The Basics of Underground Natural Gas Storage

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Natural gas–a colorless, odorless, gaseous hydrocarbon–may be stored in a number of different ways. It is most commonly held in inventory underground under pressure in three types of facilities. These are: (1) depleted reservoirs in oil and/or gas fields, (2) aquifers, and (3) salt cavern formations. (Natural gas is also stored in liquid form in above-ground tanks. A discussion of liquefied natural gas (LNG) is beyond the scope of this report. For more information about LNG, please see the EIA report, *The Global Liquefied Natural Gas Market: Status & Outlook*.) Each storage type has its own physical characteristics (porosity, permeability, retention capability) and economics (site preparation and maintenance costs, deliverability rates, and cycling capability), which govern its suitability to particular applications. Two of the most important characteristics of an underground storage reservoir are its capacity to hold natural gas for future use and the rate at which gas inventory can be withdrawn–its deliverability rate (see *Storage Measures*, below, for key definitions).

Most existing gas storage in the United States is in **depleted natural gas or oil fields** that are close to consumption centers. Conversion of a field from production to storage duty takes advantage of existing wells, gathering systems, and pipeline connections. Depleted oil and gas reservoirs are the most commonly used underground storage sites because of their wide availability.

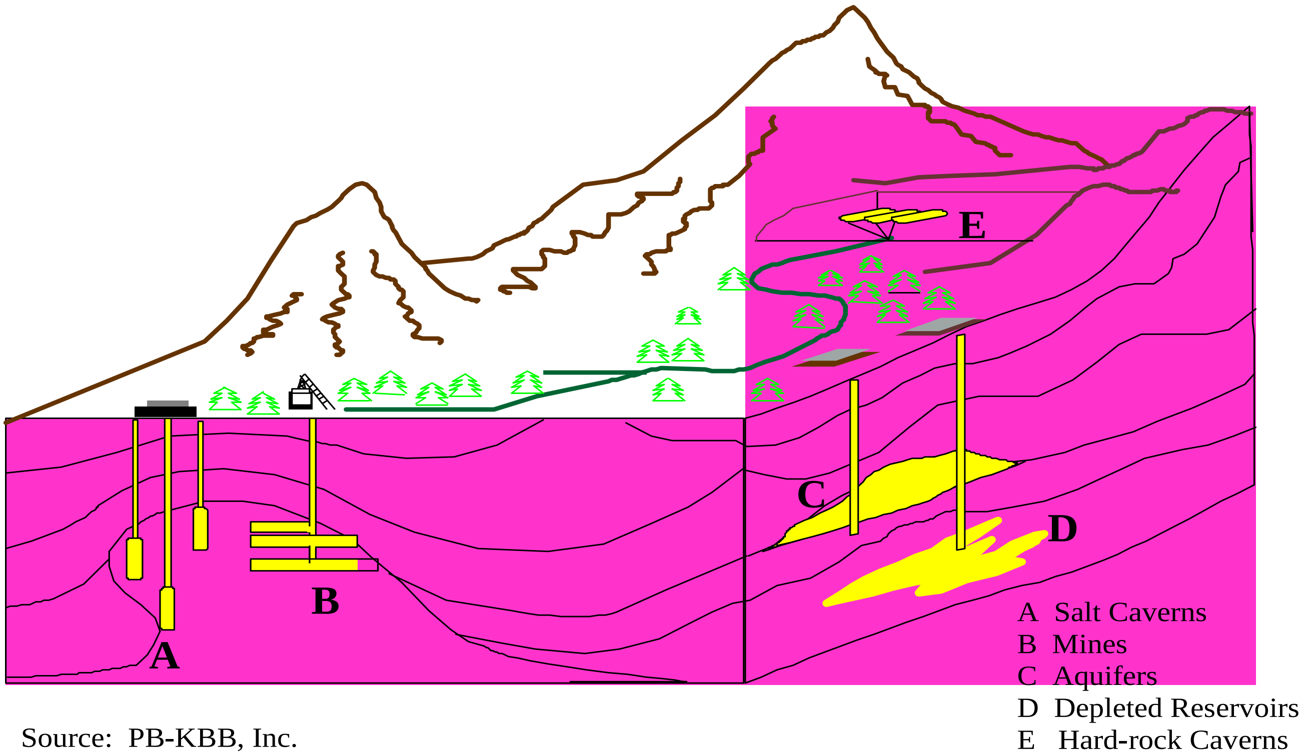
In some areas, most notably the Midwestern United States, natural **aquifers** have been converted to gas storage reservoirs. An aquifer is suitable for gas storage if the water-bearing sedimentary rock formation is overlaid with an impermeable cap rock. While the geology of aquifers is similar to depleted production fields, their use in gas storage usually requires more base (cushion) gas and greater monitoring of withdrawal and injection performance. Deliverability rates may be enhanced by the presence of an active water drive.

