Natural Gas Compressor Stations on the Interstate Pipeline Network: Developments Since 1996

This special report looks at the use of natural gas pipeline compressor stations on the interstate natural gas pipeline network that serves the lower 48 States. It examines the compression facilities added over the past 10 years and how the expansions have supported pipeline capacity growth intended to meet the increasing demand for natural gas. Questions or comments on the contents of this article may be directed to James Tobin at James.Tobin@eia.doe.gov or (202) 586-4835.

The U.S. interstate natural gas pipeline network relies on more than 1,200 natural gas compressor stations to maintain the continuous flow of natural gas between supply area and consumers (Figure 1). Compressor stations are "pumping" facilities that advance the flow of natural gas. They are usually situated between 50 and 100 miles apart along the length of a natural gas pipeline system and are designed to operate on a nonstop basis. The average station is capable of moving about 700 million cubic feet (MMcf) of natural gas per day, while the largest can move as much as 4.6 billion cubic feet (Bcf) per day.

Between 1996 and 2006, the number of natural gas pipeline compressor stations attached to the interstate mainline natural gas pipeline grid increased significantly. In 1996 there were approximately 1,047 mainline compressor stations, with installed horsepower of about 13.4 million and a combined throughput capability of approximately 743 billion cubic feet per day.[1] By 2006, these figures had grown to 1,201 mainline compressor stations, 16.9 million installed horsepower, and a throughput capability of 881 Bcf per day (Table 1). This expansion represented a 26-percent increase in installed horsepower and a 19-percent increase in throughput capacity during the period.

This growth was not driven solely by an increase in overall natural gas production and consumption during the period. In fact, compared with 1996 levels, both natural gas production and consumption in the United States in 2006 are slightly lower, although both measures increased somewhat (about a 4-percent increase by 2001 in production) during the interim.[2] Rather, a series of factors, reflecting the changing character of the U.S. natural gas industry, influenced this expansion in mainline compression facilities:

- New domestic production sources were developed in areas that required installation of new natural gas pipeline systems or expansion of existing ones.
- As domestic natural gas production reached a plateau during the 1990s, demand increased for Canadian natural gas supplies and new pipelines to transport them were created.
- Major growth in the number of large-volume natural-gas-fired electric power generating plants required additional capacity in specific markets.
- Regulatory demands to reduce the environmental footprint of compressor stations increased the scale of station revitalization and retrofits with improved technology.

Meanwhile, the decrease in U.S. natural gas production overall and the decrease in natural gas supplies flowing from declining production areas contributed to deactivating 22 mainline compressor stations and the downsizing of 45 more stations during the period. The loss in installed horsepower and/or throughput capacity from deactivation, however, was more than offset by the installation of more than 176 new compressor stations, and upgrades to over 250 other stations, throughout the national network.

Background

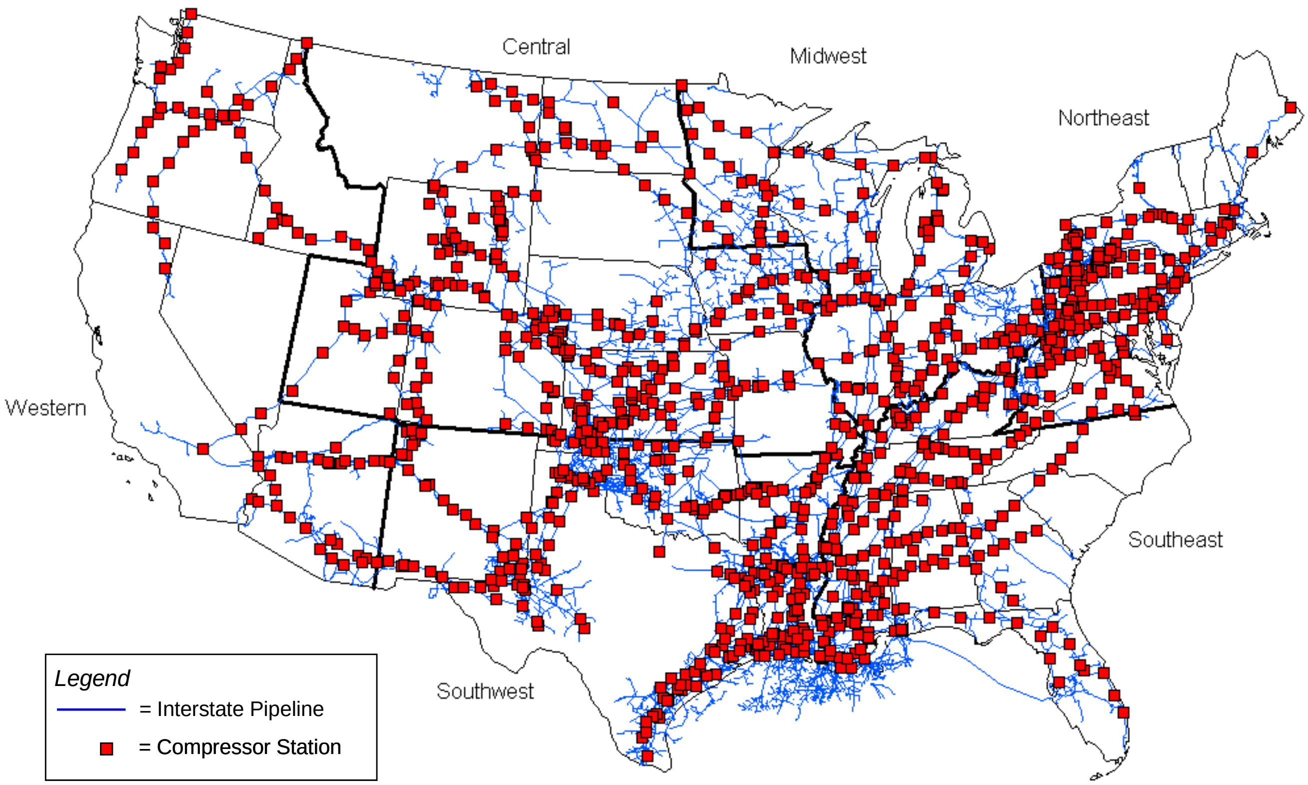
Although mainline natural gas compressor stations vary widely in size and layout, the basic components of such a station include compressor units, scrubber/filters, cooling facilities, emergency shutdown systems, and an on-site computerized flow control and dispatch system that maintains the operational integrity of the station (Figure 2).[3] Today, most compressor stations are unmanned and monitored by an off-site Supervisory Control and Data Acquisition (SCADA) system that manages and coordinates the operations of the several compressor stations that tie together a natural gas pipeline system (A) (Figure 2).

