Survey of Underground Storage Of Natural Gas In the United States And Canada: 2013/2014

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AGA Underground Storage Committee

American Gas Association

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FOREWORD

The first *Survey of Underground Gas Storage Facilities in the United States and Canada* (Catalog No. X54266) was undertaken during 1965–66 and published by the American Gas Association (AGA) in 1966. Pertinent data on the general physical characteristics of known underground gas storage projects were reported. The second edition (and first revision — Catalog No. X54270) was published in 1970. Subsequent editions were published as follows: third edition published in 1978 (Catalog No. XU0678); fourth edition published in 1983 (Catalog No. XY0783); fifth edition published in 1988 (Catalog No. XU8809A); sixth edition published in 1993 (Catalog No. XU9307); seventh edition published in 1997 (Catalog No. XU9701); eighth edition published in 1999 (Catalog No. XU9901); ninth edition published in 2001 (Catalog No. XU0212)); tenth edition published in 2007 (Catalog No. XU0404). Eleventh edition published in 2011 (Catalog No. XY1102). This is the twelfth edition in the series.

This document contains information as provided by the operators and/or owners of the underground storage facilities and/or reported to the editor (in the case of sold facilities) for the participation year listed in under "Last Updated" or noted in "Footnotes". Part I provides a brief synopsis of the history of underground gas storage in North America. Part II lists data reported by the storage facility operators/owners. All facilities – active, inactive, abandoned, in the process abandonment or under construction – are listed and identified. Information is reproduced as submitted to AGA. In instances where the data were provided in units other than requested, conversions were made accordingly.

This survey is a product of the AGA Underground Storage Committee (USC). AGA would like to thank the officers of the USC and the members of the Statistics / Computer Capabilities task group, in particular, Mark Gredell, Thomas Chrisfield and Matthew Rowan, for their significant contributions to this edition of the publication. Furthermore, the USC would like to acknowledge all survey respondents who provided facility data updates.

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PART I

UNDERGROUND GAS STORAGE HISTORY

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Underground Gas Storage History

<u>The Purpose of Underground Gas Storage</u>

Natural gas supply sources often experience large variations of flow. Gas demand from pipelines also can fluctuate seasonally, daily and even hourly. Underground gas storage is an efficient way to balance these discrepancies between gas supply input and gas market demand. Gas goes into storage when market requirements are lower than supply volumes flowing into the pipeline. Gas comes out of storage when market demand exceeds available supply.

Effective use of underground gas storage requires delivery and permanent containment of a certain level of gas as "base" or "cushion" gas. The base gas maintains the pressure required for gas delivery at the minimum acceptable flow rate.

Gas delivery from an underground gas storage facility requires the pre-injection of the desired level of "top" or "working" gas. The rate at which an underground gas storage facility can take gas on injection and deliver gas on withdrawal is normally dependent on the characteristics of both the underground reservoir and the surface facilities.

<u>A Brief History of the Development of Underground Gas Storage</u>

In 1915, the first recorded experiment that successfully stored gas underground was accomplished in Welland County, Ontario, Canada. Several old wells in a partially depleted gas field were reconditioned for gas storage service. The pressure in the reservoir increased as injected gas entered the wells. Gas withdrawn from the wells the following winter was used for peaking purposes. Thus, the underground gas storage industry was born.

M.J. Judge (National Fuel Gas Company) envisioned this novel approach for natural gas storage, inspired by the experiences of East Ohio Gas Company (EOG). Several years earlier EOG unsuccessfully attempted to dewater an abandoned salt mine near Cleveland, Ohio, for gas storage use. There had been other unrecorded attempts at gas storage in partially depleted sands. These efforts were temporary and operational in nature (for controlling high line pressures and for recycling operations in oil fields), not for managing gas supply and demand.

The success of the Welland County experiment prompted Iroquois Gas Company (a National Fuel affiliate) to apply the same technology in 1916 to the depleted Zoar Field south of Buffalo, N.Y. This project was also successful, and the Zoar project (the first storage operation in the United States) today is the oldest continuously operated underground gas storage facility.

By the end of 1930, the gas storage industry consisted of nine storage pools in six states, with total capacity of 18 billion cubic feet (Bcf). In 1931, Louisville Gas and Electric Company (LG&E) started gas storage experiments at the Muldraugh Field in Meade County, Ky. Muldraugh was a small gas field on a symmetrical dome flanked by a large water-bearing sand formation. LG&E's experience at Muldraugh led to the development of the first aquifer storage project. Aquifer storage occurs in reservoirs that do not contain any naturally occurring hydrocarbons, but instead are initially filled with water. LG&E developed the first aquifer project at its Doe Run facility (also in Meade County, Ky.) in 1946.