Salt caverns provide very high withdrawal and injection rates relative to their working gas capacity. Base gas requirements are relatively low. The large majority of salt cavern storage facilities have been developed in salt dome formations located in the Gulf Coast states. Salt caverns have also been leached from bedded salt formations in Northeastern, Midwestern, and Southwestern states. Cavern construction is more costly than depleted field conversions when measured on the basis of dollars per thousand cubic feet of working gas capacity, but the ability to perform several withdrawal and injection cycles each year reduces the per-unit cost of each thousand cubic feet of gas injected and withdrawn.

There have been efforts to use abandoned **mines** to store natural gas, with at least one such facility having been in use in the United States in the past. Further, the potential for commercial use of **hard-rock cavern** storage is currently undergoing testing. None are commercially operational as natural gas storage sites at the present time.

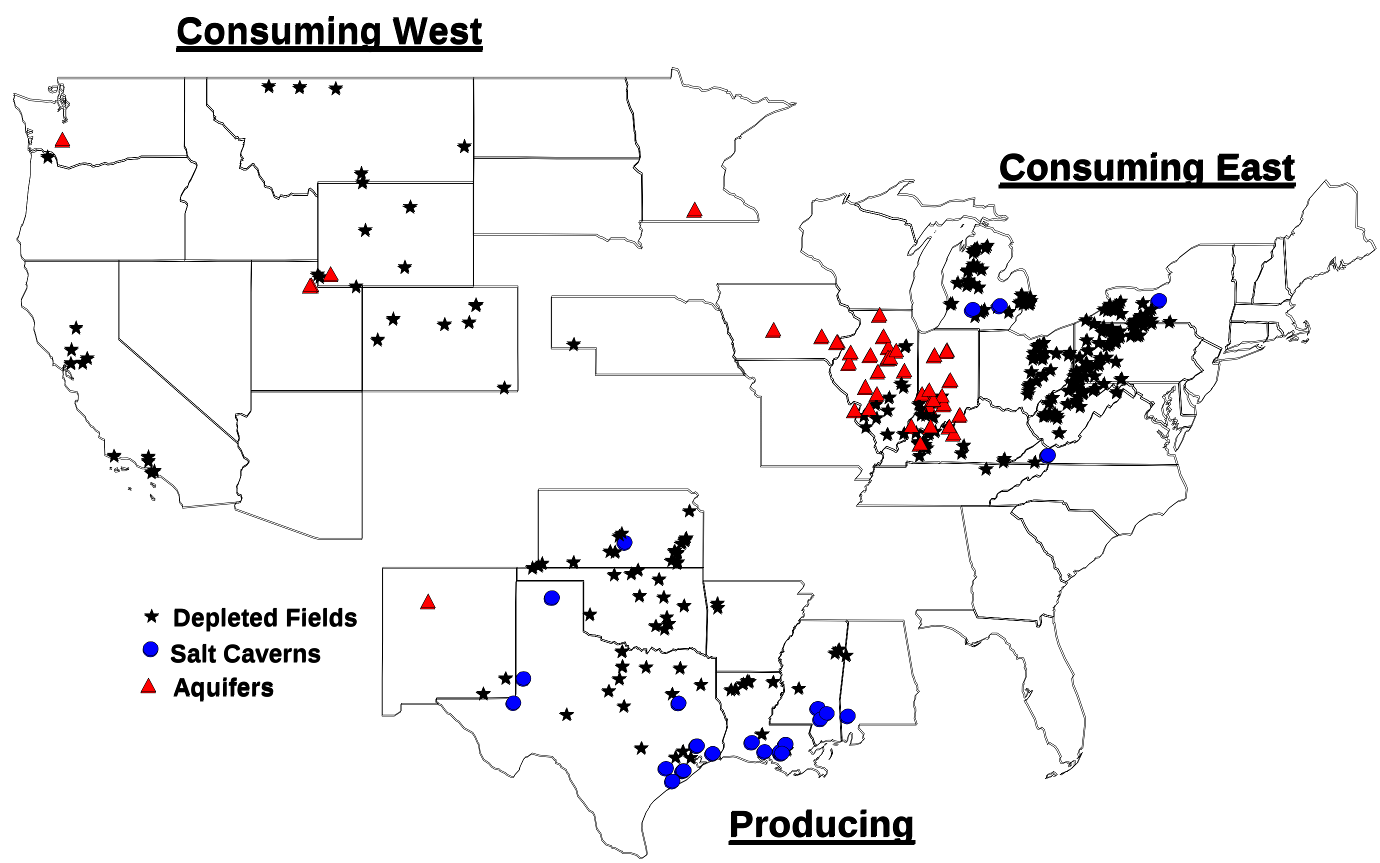
Figure 1 is a stylized representation of the various types of underground storage facilities, while Figure 2 shows the location of the nearly 400 active storage facilities in the Lower 48 States.