[1] Compressor stations operated by interstate pipeline companies but used in association with underground natural gas storage, field/gathering, and offshore operations were not included in this analysis.

[2] Energy Information Administration, *Natural Gas Annual*, various issues. http://tonto.eia.doe.gov/ dnav/ng/hist/n9050us2a.htm

[3] Compressor stations are also used at underground natural gas storage sites for injection and withdrawal operations and in production areas where operational wellhead pressures are not always enough to move the flow into the high-pressure mainline or gathering header systems. Compressor stations associated with field/gathering or offshore natural gas transmission often also have facilities for water removal (dehydration) and heavy hydrocarbon liquid processing which are common characteristics of the natural gas streams that enter these stations.

Figure 1. Interstate Natural Gas System Mainline Compressor Stations, 2006



Note: EIA has determined that publication of this figure does not raise security concerns, based on the application of Federal Geographic Data Committee's *Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns*.
Source: Energy Information Administration, Natural Gas Division, Natural Gas Transportation Information System, Compressor Station Database.

Almost all mainline compressor stations, except the smallest, contain multiple compressor units[4] and are designed with enough horsepower and throughput capacity to meet current firm contractual requirements levied on the system. Since most stations need to be operational 24 hours per day, 365 days a year and are unmanned, the on-site computerized flow control system (B) (Figure 2) sees to it that only the appropriate number of units required to meet current flow requirements ever operate at one time, thus optimizing operational efficiency and extending the life of the equipment.[5]

The purpose of a compressor station is to boost the pressure in a natural gas pipeline and move the natural gas further downstream.[6] Pipeline flow pressure decreases between stations because of friction between the natural gas flow and the inside wall of the natural gas pipeline and as natural gas is received and/or delivered along the route. The natural gas stream entering the station (C) (Figure 2) is passed through scrubbers and filters (D) (Figure 2) to extract any liquids that may have condensed out of the natural gas stream as line pressure decreased and to remove any particulate matter that may have formed during contact with the materials that coat the inside of the natural gas pipeline. Once the natural gas stream has been cleaned, it is directed through smaller piping segments assigned to individual compressor engines of varying horsepower and capacity (E) (Figure 2). Computers regulate the flow and number of units that are needed to handle the scheduled system flow requirements.

At the vast majority of compressor stations the compressor units operate in parallel, with the individual compressor units providing the needed additional pressure. After compression, the natural gas is directed to the cooling facilities (H)

[4]In 2006, the 1,201 operational natural gas compressor stations located on the U.S. interstate natural gas pipeline network contained more than 4,700 individual compressor units, or about 4 units per station, averaging about 3,590 horsepower per unit.

[5]One compressor station, operated by the Tennessee Gas Pipeline Company, has 23 compressor units installed, although not all operate at any one time.

[6]Based upon 1,000 compression stations for which data were available on the intake and outtake pressures, the average ramp up in pressure per station was 250 psig (pounds per square inch gauge). The highest discharge pressure was in the range of about 1,500 to 1,750 psig, primarily to 42-inch and 36-inch diameter pipelines.

Table 1. Installed Horsepower and Capacity of Mainline Compressor Stations, 1996 and 2006

