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The Basics of Underground Natural Gas Storage

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. (Several reconditioned mines are also in use as gas storage facilities.) Each type has its own physical characteristics (porosity, permeability, retention capability) and economics (site preparation costs, deliverability rates, cycling capability), which govern its suitability to particular applications. Two of the most important characteristics of an underground storage reservoir are its capability to hold natural gas for future use and the rate at which gas inventory can be withdrawn–its deliverability rate (see *Storage Measures*, below, for key definitions).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 to take advantage of the high injection/withdrawal rates and flexible operations possible with a cavern facility. 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 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 over 400 storage facilities in the Lower 48 States.

Figure 1. Types of Underground Natural Gas Storage Facilities

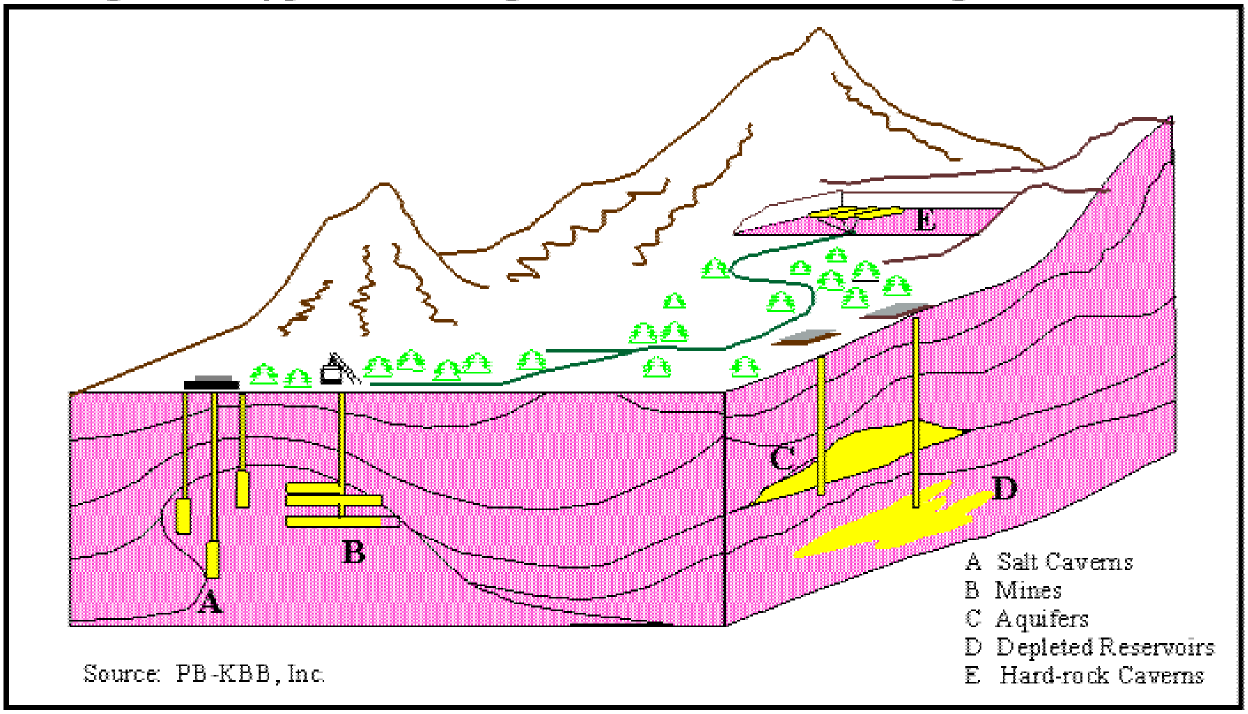
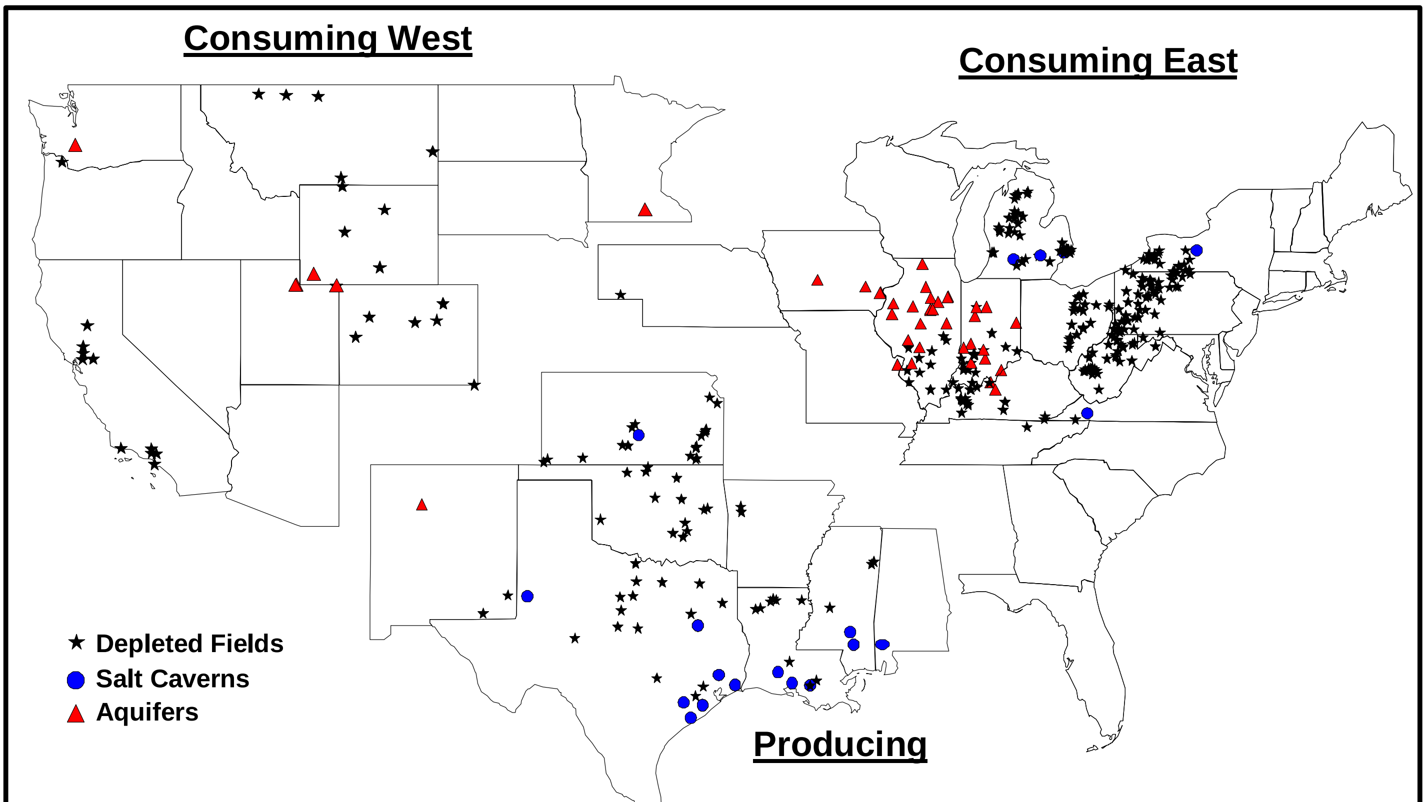