Figure 1. Types of Underground Natural Gas Storage Facilities



Source: PB-KBB, Inc.

Figure 2. Underground Natural Gas Storage Facilities in the Lower 48 States



Source: Energy Information Administration (EIA), EIA GasTran Geographic Information System Underground Storage Data Base.

Owners and Operators of Storage

The principal owners/operators of underground storage facilities are (1) interstate pipeline companies, (2) intrastate pipeline companies, (3) local distribution companies (LDCs), and (4) independent storage service providers. There are about 120 entities that currently operate the nearly 400 active underground storage facilities in the lower 48 states. In turn, these operating entities are owned by, or are subsidiaries of, fewer than 80 corporate entities. If a storage facility serves interstate commerce, it is subject to the jurisdiction of the Federal Energy Regulatory Commission (FERC); otherwise, it is state-regulated.

Owners/operators of storage facilities are not necessarily the owners of the gas held in storage. Indeed, most working gas held in storage facilities is held under lease with shippers, LDCs, or end users who own the gas. On the other hand, the type of entity that owns/operates the facility will determine to some extent how that facility's storage capacity is utilized.

For example, **interstate pipeline companies** rely heavily on underground storage to facilitate load balancing and system supply management on their long-haul transmission lines. FERC regulations allow interstate pipeline companies to reserve some portion of their storage capacity for this purpose. Nonetheless, the bulk of their storage capacity is leased to other industry participants. **Intrastate pipeline companies** also use storage capacity and inventories for similar purposes, in addition to serving end-user customers.

In the past, **LDCs** have generally used underground storage exclusively to serve customer needs directly. However, some LDCs have both recognized and been able to pursue the opportunities for additional revenues available with the deregulation of underground storage (see **"Open Access" to Storage Capacity**, below). These LDCs, which tend to be the ones with large distribution systems and a number of storage facilities, have been able to manage their facilities such that they can lease a portion of their storage capacity to third parties (often marketers) while still fully meeting their obligations to serve core customers. (Of course, these arrangements are subject to approval by the LDCs' respective state-level regulators.)

The deregulation of underground storage has combined with other factors such as the growth in the number of gas-fired electricity generating plants to place a premium on high-deliverability storage facilities. Many salt formation and other high-deliverability sites, both existing and under development, have been initiated by i**ndependent storage service providers**, often smaller, more nimble and focused companies started by entrepreneurs who recognized the potential profitability for these specialized facilities. They are utilized almost exclusively to serve third-party customers who can most benefit from the characteristics of these facilities, such as marketers and electricity generators.

Storage Measures

There are several volumetric measures used to quantify the fundamental characteristics of an underground storage facility and the gas contained within it. For some of these measures, it is important to distinguish between the characteristic of a facility such as its *capacity*, and the characteristic of the gas within the facility such as the actual *inventory level*. These measures are as follows:

Total gas storage capacity is the maximum volume of gas that can be stored in an underground storage facility in accordance with its design, which comprises the physical characteristics of the reservoir, installed equipment, and operating procedures particular to the site.

Total gas in storage is the volume of storage in the underground facility at a particular time.

Base gas (or **cushion gas**) is the volume of gas intended as permanent inventory in a storage reservoir to maintain adequate pressure and deliverability rates throughout the withdrawal season.

Working gas capacity refers to total gas storage capacity minus base gas.

Working gas is the volume of gas in the reservoir above the level of base gas. Working gas is available to the marketplace.

