S. have adequate depleted oil and gas fields available, natural gas transmission operators began looking at aquifers as a storage option. The first experiments with gas storage in water-bearing formations began in 1931 and the first successful storage project in an aquifer was completed in Kentucky in 1946.[14]

The first usage of a salt cavern for gas storage was in 1961 using an abandoned salt cavern from the Morton Salt Company. Subsequent salt cavern storage facilities were constructed in salt deposits that had been mined for their salt for use in the chemical industry. The first salt cavern designed specifically for use as a gas storage facility was in Saskatchewan, Canada, in 1963, followed by the first "purpose-built" gas storage salt cavern in the U.S. being constructed in Mississippi in 1970.[15]

Additionally, storage has historically been conducted in abandoned mines, although none are currently in operation in the U.S. The first abandoned mine used for gas storage was conducted in Jefferson County, Colorado, in an abandoned coal mine. This abandoned mine storage was in operation until 2003 when the city of Aurora, Colorado, bought the mine for use as a subsurface water reservoir.[16]

Over the years, various factors have resulted in a continued increase in the demand for natural gas storage capacity, which has risen 12% between 2000 and 2015.[17] As of December 2015, according to the U.S. Energy Information Administration (EIA), the U.S. has 390 active underground gas storage projects, which is more than any other country in the world.[18]

# 6 RISKS ASSOCIATED WITH UNDERGROUND STORAGE

The storage of natural gas in underground formations comes with inherent risks that are managed through appropriate operational controls. In some instances, these risks have not been properly managed and resulted in incidents that had environmental and human health consequences. However, these incidents have led to operational and regulatory changes that have made underground gas storage safer and more efficient.

## 6.1 Operational Risks

Similar to any energy-based operation, underground gas storage operations have certain inherent risks that must be mitigated to reduce the potential for adverse impacts to human health and the environment. Some of the potential risks associated with underground natural gas storage include the following:

- Well casing or cement failure;

- Leaks in wellhead and surface pipe;
- Upset events at surface facilities;
- Migration of gas out of the reservoir:
    - Faulting in caprock;
    - Migration through artificial penetrations;
- Unexpected enlargement of salt caverns.

The risks encountered at a given facility depend on a number of factors including, but not limited to, operating pressures, age of the wells, local faulting, reservoir characteristics, and the type of storage structure being used. For instance, in the event of a catastrophic loss of containment, such as an explosion at the wellhead, a salt cavern facility has the potential to release its stored gas much more quickly than a depleted reservoir or aquifer due to its significantly higher deliverability. For example, as described below, during the recent gas storage incident at the Aliso Canyon Storage field near Los Angeles, California, (a depleted reservoir) a well failure resulted in the release of approximately 5 billion cubic feet (bcf) of gas over a period of about 5 months.[19] In 2004, a well failure from a salt cavern facility in Moss Bluff, Texas, resulted in the loss of approximately 6 bcf in less than a week.[20]

A study completed in 2008 by the British Geological Survey (BGS) identified 65 incidents that had occurred at underground gas storage facilities across the world. According to this study, a large portion of the incidents (27) occurred at salt cavern facilities where most of the incidents were attributed to well casing and cement failure or operator error (excessive leaching of the salt cavern). As mentioned previously, the early salt caverns (1960s) were repurposed from commercial salt mining operations, which are not ideally made for natural gas storage. It wasn't until 1970 that salt caverns began being built for the specific purpose of storing natural gas. This switch to purpose-built facilities is one factor that has contributed to the approximately 50% reduction in underground storage incidents in the early 2000s.[21]

Of the 65 incidents identified in the study, 53 occurred within the United States with 12 of these incidents occurring in California, 10 in Texas, and 10 in Illinois.[22] The likely reason that so many of the identified incidents have occurred in the U.S. is that the depleted reservoirs, constituting approximately 80% of the storage facilities in the U.S., utilize existing infrastructure. This existing infrastructure, including pipelines and former producing wells, which may be decades old, is converted to inject and withdraw natural gas.[23] This older equipment has an increased potential for mechanical integrity issues due to corrosion over time and because many producing wells were constructed with expectations of producing oil or gas at pressures in the range of several hundred pounds per square inch gauge (psig), as compared to storage operating pressures of several thousand psig. This aging equipment has an increased chance of leaking due to corrosion of the materials and the fact that the equipment in place may not have been constructed to hold the pressures at which they are being operated. For example, over 55% of Southern California Gas Company's natural gas storage wells are over 50 years old.[24] Additionally, a survey conducted by the California Public Utilities Commission in 2015 and 2016 resulted in 229 leaks being identified from faulty valves, flanges, and wellheads from California's 12 storage fields.[25]

## 6.2 Incidents

Throughout the history of gas storage operations, several incidents have occurred that have served to shape future operation and regulation of the practice. Below are brief summaries of some of the more widely publicized incidents that have occurred in recent history.