Figure 2. Underground Natural Gas Storage Facilities in the Lower 48 States



Source: Energy Information Administration, EIAGIS-NG Geographic Information System, Underground Storage Database, as of June 2002.

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 by design and is determined by the physical characteristics of the reservoir and installed equipment.

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 roughly equivalent to 100 cubic feet of natural gas; a dekatherm is the equivalent of about one thousand cubic feet, or 1 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.

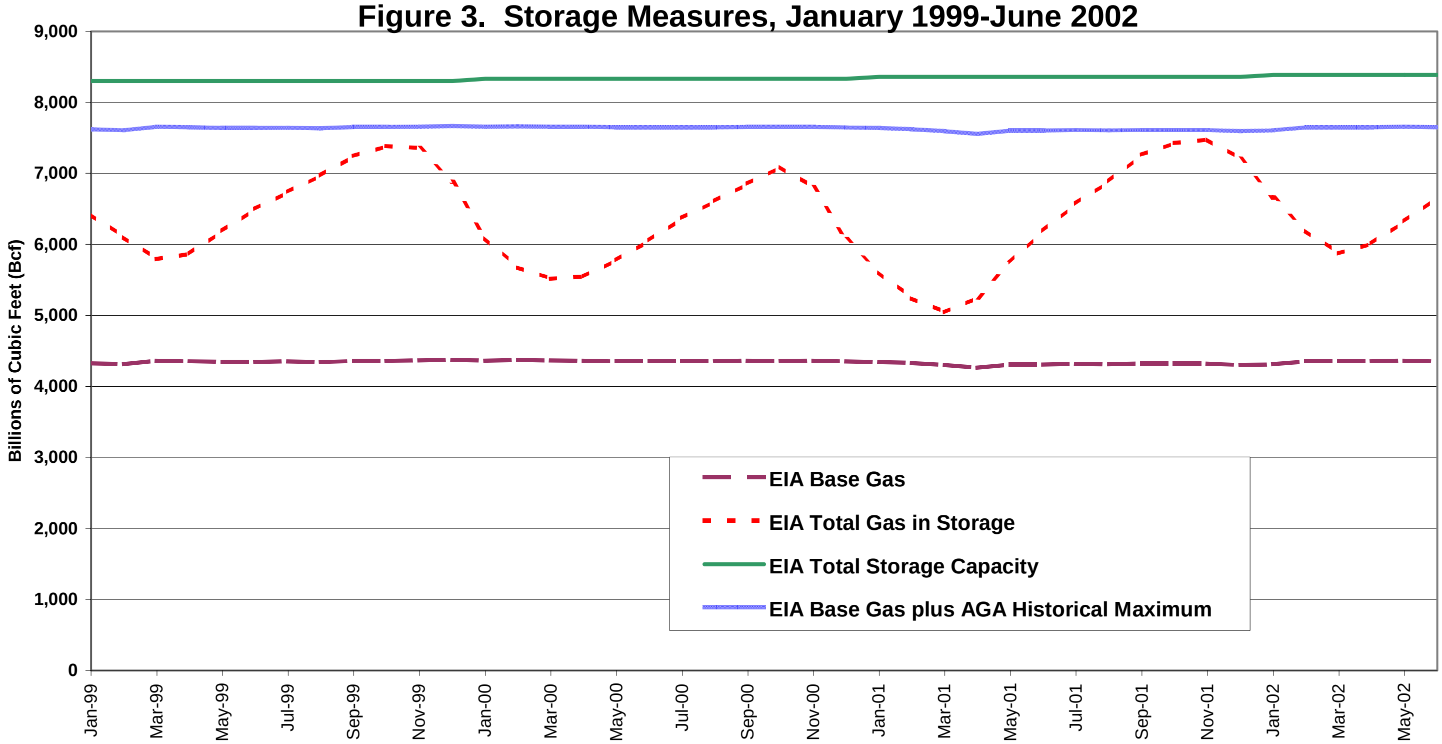
Injection capacity (or rate) is the complement of the deliverability or withdrawal rate–it is the amount of gas that can be injected into a storage facility on a daily basis. As with deliverability, injection capacity is usually expressed in MMcf/day, although dekatherms/day is also used. The injection 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.

These measures for any given storage facility are not necessarily absolute and are subject to change or interpretation. For example, in practice, a storage facility may be able to exceed certificated total capacity in some circumstances by exceeding certain operational parameters. Additionally, the distinction between base gas and working gas is to some extent arbitrary; so gas within a facility is sometimes reclassified from one category to the other. Further, 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.

Relative Measures of Gas Inventories

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 shows some key EIA storage data for the recent past, as well as the American Gas Association's (AGA) "historical maximum" working gas in storage, described below.