In the five-year period prior to World War II, the number of underground gas storage facilities increased from 22 to 51, located in 10 states. The gas industry was very important to the war effort, and gas storage was very important to the gas industry. During the war years, 24 new reservoirs emerged, for a total of 75 fields in 14 states, with total storage capacity of 416 Bcf.

By the end of World War II it was clear that adequate gas storage facilities were essential for market expansion, for new market development and for the construction of long-distance gas transmission lines.

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Most of the storage reservoirs were in the northeastern states, where local production had declined. Since pipeline gas from the Southwest was needed to meet market requirements, gas storage was needed to ensure high load factors for the pipelines.

While most gas storage projects were developed in depleted gas fields, novel approaches were undertaken in areas where depleted gas fields were not available. Storage in a combination oil/gas reservoir was first developed in 1941 by Hope Natural Gas Company, which converted the Fink Field in West Virginia's Lewis and Doddride Counties to gas storage service.

The first successful gas storage project in an oil reservoir was accomplished in 1954. Lone Star Gas Company made the New York City Field in Clay County, Texas, into a gas storage facility. In 1959, an abandoned coal mine near Denver, Colo., was converted to gas storage service. Gas storage in a salt cavern was first developed in St. Clair County, Mich., in 1961.

Today's gas storage industry has descended directly from these entrepreneurial ancestors. Novel uses for gas storage continue to develop, as the natural gas industry continues the deregulation process. Some of these services center around the traditional gas storage role as a balancing tool and as a means of minimizing the cost of gas service. The gas storage industry is certain to continue to grow and evolve as the gas industry itself continues to change.

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PART II

STORAGE DIRECTORY

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DEFINITIONS FOR UNDERGROUND STORAGE FACILITY DATA SHEET

GEOGRAPHICAL/ HISTORICAL INFORMATION

Operating Company
The name of the company operating the facility.

Storage Facility Name
The name used by the storage operator to designate a reservoir or cavern storage facility.

State/ Province
The name of the state or province in which the major portion of the reservoir/cavern lies.

Facility Status
Indicate whether it is:
Active: A storage facility capable of injecting and withdrawing gas.
Inactive: Wellhead, gathering line, or cavern valves are closed and storage facility is not operational.
Abandonment In Progress: Permanently withdrawing base gas, plugging wells, other preparations for abandonment.
Abandoned: Facility no longer provides natural gas service.
Under -Construction: A new facility in the process of being constructed to provide natural gas storage service.

County
The name of the county (or counties) in which the major portion of the storage reservoir or cavern is located.

Discovery/ Development Year
The year in which the reservoir was discovered (or for aquifers and caverns, the year in which the aquifer or cavern was initially developed or mined).

Year Activated/Deactivated For Storage
The year in which the storage facility was placed into gas storage operation or abandoned.

RESERVOIR DESCRIPTION

Type of Storage
Select the type of storage from the list below:
Depleted Reservoir: Sub-surface natural geological reservoir; usually depleted gas or oil field.
Aquifer: Porous and permeable rock stratum; pore space, which was originally filled with water, into which stored gas is confined by suitable structure, permeability barriers and hydrostatic water pressure
Domal Salt Cavern: An artificially created solution-mined cavity within a domal salt body.
Bedded Salt Cavern: An artificially created solution-mined cavity within a laterally extensive, layered or bedded salt body.
Mined Cavern: An artificially created mined cavity within any rock type.
Abandoned Mine: A structure originally created to extract mineral deposits and has been converted for gas storage.
Other: A type of storage not listed above. Please specify.

Original Content
The original contents of the reservoir or storage space: gas, water, oil, salt water, salt, rock, or coal

Discovery Pressure (Psig – wh) (well head pressure)
The average shut-in surface wellhead pressure of the gas filled porosity. (Omit for cavern facilities – “na” should be used.)

Original In-Place Reserves (Omit for cavern and aquifer facilities – “na” should be used).
Gas (MMcf): The original estimated total quantity of gas in place for a depleted gas field (includes both recoverable and non-recoverable)
Oil (bbls): The original estimated total quantity of oil in place for a depleted oil field (includes both recoverable and non-recoverable)

Storage Formation Name
The geologic or drillers’ name for the rock strata being used for storage.

Storage Lithology
The type of rock constituting the storage formation, e.g. sandstone, granite, carbonate, domed salt, bedded salt, coal, etc.

Gross Thickness (feet)
The average thickness of total formation intervals containing gas. For caverns, average height of caverns used for gas storage.