Ranking	Pipeline System	Region Begins	Region Ends	Number of Stations		Total Installed (Horsepower)		Total Throughput Rating (MMcf/d)	
				1996	2006	1996	2006	1996	2006
	<u>Ten Largest Systems</u>								
1	Texas Eastern Trans Corp.	Southwest	Northeast	68	75	1,411,310	1,517,465	85,800	91,384
2	Transcontinental Gas P L Co.	Southwest	Northeast	36	47	1,139,380	1,461,031	78,555	103,250
3	Tennessee Gas Pipeline Co.	Southwest	Northeast	67	71	1,279,255	1,327,293	72,237	74,549
4	El Paso Nat Gas Co.	Southwest	Western	57	58	1,029,790	1,141,995	65,980	66,806
5	ANR Pipeline Co.	Southwest	Midwest	45	45	821,145	860,855	33,998	34,772
6	Nat Gas P L Co. Of America	Southwest	Midwest	49	50	821,825	838,450	49,421	49,785
7	Northern Natural Gas Co.	Southwest	Central	70	82	711,961	783,989	28,186	32,965
8	Southern Natural Gas Co.	Southwest	Southeast	36	40	363,851	566,280	28,770	31,216
9	Northern Border Pipeline Co.	Canada	Midwest	7	17	140,000	531,000	11,243	33,814
10	Gas Transmission Northwest Co.	Canada	Western	12	13	395,720	516,200	25,328	29,126
	Subtotal			**447**	**498**	**8,114,237**	**9,544,558**	**479,518**	**547,667**
	<u>New Systems Since 1996 (11)</u>								
23	Alliance Pipeline Co.	Canada	Midwest	0	7	0	218,400	0	10,778
29	Gulfstream Natural Gas System	Southwest	Southeast	0	1	0	113,688	0	1,130
40	Vector Pipeline Co.	Midwest	Canada	0	2	0	60,000	0	2,000
44	Destin Pipeline Co.	Southwest	Southwest	0	2	0	33,600	0	1,800
45	Maritimes & Northeast Pipeline Co.	Canada	Northeast	0	2	0	33,244	0	847
46	Transcolorado Gas Trans Co.	Central	Southwest	0	5	0	33,149	0	2,087
47	Guardian Pipeline Co.	Midwest	Midwest	0	1	0	25,080	0	750
49	Cheyenne Plains Pipeline Co.	Central	Central	0	2	0	22,164	0	930
52	North Baja Pipeline Co.	Western	Mexico	0	1	0	21,084	0	500
55	Tuscarora Pipeline Co.	Western	Western	0	3	0	17,076	0	469
58	Horizon Pipeline Co.	Midwest	Midwest	0	1	0	8,900	0	534
	Subtotal			**0**	**27**	**0**	**586,385**	**0**	**21,825**
--	**Other Systems (41)**[1]	--	--	**600**	**676**	**5,236,624**	**6,749,402**	**263,527**	**311,980**
Total				**1,047**	**1,201**	**13,350,861**	**16,880,345**	**743,045**	**881,472**

[1]Includes all other interstate natural gas pipeline systems operating mainline compressor stations that are not listed above.
Note: Only interstate natural gas pipeline systems with mainline compressor stations are included. Does not include compressor stations associated with underground natural gas storage or field/gathering operations. MMcf/d = million cubic feet per day.
Source: Federal Energy Regulatory Commission (FERC), FERC Form-567, "System Flow Diagram;" FERC Forms 2 & 2A, "Annual Report of Natural Gas Pipeline Companies."

(Figure 2) and finally returned to the transmission mainline (I) (Figure 2) with full operational pressure restored.

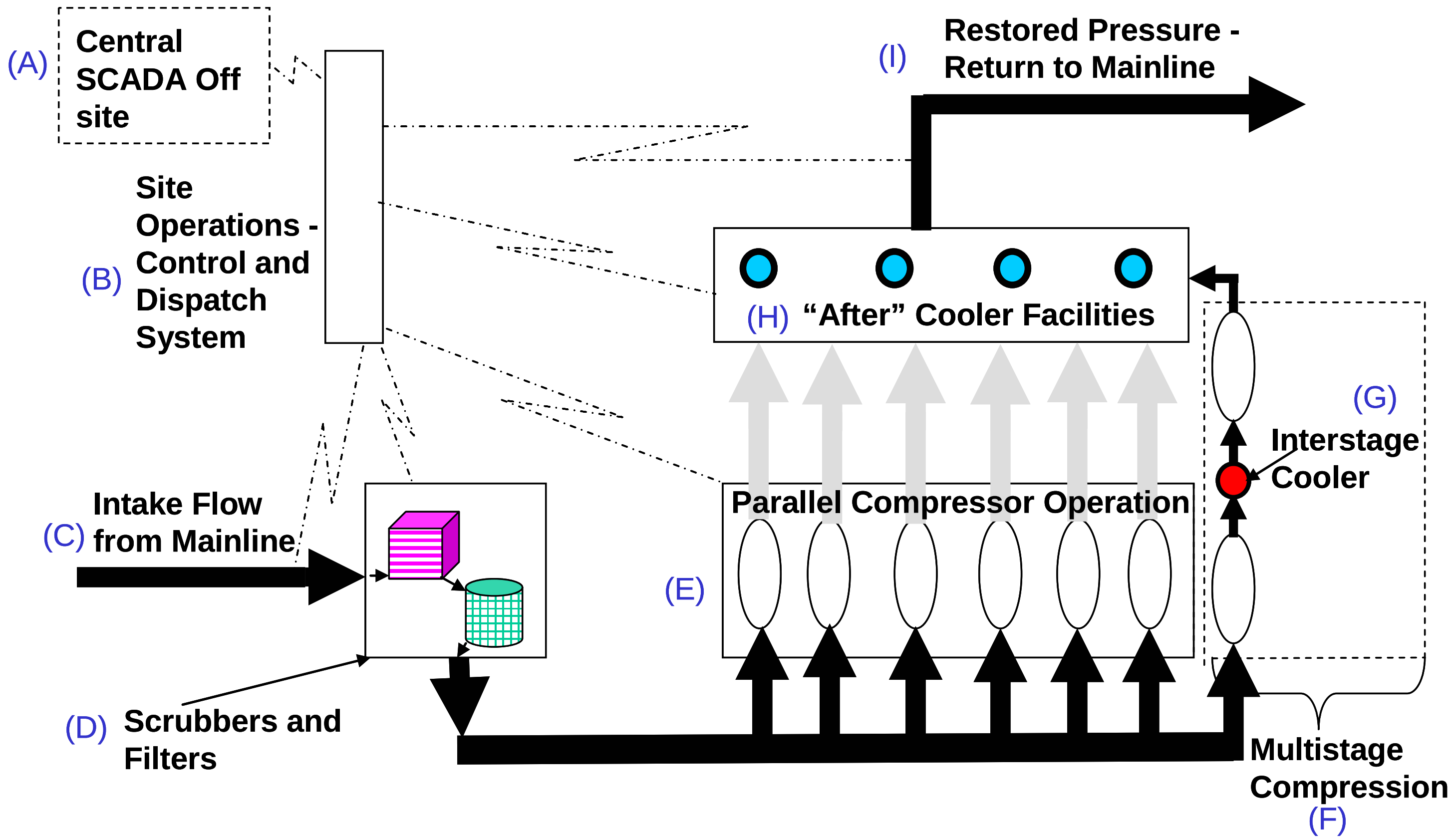
When the required boost in pressure is very high and the compression ratio exceeds a specified level,[7] several compressor units are operated in stages (serially) to achieve the desired pressure (F) (Figure 2). Because this process results in the natural gas being heated to a very high temperature, an interim cooler unit is used between each stage (G) (Figure 2).