### *6.2.1 Los Angeles, CA*
On October 23, 2015, a well associated with an Aliso Canyon storage facility in Los Angeles, California, (depleted reservoir) began leaking uncontrollably.[26] The leak continued for over 3 months before the well was killed on February 11, 2015, by pumping heavy fluids into the wellbore from a relief well.[27] The leak resulted in the evacuation of approximately 4,400 households in the community of Porter Ranch due to complaints of headaches, nosebleeds, and nausea.[28,29] By the time the well was killed, approximately 5 bcf of natural gas had been released.[30]

### *6.2.2 Moss Bluff, TX*
On August 19, 2004, a well in the Moss Bluff Storage Facility (domal salt cavern) located in Liberty County, Texas, exploded and caught fire. The fire self-extinguished 6.5 days later and the emergency crews were able to place a blowout preventer on the well, allowing for the well to be shut-in, after approximately 6 bcf of natural gas had been released. The suspected cause of the explosion was a leak between the master valve and emergency shut-off valve on the wellhead.[31]

### *6.2.3 Hutchinson, KS*
In January 2001, natural gas stored in the Yaggy Storage Field (bedded salt cavern) leaked from the reservoir, due to a wellbore failure, and migrated approximately nine miles underground to abandoned wells located within the town of Hutchinson, Kansas. The gas migration into the abandoned wells resulted in explosions, fires, and natural gas geysers that destroyed two downtown buildings and damaged dozens of others, and resulted in one death. In total, it is estimated that approximately 143 million cubic feet (mmcf) of natural gas leaked from the storage field.[32]

## 7.0 Regulation
The regulation of underground natural gas storage facilities is currently divided between federal and state regulatory jurisdictions. Storage facilities associated with interstate commerce are regulated by the Federal Energy Regulatory Commission (FERC) and the Pipeline and Hazardous Materials Safety Administration (PHMSA). . FERC is responsible for permitting underground gas storage facilities, and PHMSA, a branch of the U.S. Department of Transportation (DOT), has primary authority over operation of interstate gas storage facilities. Storage facilities associated solely with intrastate commerce are regulated by the state in which they are located. The states' oil and gas agencies regulate operations associated with the well and reservoir, and the states' public utility commissions regulate the aboveground pipelines and facilities.

Over time, both federal and state gas storage regulations have evolved to, first, increase regulations in an attempt to control the inherently monopolistic gas transmission companies, and later, to decrease regulations as a means of addressing the increases in, and volatility of, natural gas prices. Additionally, regulations are continuing to evolve to address safety and health considerations.

## 7.1 History of Federal Regulation
In the early days of gas transmission and storage, such activities were regulated by individual local governments. As the use and transportation of natural gas increased, there were gaps in regulatory coverage as the gas was transported between municipalities. To address the regulatory gaps, state governments intervened to regulate the transfers of gas within the state through public utility commissions. The first states to regulate natural gas on a state level were New York and Wisconsin in 1907.[33]

Technological improvements and increasing demand made it economical to transport natural gas longer distances and beyond state boundaries. In the early years, this interstate transmission was essentially unregulated. In 1938, the first instance of federal regulation of the natural gas industry was the Natural Gas Act, which sought to control the operations and rates of the large, monopolistic electric and utility companies. The Natural Gas Act provided a means of controlling costs and facilitating a steady supply of natural gas to the country.