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Type of Geological Trap
The type of geologic containment mechanism used to trap the gas. Select from the list below:
Structural Trap: A sealed geologic structure in deformed strata such as a fold or fault. Principal hydrocarbon sealing mechanism is due to the shape or contour of the overlying caprock, preventing escape of the hydrocarbons contained within the reservoir rock.
Stratigraphic Trap: Principal hydrocarbon trapping mechanism is due to lateral changes from reservoir rock to trapping rock because of changes in rock type, pinchouts, rock quality, hydrodynamics, unconformities, sedimentary features etc., not due to shape or contours of the reservoir or trapping rock.
Struct./ Strat.: Principal hydrocarbon trapping mechanism is due a combination of structural and stratigraphic trapping conditions as defined above.
Reef: Principal hydrocarbon trapping mechanism is due to confinement of hydrocarbons in a mound-like reservoir rock type built by organisms such as corals, etc., surrounded by gas-impermeable, trapping non-reef rock types.
Domal Salt Cavern: An artificially created solution-mined cavity within a domal salt body.
Bedded Salt Cavern: An artificially created solution-mined cavity within a laterally extensive, layered or bedded salt body.
Mined Cavern: An artificially created mined cavity within any rock type.

Maximum Depth to Formation (feet)
The maximum depth in feet to the **TOP** of the storage formation from ground level. For caverns, the maximum depth to the bottom of the cavern space.

Minimum Depth to Formation (feet)
The minimum depth in feet to the **TOP** of the storage formation from ground level. For caverns, the minimum depth to the top of the cavern space.

Areal Extent of Reservoir (acres)
Approximate number of acres occupied by the gas bubble (excluding buffer zone).

FACILITY DATA

Injection/ Withdrawal Wells
Total: Total number of active wells used for injection and/ or withdrawal of gas (includes vertical, horizontal and deviated).
Horizontal/Deviated: Number of active wells used for injection and/ or withdrawal of gas that are horizontal or highly deviated with an inclination greater than 75 degrees

Pressure Control and/ or Observation Wells
The number of wells used for monitoring pressure and/ or fluid levels.

Total Horsepower
The total horsepower rating of compression available for injection or withdrawal for the reservoir/cavern. This compression may be dedicated to the specific reservoir or shared with other reservoirs/caverns. If horsepower is shared, indicate "Yes" after the value and list under "Footnotes" the name(s) of the other reservoir(s)/cavern(s).

Gathering Lines (miles)
Total: The number of miles of storage pipeline within the storage facility.
Max Size (inches): The largest diameter pipe for injection/withdrawal in the storage field.

DESIGN VALUES

Base Gas (MMcf) (injected plus native base)
The volume of gas required to provide enough pressure to cycle the normal working storage volume. (Base gas volumes are reported in total without reference as to whether the volume reported might be recovered when storage operations are ultimately terminated).

Working Gas Capacity (MMcf)
The maximum designed gas capacity in the reservoir above the designed level of base gas. This volume is NOT tied to any specific date or pressure. It may or may not be completely injected or withdrawn during any particular season. Conditions permitting, the total working capacity could be used more than once during any season – (see annual cycling capability).

Maximum Storage Pressure (Psig –wh) (well head pressure)
The average shut-in surface wellhead pressure at planned maximum design capacity of gas in storage.

Maximum Design Deliverability (MMcf/d)
The maximum daily volume of gas planned to be available for delivery on a design day basis using current facilities (e.g., well, pipeline, compression, metering, dehydration) and taking into account other operational constraints. (This is not tied to a specific date).

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Late Season / Last Day Deliverability (Mcf/d)
The maximum daily volume of gas available for delivery using current facilities (e.g., well, pipeline, compression, metering, dehydration) and taking into account other operational constraints when the reservoir or cavern is at or near its base gas volume. (This is not tied to a specific date).

Annual Cycling Capability
The typical number of times the working gas is cycled (withdrawn and re-injected) on an annual basis. Traditionally, depleted reservoirs and aquifers have been cycled once per year; however, today's environment may increase the cycles. Salt caverns and other void space storage formation may have capabilities of multiple cycles each year.

FOOTNOTES
Please use the Footnotes section to further explain your responses as needed.

NOTES ON UNITS USED

Bbls
42 U.S. gallons

MMcf
Millions of cubic feet.

Mcf
Thousands of cubic feet

Mcf/d
Thousands of cubic feet per day

Psig-wh
Pounds per square inch gage at wellhead

EXPLANATION OF "nr", "na"

The current information on the data sheets may include the following notations:

"nr"
This means "no response" has been received to date. Respondents are encouraged to fill in missing information.

"na"
This means "not applicable" and is used when the information does not apply to your situation (e.g. initial reserves for a salt cavern storage facility is "na".)

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