As the natural gas is compressed, the heat that is generated must be vented and the natural gas stream cooled before reentering the mainline system (H) (Figure 2). If the temperature of the natural gas stream reentering the mainline exceeds a specified level, the potential for corrosion to the inside of the natural gas pipeline may increase and damage to materials used to coat the pipeline may occur. Most compressor stations have an aerial cooler system to dissipate excess heat from the natural gas stream as it exits the compression process (an "After" cooler). The heat generated by the operation of the individual compressor units is dissipated via a sealed jacket (coolant) water system and through the circulating lubrication fluid system, the heat level of which is lowered via an atmospheric cooler unit.

Two types of compressors are in use today, reciprocating and turbine engines. The majority, natural-gas-fired high-speed reciprocating engines conform to the basic compressor station unit design originating in the first half of the 20th century. Natural gas turbine units with centrifugal compressors did not appear until the second half of the century. Both types of units are periodically retrofitted to include the newest technology. In many instances, the objective of this revitalization and redesign is not to increase throughput capacity *per se*, but rather to increase efficiency and safety, with an emphasis on minimizing greenhouse gas emissions and site contamination.

[7]For a technical discussion of this and other aspects of compression operations, see Dr. Chi U. Ikoku, *Natural Gas Engineering: A Systems Approach*, (PennWell Books, Tulsa, Oklahoma, 1980), Chapter 5.

Figure 2. Generalized Compressor Station Schematic



Note: Most compressor stations are either parallel or multistage operations.
Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division

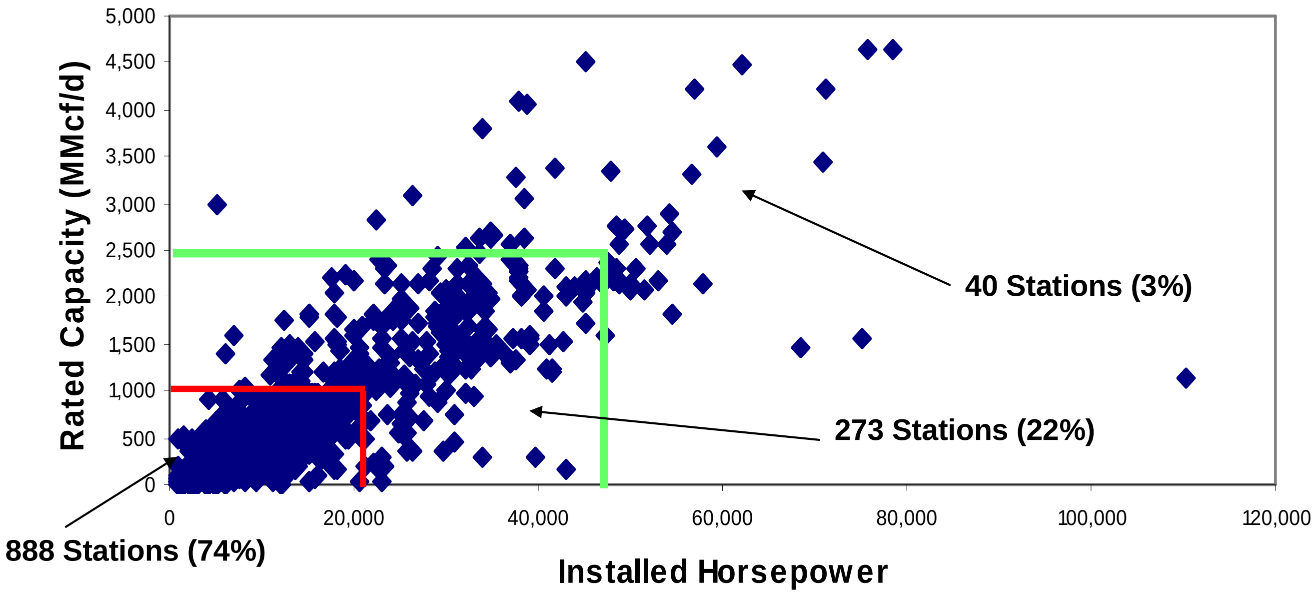
Most compressor stations are fueled by a portion of the natural gas flowing through the station, although in some areas of the country, all or some of the units may be electrically powered primarily for environmental or security reasons. All compressor stations are also equipped with emergency shutdown systems that can detect abnormal conditions such as an unanticipated pressure drop or natural gas leakage. These systems are designed to automatically shut down the engines, isolate and vent the affected piping, and direct the natural gas flow from the main part of the station.