## 7.2 History of Federal Deregulation

Historically, the use of natural gas storage facilities was limited to use as a buffer between the near constant supply and variable demand. Under this framework, storage was included with transmission and distribution as a bundled commodity that was sold by the pipelines to distribution utilities. Although FERC Order 436 in 1985 allowed for the voluntary unbundling of services, it wasn't until FERC issued Order 636 in 1992 that interstate transmission companies were required to unbundle their services (transmission, storage, and distribution). By unbundling transmission, storage, and distribution services, the capacity in each was opened to non-discriminatory and non-preferential contracts. Additionally, Order 636 expanded the potential uses of underground storage to include arbitrage, as opposed to only being available for meeting the operational needs of the utility companies, which opened the door for operators to be able to store gas when prices were low and withdraw and sell when prices were high. When this restriction was removed, anyone could use the available storage capacity for commercial or operational uses, giving rise to the first natural gas marketers.[34] FERC's unbundling had two main purposes: to encourage construction of additional storage capacity and to increase competition for the various parts of the downstream natural gas industry (transmission, storage, and distribution) with a common goal of keeping prices low and reducing volatility.[35]

## 7.3 Recent Regulatory Updates

Due to concerns over human and environmental health associated with potential issues at underground storage facilities, both state and federal regulatory agencies have been reviewing their regulations to determine whether revisions are needed to ensure that operations within their jurisdictions are carried out in a safe manner going forward.

In response to the Aliso Canyon incident of October 2015, the California Department of Oil, Gas and Geothermal Resources has issued emergency gas storage rules, and is currently in the process of revising their underground injection rules, which include provisions pertaining to gas storage operations. Other states, including Utah and New York, have also been reviewing their regulations in light of the incident to determine if any revisions may be necessary. This process of reviewing regulations for appropriateness after an incident is a common occurrence and has taken place in many jurisdictions and across all industrial sectors. Examples of such reviews include those conducted in both Kansas and Texas following incidents within their states. These processes generally result in improved regulations and explain why Kansas and Texas have some of the most comprehensive state gas storage regulations to date.

On the Federal level, PHMSA has the authority to regulate underground gas storage wells, but does not currently have any such regulations; however, the Safe Pipes Act (S. 2276) may change this fact. The Safe Pipes Act was introduced in November 2015 and passed by the House and Senate on June 13, 2016, and has been sent to the President of the U.S. for signature. The Safe Pipes Act directs the Secretary of Transportation, in consultation with other relevant agencies, to promulgate nationwide minimum standards that would apply to both interstate and intrastate underground natural gas storage facilities. In February 2016, after the Safe Pipes Act had been introduced, PHMSA issued an Advisory Bulletin as a reminder to operators to review their operations and infrastructure and to take measures to identify any potential leaks and failures. The advisory bulletin also encouraged the operators to voluntarily implement the American Petroleum Institute's (API) Recommended Practices (RPs) for underground natural gas storage (API RPs 1170 and 1171). Passage of the Safe Pipes Act into law could result in API RPs 1170 and 1171 being implemented as nationwide minimum underground gas storage standards.[36]

# 8 UNDERGROUND NATURAL GAS STORAGE FACILITIES

The demand for natural gas, and therefore the demand for gas storage, has changed over time and the type and volume of gas storage throughout the country has evolved accordingly. Currently, there are 390 active gas storage facilities in the U.S.—80% depleted reservoirs, 10% aquifers, and 10% salt caverns. These facilities are operated by 127 companies, with approximately 60% (75) of these companies owning only a single storage facility.[37]

Below is an overview of natural gas storage facilities currently in use in the U.S. by jurisdiction and deliverability.

## 8.1 Facility Jurisdiction

As noted above, regulation of underground storage facilities is divided between state (intrastate facilities) and federal (interstate facilities) jurisdictions. Currently, the number of interstate and intrastate facilities are roughly similar—203 intrastate facilities and 187 interstate facilities. Additionally, both intrastate and interstate facilities have roughly the same number of the three facility types, with depleted reservoirs comprising approximately 80% and aquifer and salt cavern storage facilities each comprising approximately 10% of the total for each jurisdiction (**Figure 6**). A table describing each states' gas storage facilities, broken down by jurisdiction, is included in the Appendix.