Figure 3. Storage Measures, January 1999-June 2002



Source: Energy Information Administration, Form EIA-191, "Monthly Underground Gas Storage Report;" American Gas Association, "Weekly American Gas Storage Survey," April 5, 2000.

For some analytic purposes, there is interest also 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 3 ways of computing an estimate of how full are the nation's storage facilities, resulting in 3 numbers, each of which has a different meaning or interpretation.

1. <u>Working Gas Relative to Historical Maximums</u>
An approach popularized by the AGA is to define "full" based on 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. (AGA's last published update of these sums was in its *Weekly American Gas Storage Survey* report of April 5, 2000 for the week ended March 31, 2000.) The total U.S. historical maximum was the sum of the 3 regional numbers. It is important to note that the largest volumes 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 based on recorded working gas volumes. During the period from April 5, 2000 to the termination of AGA's weekly storage report, the U.S. historical maximum, or non-coincident peak, volume was 3,294 Bcf. AGA's "percent full" was calculated as the ratio of its estimated current volume to its historical maximum volume. An examination of AGA's weekly storage reports shows that AGA's highest estimated current volume of working gas actually held in storage in any given week during 1992-March 2000 was 3,127 Bcf, for the week ended Friday, November 6, 1998. Given that AGA reported working gas of 3,144 Bcf for the week ended November 23, 2001, an historical maximum figure larger than 3,294 Bcf might have been computed had there been an update subsequent to April 5, 2000.

   As stated by AGA, its estimate of maximum was not intended to capture a theoretical value, but instead reflect what had been in storage when facilities were at their respective peaks during 1992-2000. (Source: "American Gas Storage Survey: Procedures and Methodology 2001 Update," *Issue Brief 2001-03*, American Gas Association, June 28, 2001). The historical maximum volume clearly differs from a design maximum, and, in fact, working gas in storage could exceed the historical maximum volume, although the likelihood of this might be low.

2. <u>Working Gas Relative to Working Gas Capacity</u>
Although working gas capacity is not measured directly, it generally can be derived as total capacity minus base gas, which reflects the capacity available to store working gas. Percent full based on working gas capacity is obtained by dividing 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.

3. <u>Total Gas in Storage Relative to Capacity</u>
Yet another measure of full is obtained by dividing the total amount of gas in the facility by its total gas storage capacity. According to EIA data, total gas storage capacity has increased from 7,932 Bcf at the end of December 1992 to 8,376 Bcf on June 30, 2002. This measure is almost never 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.

The relation between each of the measures may be illustrated in an example. The EIA estimates that as of September 20, 2002, 2,991 Bcf of working gas was in storage. EIA's recent data for total capacity and base gas are 8,376 Bcf and 4,355 Bcf, respectively, resulting in working gas capacity of 4,021 Bcf. (EIA data for the end of June 2002 from *Natural Gas Monthly*, August

2002.) As mentioned above, AGA's last estimate for maximum working gas volume was 3,294 Bcf. The percent full value using each of the 3 approaches appears in the table below as Scenario A.

Scenario A: Working Gas Equals 2,991 Bcf (estimate for September 20, 2002)					
Method	Percent Full	Working Gas	Base Gas	Capacity	Remarks
1	91%	2,991	N/A	3,294	Capacity is AGA's historical maximum volume
2	74%	2,991	N/A	4,021	Capacity is total capacity minus reported base gas
3	88%	2,991	4,355	8,376	Capacity is total capacity

Note: N/A indicates not applicable.

The percentages vary significantly. The Method 1 measure of 91 percent indicates that working gas stocks are only 9 percent below AGA's historical non-coincident maximum, while the 74 percent from Method 2 indicates that 26 percent of working gas capacity is available if needed. Utilization of total capacity from Method 3 shows that only 12 percent of total capacity is available.

In all cases, the amount of working gas in storage is the same, 2,991 Bcf. For Methods 2 and 3, the same amount of empty capacity is available—1,030 Bcf (total capacity minus the sum of base and working gas volumes**:** 8,376–(4,355+2,991)), however, the measure of percent full differs substantially. In Method 2, working gas is compared directly to the estimate of working gas capacity, while in Method 3, the sum of working gas and base gas is compared to total capacity. Although Methods 1 and 3 yield numbers that are rather close in value, this is a result conditional on the level of working gas. For example, if working gas were 742 Bcf as in Scenario B, Method 1 would yield a percent full of 23 percent, while Method 3 would indicate that the total volume of stored gas takes up 61 percent of total capacity.