Although the large-scale compressor stations generally associated with the major interstate "trunklines" stand out in terms of installed horsepower and throughput capacity, most compressor stations are relatively small-scale operations. For instance, about three-fourths of all compressor stations have an installed horsepower level below 20,000 and a throughput capacity of less than 1 Bcf per day (Figure 3). The prevalence of smaller scale compressor stations reflects the large number of "grid" type interstate natural gas pipeline systems that operate within established regional markets such as the Northeast, Midwest, or Southeast.[8] Moreover, compressor stations located on grid-type systems tend to be designed with less horsepower because operational line pressures are less, average capacity is lower, and much of the system consists of thinner-walled, smaller-diameter natural gas pipelines.

The predominance of small-scale compressor stations is also reflected in the spread between the mean (average) and median (half are above, half are below) horsepower capacity rating of the 1,201 compressor stations. The influence of the large-scale "trunkline" compressor stations can be seen in an overall average installed horsepower rating of 14,055 versus a median of 8,900 horsepower and an average throughput capacity rating of 734 MMcf per day versus a median of 430 MMcf per day (Table 2). On the other hand, the 313 larger-scale compressor stations, while comprising only 25 percent of all compressor stations (Figure 3), account for more than

[8] Grid-type pipeline systems are characterized by their network of many laterals, interconnections, and delivery points operating within a localized market area or region. Trunkline systems, on the other hand, are usually relatively straight-lined, large-diameter, long-distance pipelines that generally link major supply areas to consuming market areas. Some major intestate natural gas pipelines possess characteristics of both.

Figure 3. Relationship of Installed Horsepower and Throughput Rating, 2006



MMcf/d = million cubic feet per day.
Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division Gas, Gas Transportation Information System

57 percent of both installed horsepower and total throughput capacity in the lower 48 States.

Upgrades and Expansions

When a new long-distance natural gas pipeline system is designed and built, the number and capacity of associated compressor stations is a key design feature. After the natural gas pipeline system becomes operational, periodic increases in transportation demand may occur, requiring an expansion of the current system. In many instances, this expansion is achieved by adding new compressor stations, upgrading existing stations with additional compressor units, or replacing smaller capacity units with larger ones.

Of the more than 290 natural gas pipeline expansion projects completed between 1996 and 2006, about 195, or two-thirds, involved adding compression to expand capacity on an existing natural gas pipeline system.[9] Of these 195 projects, 78 were strictly compressor station upgrades or additional stations, while the remainder were in conjunction with other expansion methods such as looping (i.e., adding parallel pipe).

One of the largest expansions of natural gas pipeline compression during the period occurred on the natural gas transportation corridor[10] that moves natural gas from the Southwest Region to the Northeast Region (Figure 1 and Figure 4, Corridor 2).[11] Throughput capacity grew by 39 Bcf per day while installed horsepower increased by 653,000 (Figure 5). Expansion to support the installation of new natural-gas-fired electric generating plants in the Northeast Region contributed heavily to this growth.

Other major expansions of compressor station capabilities occurred on natural gas transportation Corridors 7, 8, and 9, which flow natural gas from Canada (Figure 4), as that supply source helped alleviate some of the growing deficit between U.S. natural gas demand and domestic natural gas production.

[9]Energy Information Administration, Natural Gas Division, Gas Transportation Information System, Natural Gas Pipeline Projects database.

[10]Although the national natural gas pipeline network is made up of a number of individual pipeline systems, most can be grouped in 11 somewhat distinct transportation corridors.

[11]The largest numbers of compressor stations in the United States operate within this natural gas transportation corridor that extends from the areas of East Texas, southern Louisiana, and the Gulf of Mexico. More than 320 compressor stations, one-quarter of all mainline compressors stations on the interstate natural gas pipeline grid, can be found along this corridor. Between 1996 and 2006, expansions to existing stations and installation of new station capacity/horsepower along this route increased by about 14 percent (Figure 5).