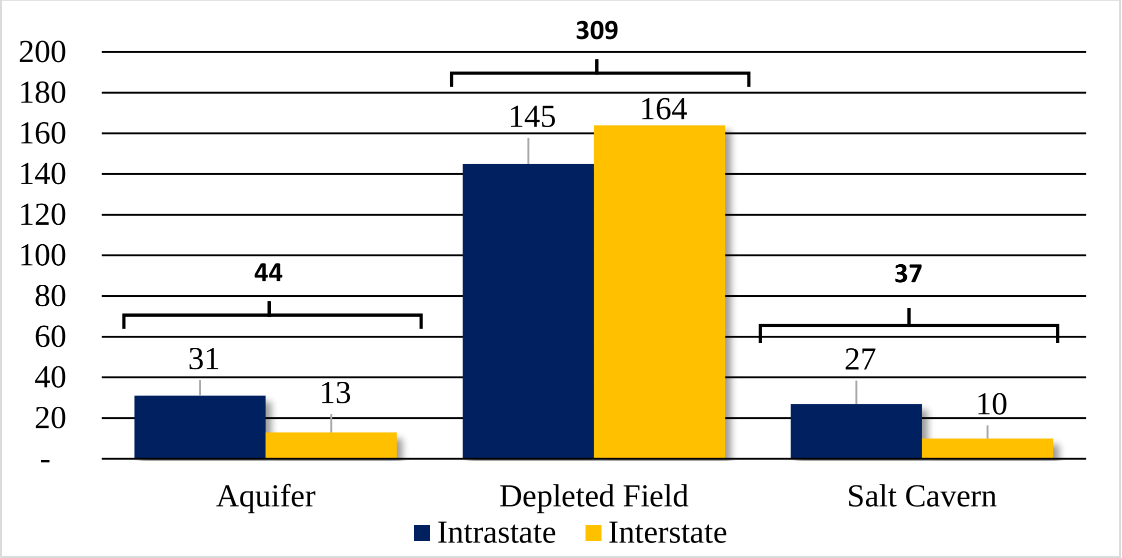


**Figure 6. Comparison of Storage Facility Counts by Type**
(data source: EIA[38])

Although intrastate facilities are more numerous, the interstate facilities have a higher total working gas capacity (58% of the U.S. total).[39] This indicates that, on average, interstate facilities have a larger working gas capacity than their intrastate counterparts. Although the average working gas capacity of each type of interstate facilities is larger than that of the interstate facilities, it is the salt caverns where the largest difference is observed (**Figure 7**). It is because of a handful of very large interstate salt caverns located in Texas, Louisiana, and Mississippi that the average working gas capacity of interstate salt caverns is approximately three times the size of intrastate salt domes.

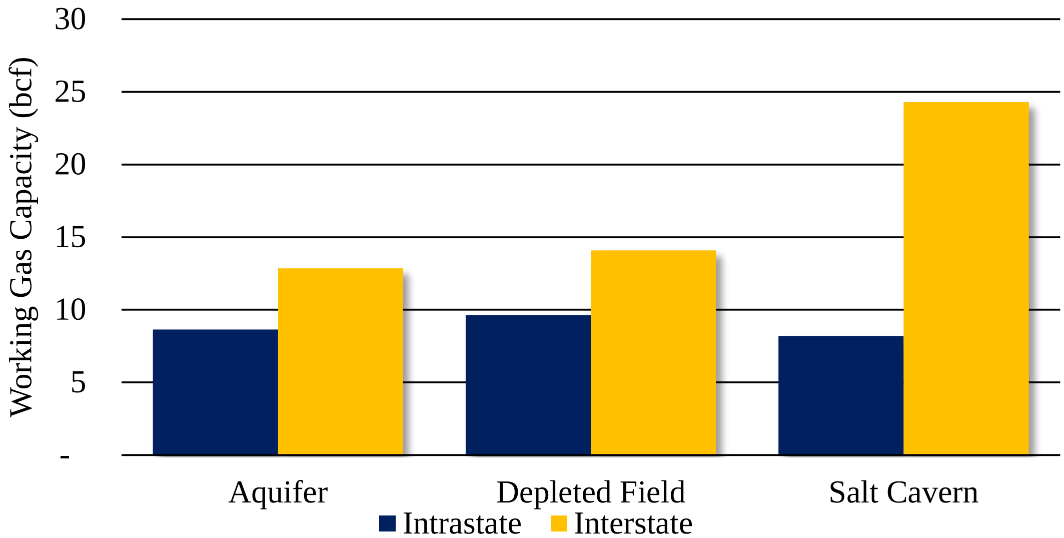


**Figure 7. Comparison of Working Gas Capacity by Type of Facility**
(data source: EIA[40])

### 8.2 Increases in Deliverability

With changes in the natural gas storage regulation and demand, storage facilities have increasingly needed to be able to meet dramatic daily and even hourly swings in demand, which has resulted in a need for storage facilities with shorter injection and withdrawal cycle times.[41]