Deliverability is most often expressed as a measure of the amount of gas that can be delivered (withdrawn) from a storage facility on a daily basis. Also referred to as the deliverability rate, withdrawal rate, or withdrawal capacity, deliverability is usually expressed in terms of millions of cubic feet per day (MMcf/day). Occasionally, deliverability is expressed in terms of equivalent heat content of the gas withdrawn from the facility, most often in dekatherms per day (a therm is 100,000 Btu, which is roughly equivalent to 100 cubic feet of natural gas; a dekatherm is the equivalent of about one thousand cubic feet (Mcf)). The deliverability of a given storage facility is variable, and depends on factors such as the amount of gas in the reservoir at any particular time, the pressure within the reservoir, compression capability available to the reservoir, the configuration and capabilities of surface facilities associated with the reservoir, and other factors. In general, a facility's deliverability rate varies directly with the total amount of gas in the reservoir: it is at its highest when the reservoir is most full and declines as working gas is withdrawn.

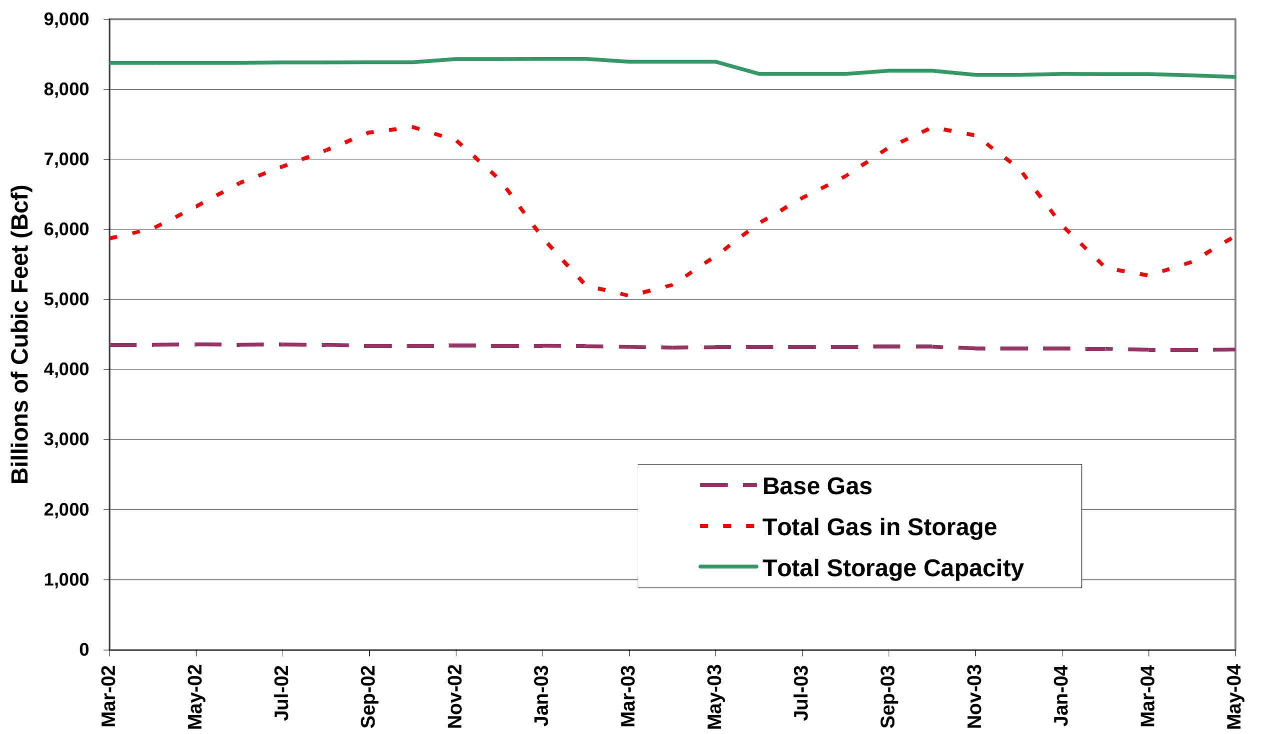
Injection capacity (or rate) is the complement of the deliverability or withdrawal rate–it is the amount of gas that can be injected into a storage facility on a daily basis. As with deliverability, injection capacity is usually expressed in MMcf/day, although dekatherms/day is also used. The injection capacity of a storage facility is also variable, and is dependent on factors comparable to those that determine deliverability. By contrast, the injection rate varies inversely with the total amount of gas in storage: it is at its lowest when the reservoir is most full and increases as working gas is withdrawn.