Table 2. Summary of Installed Horsepower and Capacity of Mainline Compressor Stations by Transportation Corridor, 2006

Corridor (Map Key)	Region Begins	Region Ends	Number Stations	Installed Horsepower	Average Horsepower per Station	Median Horsepower Rating	Total Rating Capacity (MMcf/d)	Average Rating per Station	Median Capacity Rating
1	Southwest	Southeast	123	1,463,159	11,896	7,980	69,838	568	400
2	Southwest	Northeast	326	5,429,934	16,656	10,170	319,627	980	527
3	Southwest	Midwest	195	2,667,398	13,679	10,700	132,837	681	595
4	Southwest	Midwest	164	1,915,342	11,679	8,060	86,981	530	336
5	Southwest	Western	90	1,540,793	17,120	12,000	84,345	937	675
6	Canada	Western	49	895,972	18,285	6,350	43,617	890	405
7	Canada	Midwest	93	1,608,261	17,293	8,625	85,375	918	407
8	Canada	Northeast	25	243,062	9,722	8,350	11,758	470	477
9	Canada Offshore	Northeast	4	46,393	11,598	8,150	1,696	424	354
10	Central	Western	43	479,730	11,157	5,500	22,177	516	208
11	Central	Midwest	89	590,301	6,633	4,500	23,222	261	150
Total			**1,201**	**16,880,345**	**14,055**	**8,900**	**881,472**	**734**	**430**

Note: Map key found on Figure 4. Does not include compressor stations associated with underground natural gas storage or field/gathering operations. MMcf/d = million cubic feet per day.

Source: Federal Energy Regulatory Commission (FERC), FERC Form-567, "System Flow Diagram;" FERC Form 2 & 2A, "Annual Report of Natural Gas Pipeline Companies."

Major Reasons for Growth

Shifts in Domestic Production

Natural gas production growth in previously underdeveloped areas since 1996 created a need for new take-away natural gas transportation capacity for producers to get their product to market. For instance, increasing development of reserves in the Green River Basin of western Wyoming in conjunction with a rising demand for natural gas in the Las Vegas, Nevada, metropolitan area (mainly to meet new natural-gas-fired electric generating plant demand) led to an expansion of the Kern River Transmission system through compression and looping in 2003. Compressor station throughput capacity and installed horsepower on the Kern River Transmission system more than doubled as a result (Figure 5, Corridor 10).

Colorado/Wyoming production expansion also spurred compression growth in other directions

In the same general area, expanding natural gas production in the Powder River Basin of eastern Wyoming and the Piceance Basin of western Colorado also increased demand for additional natural gas pipeline capacity along Corridor 11, which extends from the Cheyenne Hub in eastern Colorado to interconnections with major interstate natural gas pipeline systems delivering to the Midwest Region. Although it is one of the smaller transportation corridors, since 1996 installed horsepower on this route has increased by 75 percent, with 17 new compressor station installations and 20 station upgrades.

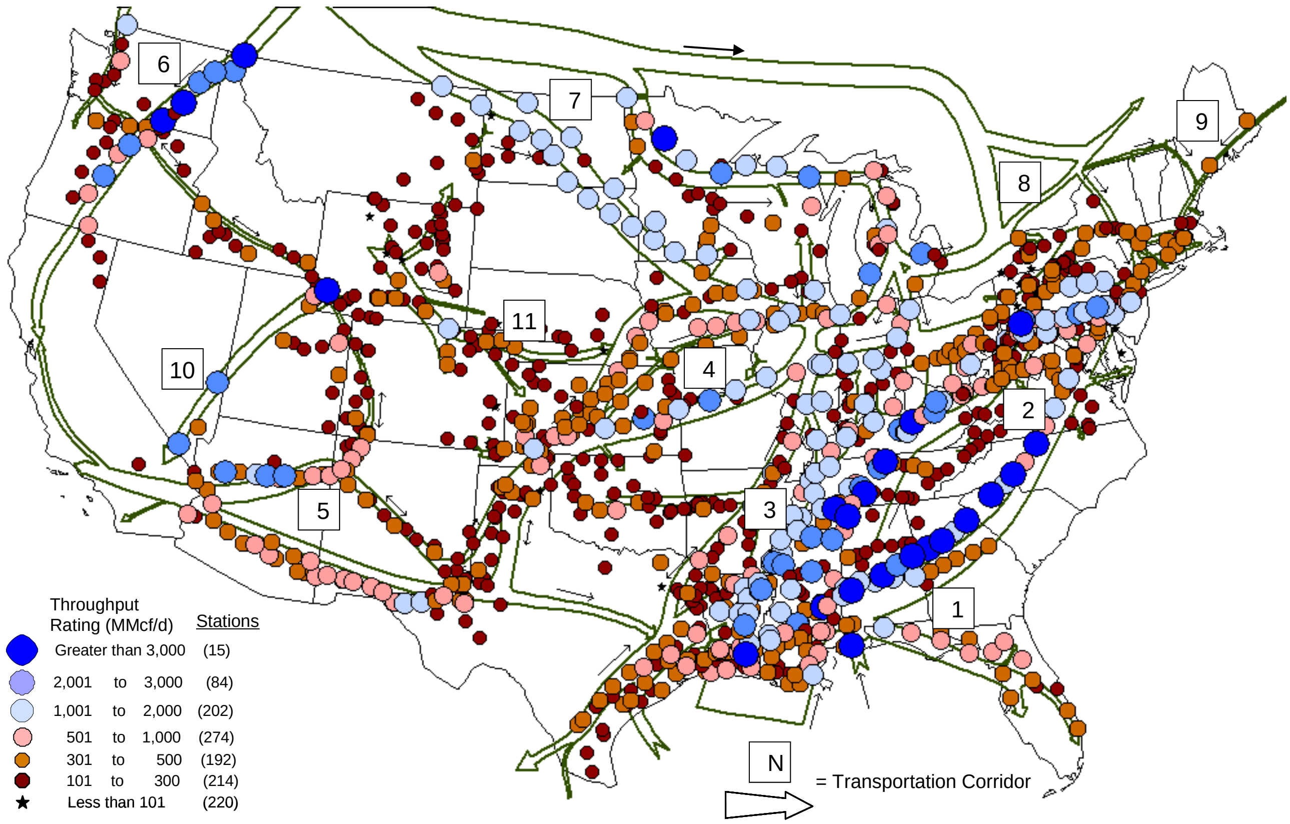
However, an even greater expansion of Corridor 11 is in progress. The Kinder Morgan Rockies Express pipeline system, which will be built in phases through 2009, will increase take-away capacity from the Cheyenne Hub by 1.5 Bcf per day. This new natural gas pipeline system, which will extend eastward to eastern Ohio and perhaps further east, will have at least seven new compressor stations along its route, with an initial installed rating of 236,000 horsepower, an increase of 40 percent along the corridor. A preliminary phase of the Rockies Express system, which began operations between the Piceance Basin production area of western Colorado and the Cheyenne Hub in early 2007, included the installation of three additional compressor stations in the area.