The deregulation (un-bundling) of the natural gas industry has caused an uptick in demand for high deliverability storage facilities by independent storage service providers, such as marketers, as they attempt to take advantage of swings in natural gas prices.[42] This new demand has resulted in an increase of nearly 350% in the total salt cavern capacity in the last 21 years due to the high deliverability of these storage facilities and their ability to allow for capitalization of market fluctuations.[43]

To meet the need for higher deliverability, storage operators are taking steps to increase the deliverability from existing depleted reservoir and aquifer storage facilities. Such steps have included constructing horizontal wells to increase the amount of formation area exposed to the wellbore as well as reengineering existing wells to enhance their deliverability through stimulation practices such as acidizing and hydraulic fracturing.[44]

Although overall storage capacity hasn't increased dramatically in the past decade, deliverability has increased sharply to keep up with market forces and increases in peak demand. In the last decade, overall storage capacity has increased 22%, while overall deliverability has increased

41%.[45] Salt caverns have seen the greatest increase in deliverability in the last decade (142%) and this change is largely due to the added capacity provided by eight new facilities. This is in contrast to increased deliverability from depleted reservoirs (22%) that is due to re-engineering and storage enhancements, since there are actually two fewer depleted reservoirs in 2015 than were present in 2005.[46] These changes in storage volumes and deliverability indicate that operators are focusing on increasing deliverability as opposed to simply adding new storage volume (**Figure 8**).

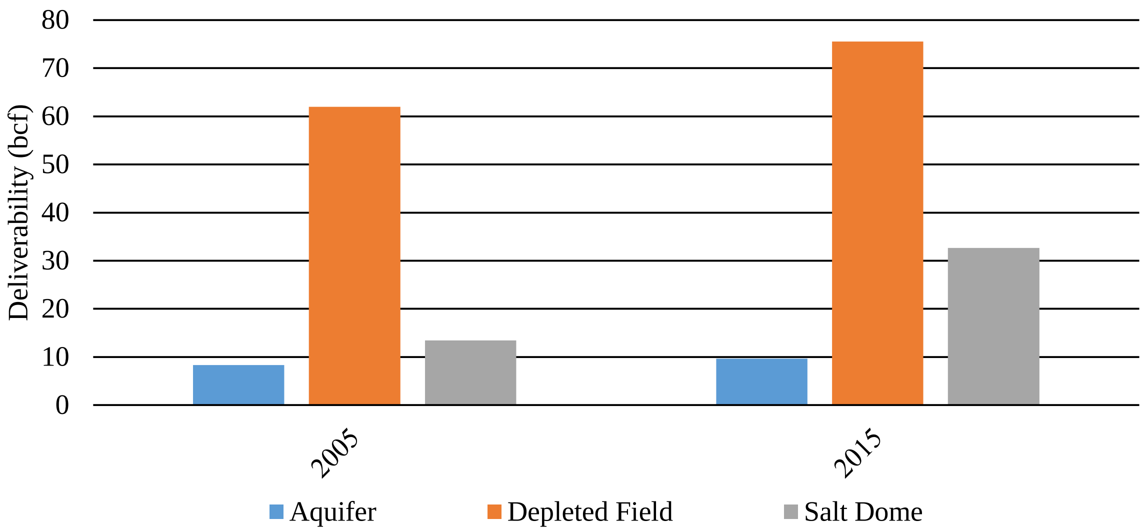


**Figure 8. Comparison of Storage Deliverability: 2005-2015**
(data source: EIA[47])

## 9 SUMMARY

Natural gas is a vital component of the nation's energy supply and underground gas storage plays an important role in ensuring that natural gas is able to be delivered to end users on a consistent basis to meet the expected demand. Throughout its history, the underground gas storage landscape has continued evolving based on constantly changing volume and deliverability demands, including the recent increases in demand for natural gas for electric power generation. Additionally, regulatory changes have undergone a cycle of regulation and subsequent deregulation in attempt to ensure reliability and decrease the volatility of gas prices for end users. This regulatory evolution resulted in changes to both the gas storage environment and the manner in which gas is stored throughout the U.S. In response to concerns regarding the safety and potential environmental impacts of gas storage operations, and with an appreciation of its importance to the U.S. economy, state and federal agencies are reviewing their current regulatory programs and revising regulations accordingly. This increased scrutiny of gas storage regulations, in conjunction with evolving operational practices, has helped to ensure that underground gas storage continues to be carried out in a manner that ensures reliable delivery of natural gas to the nation for the foreseeable future.