Scenario B: Working Gas at Record Minimum of 742 Bcf (level as of March 2001)					
Method	Percent Full	Working Gas	Base Gas	Capacity	Remarks
1	23%	742	N/A	3,294	Capacity is AGA's maximum volume
2	18%	742	N/A	4,201	Capacity is total capacity minus reported base gas
3	61%	742	4,355	8,376	Capacity is total capacity

Note: N/A indicates not applicable.

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.

Owners and Operators of Storage

The principal owner/operators of underground storage facilities are (1) interstate pipeline companies, (2) local distribution companies (LDCs) and intrastate pipeline companies, and (3) independent storage service providers. If the facility serves the interstate market it is subject to Federal Energy Regulatory Commission (FERC) regulations; otherwise, it is State-regulated. Owners and 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.

Interstate pipeline companies operate about 55 percent of all working gas capacity in the United States (Source: Form EIA-191, *Monthly Underground Gas Storage Report*, June 2002). Underground storage is important to interstate pipeline companies directly because they depend heavily on storage inventories to facilitate load balancing and system supply management on their long-haul transmission lines. The bulk of their storage capacity, however, is leased to other industry participants.

LDCs and intrastate pipeline companies account for about 35 percent of working gas capacity. LDCs generally use gas from storage sites to serve customer needs directly, whereas intrastate pipeline companies use underground storage for operational balancing and system supply as well as the energy needs of end-use customers.

Independent operators operate about 10 percent of current working gas capacity. Many of the salt formation and high-deliverability sites currently being developed have been initiated by independent storage service operators to serve third-party customers.

Seasonal factors are less important now in the use of underground storage inventories. Market conditions play a much larger role than in the past. Since 1994, almost all of the underground storage facilities that are operated by interstate pipeline companies, which are those subject to the jurisdiction of the FERC, operate 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. Prior to 1994, the use and control of capacity at a storage facility owned by an interstate pipeline was the purview of the pipeline owner.

Today, in addition to the interstate storage sites, many storage facilities not subject to FERC jurisdiction (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. At these facilities, the use of working gas capacity has become market-oriented in addition to serving as a backup or supplemental seasonal supply source. For instance, marketers and other third parties have the opportunity to 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.

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 as a result of market restructuring. During that time, the operational practices of many U.S. underground storage sites became much more market-oriented. 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.

Reflecting the 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 are mainly salt cavern storage 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, when access to interstate underground natural gas storage became completely open, daily withdrawal capability from high-deliverability salt cavern storage facilities has grown by 62 percent and the number of sites has increased from 21 to 28. Nevertheless, conventional storage facilities continue to be very important to the industry as well. During the period between 1996 and 2000, while total U.S. storage capacity for each type of storage facility increased roughly the same percentage, the bulk of new working gas capacity and growth in deliverability is attributable to expansions at depleted field storage facilities.

The increasing influence of high-deliverability storage may affect the significance of inventory levels. For instance, because gas can be rapidly injected/withdrawn from these sites, how full they are on November 1 (the traditional start of the heating season) has less significance than inventory levels for depleted field or aquifer storage, which are designed to deplete their inventories once a heating season. For example, a high-deliverability facility with a working gas capacity of 1 Bcf and an injection/withdrawal cycle time of one month theoretically could cycle up to 12 Bcf during a calendar year. A salt cavern site that is only 50-percent full at the end of a given month could be 100-percent full, then heavily depleted, all within the following month. Thus, while the high-deliverability sites in the Producing Region make up only 11 percent of that region's total working gas capacity, the implications of that capacity for deliverability, and hence total capacity to supply markets, is much different from traditional reservoir storage. The storage operations of such a site are not dictated by the seasonal need to store gas as a backup, but rather are a function of customer needs as they occur.