None of these measures for any given storage facility are fixed or absolute. The rates of injection and withdrawal change as the level of gas varies within the facility. Additionally, in practice a storage facility may be able to exceed certificated total capacity in some circumstances by exceeding certain operational parameters. But the facility’s total capacity can also vary, temporarily or permanently, as its defining parameters vary. Further, the measures of base gas, working gas, and working gas capacity can also change from time to time. This occurs, for example, when a storage operator reclassifies one category of gas to the other, often as a result of new wells, equipment, or operating practices (such a change generally requires approval by the appropriate regulatory authority). Also, storage facilities can withdraw base gas for supply to market during times of particularly heavy demand, although by definition, this gas is not intended for that use.

Underground Natural Gas Storage Data

The Energy Information Administration (EIA) collects a variety of data on the storage measures discussed above, and publishes selected data on a weekly, monthly, and annual basis. For example, EIA uses Form EIA-912, *Weekly Natural Gas Storage Report*, to collect data on end-of-week working gas in storage at the company and regional level from a sample of all underground natural gas storage operators. The sample is drawn from the respondents to the EIA-191, *Monthly Underground Gas Storage Report*, which, among other things, collects data on total capacity, base gas, working gas, injections, and withdrawals, by reservoir and storage facility, from all underground natural gas storage operators. Data from the EIA-912 survey are tabulated and published at regional (see Figure 2 for depiction of regions) and national levels on a weekly basis. Data derived from the EIA-191 survey are published on a monthly basis in the *Natural Gas Monthly*. These data include tabulations of base gas, total inventories, total storage capacity, injections, and withdrawals at state and regional levels. Figure 3 below depicts some basic storage statistics compiled by EIA.

Figure 3. Selected Monthly Storage Measures, March 2002-May 2004



Source: Energy Information Administration, *Natural Gas Montlhly* (DOE/EIA-0130), May 2002-July 2004.

Relative Measures of Gas Inventories

For some analytic purposes, there is interest in relative inventory status, expressed in terms of how nearly "full" are the nation's storage facilities. There are different approaches to measure "percent full." The remainder of this section discusses three ways of computing an estimate of how full are the nation's storage facilities, resulting in three numbers, each of which has a different meaning or interpretation.

1. Total Gas in Storage Relative to Capacity

This measure of full is obtained by dividing the total amount of gas in the facility by its total gas storage capacity. This measure is not often used, because by combining the values for base and working gas, this statistic does not provide information about the potential gas available to the market.

2. Working Gas Relative to Working Gas Capacity

Percent full for a given region based on working gas capacity is obtained by dividing the sum of estimates of working gas volumes in storage by the total working gas capacity of the relevant storage facilities. This measure is based on the physical capabilities of storage facilities to hold working gas. Although working gas capacity is not measured directly, a reasonable estimate is total capacity minus base gas for the facility(ies). Hence, working gas capacity will change as its components change.

3. Working Gas Relative to Historical Maximums

An approach popularized by the American Gas Association (AGA) was to estimate storage "percent full" by comparing current inventory to the maximum amount of gas held in storage during a given time period. The regional historical maximum used by AGA for its weekly storage report (no longer published) was the sum of the largest volumes held in storage for each facility in a region at any time during 1992-March 2000. The total U.S. historical maximum was the sum of the three regional numbers. It is important to note that the respective historical maximum volumes for storage facilities did not all necessarily occur during the same week, or even the same year. Thus, AGA's regional and total U.S. historical maximums were *non-coincident* peak volumes. AGA's U.S. historical maximum volume determined this way was 3,294 Bcf. This historical maximum volume is virtually certain to be less than the design maximum. In the future, working gas in storage could exceed the historical maximum volume from the period 1992-2000.

The three measures vary with the level of working gas in storage. These relationships may be illustrated in the following scenarios, which use actual EIA storage data from the recent past. The scenarios represent end-of-month storage data for the traditional start and end of a heating season, and were chosen so as to accentuate the effect of working gas levels (i.e., highest to begin the heating season, lowest at the end) on the different measures of percent full. All figures are in billion cubic feet (Bcf):

Scenario	Total Capacity	Base Gas	Working Gas	Working Gas Capacity (Total Capacity minus Base Gas)	Total Gas in Storage (Base Gas plus Working Gas)
A: as of October 31, 2003	8,265	4,327	3,130	3,938	7,457
B: as of March 31, 2004	8,219	4,283	1,058	3,936	5,341

Sources: **October 31, 2003:** Energy Information Administration (EIA), *Natural Gas Monthly* (DOE/EIA-0130), December 2003, Table 14. **March 31, 2004:** *Natural Gas Monthly* (DOE/EIA-0130), May 2004, Table 14.