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# APPENDIX

## U.S. Underground Natural Gas Storage Facilities

| State | Category | Facility Count | | | | Working Gas | Total Capacity |
|---|---|---|---|---|---|---|---|
| | | Total | Depleted Reservoir | Aquifer | Salt Cavern | | |
| Alaska | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 5 | 5 | 0 | 0 | 67,915,295 | 83,592,247 |
| | Total | 5 | 5 | 0 | 0 | 67,915,295 | 83,592,247 |
| Alabama | Interstate | 1 | 1 | 0 | 0 | 11,200,000 | 13,500,000 |
| | Intrastate | 1 | 0 | 0 | 1 | 21,950,000 | 30,100,000 |
| | Total | 2 | 1 | 0 | 1 | 33,150,000 | 43,600,000 |
| Arkansas | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 2 | 2 | 0 | 0 | 12,178,159 | 21,852,779 |
| | Total | 2 | 2 | 0 | 0 | 12,178,159 | 21,852,779 |
| California | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 14 | 13 | 1 | 0 | 375,496,000 | 601,808,067 |
| | Total | 14 | 13 | 1 | 0 | 375,496,000 | 601,808,067 |
| Colorado | Interstate | 5 | 5 | 0 | 0 | 46,278,777 | 90,861,085 |
| | Intrastate | 5 | 5 | 0 | 0 | 17,495,073 | 39,325,021 |
| | Total | 10 | 10 | 0 | 0 | 63,773,850 | 130,186,106 |
| Iowa | Interstate | 4 | 0 | 4 | 0 | 90,313,000 | 288,209,620 |
| | Intrastate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 4 | 0 | 4 | 0 | 90,313,000 | 288,209,620 |
| Illinois | Interstate | 4 | 1 | 3 | 0 | 86,379,919 | 252,350,000 |
| | Intrastate | 23 | 8 | 15 | 0 | 215,026,126 | 734,249,647 |
| | Total | 27 | 9 | 18 | 0 | 301,406,045 | 986,599,647 |
| Indiana | Interstate | 4 | 2 | 2 | 0 | 4,995,564 | 12,158,571 |
| | Intrastate | 16 | 6 | 10 | 0 | 28,375,734 | 99,126,663 |
| | Total | 20 | 8 | 12 | 0 | 33,371,298 | 111,285,234 |
| Kansas | Interstate | 11 | 11 | 0 | 0 | 116,717,187 | 271,782,413 |
| | Intrastate | 5 | 5 | 0 | 0 | 5,875,518 | 10,514,206 |
| | Total | 16 | 16 | 0 | 0 | 122,592,705 | 282,296,619 |
| Kentucky | Interstate | 5 | 5 | 0 | 0 | 79,259,515 | 168,197,852 |
| | Intrastate | 17 | 15 | 2 | 0 | 28,311,092 | 52,117,773 |
| | Total | 22 | 20 | 2 | 0 | 107,570,607 | 220,315,625 |
| Louisiana | Interstate | 8 | 5 | 0 | 3 | 343,157,000 | 556,290,098 |
| | Intrastate | 9 | 3 | 0 | 6 | 107,757,744 | 175,378,100 |
| | Total | 17 | 8 | 0 | 9 | 450,914,744 | 731,668,198 |
| Maryland | Interstate | 1 | 1 | 0 | 0 | 18,300,000 | 64,000,000 |
| | Intrastate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 1 | 1 | 0 | 0 | 18,300,000 | 64,000,000 |
| Michigan | Interstate | 17 | 17 | 0 | 0 | 282,531,776 | 426,739,467 |
| | Intrastate | 27 | 25 | 0 | 2 | 403,194,300 | 644,890,833 |
| | Total | 44 | 42 | 0 | 2 | 685,726,076 | 1,071,630,300 |