In the southern portion of the Rocky Mountain area, expanded natural gas production in the San Juan Basin of southern Colorado and northern New Mexico created a need for transportation capacity along Corridor 5, which consists primarily of the northern operations of the Transwestern Pipeline Company and the El Paso Natural Gas Company (Figure 4). In addition, El Paso Natural Gas Company expanded compression facilities on its southern system to meet the increased demand for natural gas in Arizona and enable shippers to connect with the newly-built North Baja Pipeline system that exports natural gas to Mexico.

Production shifts in the Southwest Region not only created compression increases but declines as well

Natural gas production has leveled off in recent years in portions of the Southwest Region, including along the southern portion of Corridor 4 (Figure 4). As production leveled off, more than 20 compressor stations were downsized and 12 deactivated, while only 21 were upgraded/expanded. And, although 10 new compressor stations were added between 1996 and 2006, the net increase in installed horsepower along the corridor was only 3 percent (Figure 5), while rated throughput capacity increased even less, by only 2 percent. Indeed, most of the added compression along this corridor occurred at its northern end, east of where it ties in with Corridor 11 and within the Central and Midwest Regions.

Figure 4. Distribution of Compressor Station Throughput Capacity Levels on the Interstate Natural Gas System Corridors, 2006



Note: EIA has determined that publication of this figure does not raise security concerns, based on the application of Federal Geographic Data Committee's *Guidelines for Providing Appropriate Access to Geospatial Data in Response to Security Concerns*.
MMcf/d = million cubic feet per day.
Source: Energy Information Administration, Natural Gas Division, Natural Gas Transportation Information System, Compressor Station Database.

While natural gas production in areas of the Southwest Region reached a plateau or even declined somewhat, two production bright spots emerged that generated a need for additional capacity and compression in the region: the Gulf of Mexico and the Fort Worth Basin area of northeast Texas. The increasing natural gas production from these two areas resulted in the addition of 18 new compressor stations and upgrades to 23 stations between 1996 and 2006 in the adjacent areas (most of which served Corridors 2 and 3).

Little new interstate natural gas pipeline capacity developed, however, as production shifted. Most new demand for exit capacity was satisfied through available unused interstate capacity or through additions to compression. But, as the level of development and production expansion in these areas continues unabated, localized constraints on interstate exit capacity are developing, especially in east Texas and northern Louisiana. Indeed, during the past several years proposals to build several new interstate systems, or to extend current ones, have been made to carry Southwest Region natural gas to the Midwest, Southeast, and the Northeast. In fact, several projects have been approved and one was recently completed (May 2007).[12]