The various estimates of storage "percent full" for the two scenarios, according to the computation methods described above, are as follows:

	Method 1	Method 2	Method 3
Percent Full Computed as:	Total Gas in Storage ÷ Total Capacity	Working Gas ÷ Working Gas Capacity	Working Gas ÷ AGA Historical Maximum (3,294 Bcf)
Scenario A	90%	79%	95%
Scenario B	65%	27%	32%

While the amount of working gas in storage in a given scenario is fixed, the "percent full" measures vary significantly. For Example, in Scenario A, the Method 3 calculation indicates that working gas stocks are only 5 percent below AGA's historical non-coincident maximum, while the 79 percent from Method 2 indicates that 21 percent of working gas capacity is available if needed. On the other hand, Method 1 shows that only 10 percent of total capacity is available. (In this scenario, Methods 1 and 3 yield percentages that are close in value, but this result is conditional on the relatively high level of working gas, as one can see from the results in Scenario B for these two methods.) In Scenario B, Method 2 indicates that gas equivalent to only 27 percent of available working gas capacity remains in storage, while Method 1 shows that storage facilities as a whole are over half "full." Yet the same amount of empty capacity is available for the two methods (Total Capacity minus the sum of Base and Working Gas volumes).

It is important to note that a given measure for percent full for the total U.S., regardless of computation method, may have limited usefulness in assessing the adequacy of inventories going into a heating season. This is true because most storage facilities are located near, and are designed for the most part to serve, local market areas. Storage facilities have therefore tended to cluster in a number of areas (Figure 2). There are impediments to sharing inventories between or among regions. Working gas stocks in the Producing Region can be directed to either of the other two regions, but sharing between the two Consuming regions is limited at best. Thus, inventory status is more realistically assessed on a regional basis.

Shifts in Storage Use Impact Inventories and Storage Activities

The natural gas industry has experienced significant changes in inventory management practices and storage utilization over the past decade or more as a result of market restructuring. During that time, the operational practices of many U.S. underground storage sites became much more market-oriented. Seasonal factors are less important now in the use of underground storage inventories. Many storage gas owners (marketers and other third parties) are attempting to synchronize their buying and selling activities more effectively with market needs while minimizing their business costs.

"Open Access" to Storage Capacity

Prior to 1994, interstate pipeline companies, which are subject to the jurisdiction of the FERC, owned all of the gas flowing through their systems, including gas held in storage, and had exclusive control over the capacity and utilization of their storage facilities. With the implementation of FERC Order 636, jurisdictional pipeline companies were required to operate their storage facilities on an open-access basis. That is, the major portion of working gas capacity (beyond what may be reserved by the pipeline/operator to maintain system integrity and for load balancing) at each site must be made available for lease to third parties on a nondiscriminatory basis.

Today, in addition to the interstate storage sites, many storage facilities owned/operated by large LDCs, intrastate pipelines, and independent operators also operate on an open-access basis, especially those sites affiliated with natural gas market centers. Open access has allowed storage to be used other than simply as backup inventory or a supplemental seasonal supply source. For example, marketers and other third parties may move gas into and out of storage (subject to the operational capabilities of the site or the tariff limitations) as changes in price levels present arbitrage opportunities. Further, storage is used in conjunction with various financial instruments (e.g. futures and options contracts, swaps, etc.) in ever more creative and complex ways in an attempt to profit from market conditions.

Reflecting this change in focus within the natural gas storage industry during recent years, the largest growth in daily withdrawal capability has been from high-deliverability storage sites, which include salt cavern storage reservoirs as well as some depleted oil or gas reservoirs. These facilities can cycle their inventories–i.e., completely withdraw and refill working gas (or vice versa)–more rapidly than can other types of storage, a feature more suitable to the flexible operational needs of today's storage users. Since 1993, daily withdrawal capability from high-deliverability salt cavern storage facilities has grown significantly. Nevertheless, conventional storage facilities continue to be very important to the industry as well.