| State | Category | Facility Count | | | | Working Gas | Total Capacity |
|---|---|---|---|---|---|---|---|
| | | Total | Depleted Reservoir | Aquifer | Salt Cavern | | |
| Minnesota | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 1 | 0 | 1 | 0 | 2,000,000 | 7,000,000 |
| | Total | 1 | 0 | 1 | 0 | 2,000,000 | 7,000,000 |
| Missouri | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 1 | 0 | 1 | 0 | 6,000,000 | 13,845,000 |
| | Total | 1 | 0 | 1 | 0 | 6,000,000 | 13,845,000 |
| Mississippi | Interstate | 9 | 4 | 0 | 5 | 169,181,926 | 287,811,159 |
| | Intrastate | 3 | 2 | 0 | 1 | 32,205,659 | 44,001,176 |
| | Total | 12 | 6 | 0 | 6 | 201,387,585 | 331,812,335 |
| Montana | Interstate | 1 | 1 | 0 | 0 | 164,427,000 | 287,200,000 |
| | Intrastate | 3 | 3 | 0 | 0 | 33,050,000 | 89,025,000 |
| | Total | 4 | 4 | 0 | 0 | 197,477,000 | 376,225,000 |
| Nebraska | Interstate | 1 | 1 | 0 | 0 | 12,653,122 | 34,850,000 |
| | Intrastate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 1 | 1 | 0 | 0 | 12,653,122 | 34,850,000 |
| New Mexico | Interstate | 1 | 1 | 0 | 0 | 44,037,872 | 68,600,000 |
| | Intrastate | 1 | 1 | 0 | 0 | 15,700,000 | 20,499,993 |
| | Total | 2 | 2 | 0 | 0 | 59,737,872 | 89,099,993 |
| New York | Interstate | 23 | 23 | 0 | 0 | 117,221,285 | 225,438,815 |
| | Intrastate | 3 | 2 | 0 | 1 | 9,650,000 | 20,340,000 |
| | Total | 26 | 25 | 0 | 1 | 126,871,285 | 245,778,815 |
| Ohio | Interstate | 17 | 17 | 0 | 0 | 167,467,176 | 402,923,850 |
| | Intrastate | 5 | 5 | 0 | 0 | 63,276,000 | 171,833,316 |
| | Total | 22 | 22 | 0 | 0 | 230,743,176 | 574,757,166 |
| Oklahoma | Interstate | 3 | 3 | 0 | 0 | 78,227,000 | 150,900,000 |
| | Intrastate | 9 | 9 | 0 | 0 | 113,197,617 | 224,072,897 |
| | Total | 12 | 12 | 0 | 0 | 191,424,617 | 374,972,897 |
| Oregon | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 7 | 7 | 0 | 0 | 15,935,000 | 29,565,000 |
| | Total | 7 | 7 | 0 | 0 | 15,935,000 | 29,565,000 |
| Pennsylvania | Interstate | 37 | 37 | 0 | 0 | 402,711,600 | 727,619,000 |
| | Intrastate | 10 | 9 | 1 | 0 | 18,173,944 | 33,362,930 |
| | Total | 47 | 46 | 1 | 0 | 420,885,544 | 760,981,930 |
| Texas | Interstate | 3 | 1 | 0 | 2 | 146,384,078 | 229,713,011 |
| | Intrastate | 29 | 14 | 0 | 15 | 365,262,174 | 581,736,796 |
| | Total | 32 | 15 | 0 | 17 | 511,646,252 | 811,449,807 |
| Utah | Interstate | 3 | 1 | 2 | 0 | 54,942,000 | 124,508,536 |
| | Intrastate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 3 | 1 | 2 | 0 | 54,942,000 | 124,508,536 |

| State | Category | Facility Count | | | | Working Gas | Total Capacity |
|---|---|---|---|---|---|---|---|
| | | Total | Depleted Reservoir | Aquifer | Salt Cavern | | |
| **Virginia** | Interstate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Intrastate | 2 | 1 | 0 | 1 | 5,400,000 | 9,500,000 |
| | Total | 2 | 1 | 0 | 1 | 5,400,000 | 9,500,000 |
| **Washington** | Interstate | 1 | 0 | 1 | 0 | 24,600,000 | 46,900,000 |
| | Intrastate | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 1 | 0 | 1 | 0 | 24,600,000 | 46,900,000 |
| **West Virginia** | Interstate | 24 | 24 | 0 | 0 | 226,887,480 | 488,553,900 |
| | Intrastate | 2 | 2 | 0 | 0 | 3,252,000 | 8,734,000 |
| | Total | 26 | 26 | 0 | 0 | 230,139,480 | 497,287,900 |
| **Wyoming** | Interstate | 4 | 3 | 1 | 0 | 68,215,400 | 130,958,213 |
| | Intrastate | 3 | 3 | 0 | 0 | 4,947,800 | 24,083,600 |
| | Total | 7 | 6 | 1 | 0 | 73,163,200 | 155,041,813 |