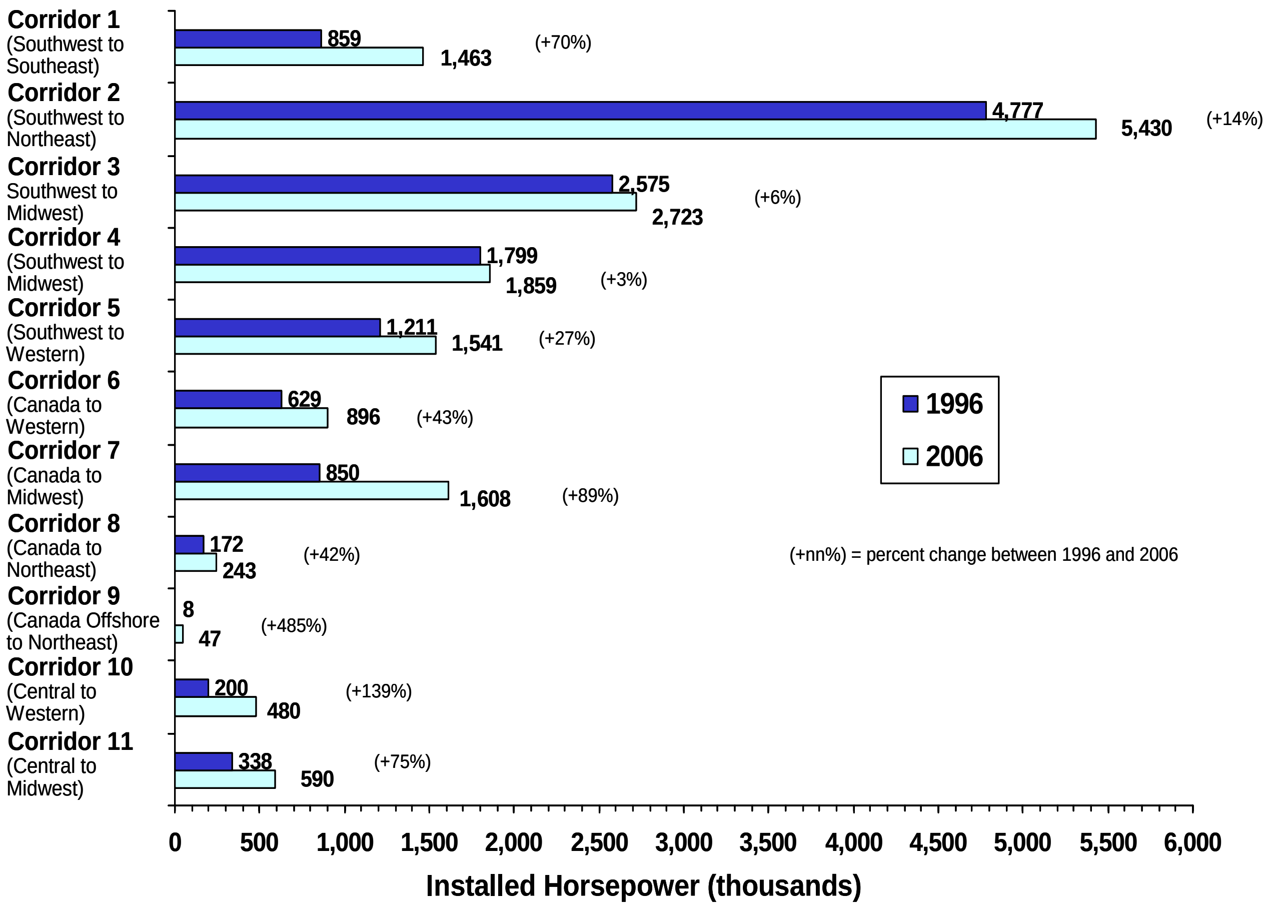
Increasing Demand for Canadian Imports

In 1996 Canadian natural gas supplies accounted for almost 13 percent of total annual U.S. natural gas consumption, a large increase from the 5 percent as late as 1986. Between 1986 and 1996, this growth in crossborder flow was due to the building of several new large scale natural gas import pipeline systems and with the expansion of existing import systems through increased compression and/or looping.

The new natural gas pipelines that were built during that time included the Iroquois Transmission System and the Empire Pipeline System flowing into New York State and the Northern Border Pipeline System flowing into the Central and Midwest regions.

[12] In April 2007, Centerpoint Energy Transmission Inc. inaugurated service on its 172-mile, 1.2 Bcf/d, Carthage-Perryville (CP Line) interstate pipeline connecting the Carthage area in east Texas with other interstate pipelines located in Perryville, Louisiana.

Figure 5. Installed Horsepower on Natural Gas Transportation Corridors, 1996 and 2006



Note: Refer to Table 2 and Figure 4 for related throughput capacity and flow direction.
Source: Energy Information Administration, Natural Gas Division, Natural Gas Transportation Information System, Compressor Station Database.

Expansions of existing natural gas pipeline import systems during the period of 1980-1996 included the upgrading of the Northwest Pipeline Company and the Gas Transmission Northwest Corporation (formerly Pacific Gas Transmission) systems in the Western Region, the Viking Transmission and the Great Lakes Transmission systems in the Midwest Region, and the Tennessee Gas Pipeline import facilities in New York State.

New natural gas import pipelines were installed, and existing ones were expanded

Between 1996 and 2002, 3 new natural gas import and/or export pipelines systems, with 11 compressor stations and an installed horsepower rating of almost 312,000 horsepower (9 percent of the overall increase in installed horsepower during the period) were placed in service (Table 1). Meanwhile, 14 new compressor stations were added and 289 upgraded on several existing natural gas import systems. However, Canadian natural gas imports peaked at 3.8 trillion cubic feet (16.5 percent of total annual U.S. natural gas consumption) in 2002, after which the level of natural gas pipeline import capacity expansion activity slowed significantly. [13]

Greater demand for natural gas in the New England States in the 1990s provided the incentive for the installation of two new import pipeline systems in 1999. Although the majority of natural gas supply into the Northeast Region still flows from the Southwest Region over Corridor 2, the region now is also served by the Maritimes and Northeast Pipeline System and the Portland Natural Gas Transportation System, which transport supplies from Canada along Corridor 9

[13] As of August 2007 four pipeline expansion projects have been announced that would impact Canada/U.S. natural gas transportation levels. Two of them (scheduled for 2007 and 2009) deal with compression expansions on the Vector Pipeline system that would increase import/export capabilities between Michigan and Ontario, Canada. The others (2008 and 2010) are to increase compression on the Maritimes and Northeast Pipeline system to bring gasified liquefied natural gas (LNG) from Canadian/U.S. LNG import facilities to New England.

(Figure 4).[14] The former transports natural gas from offshore eastern Canada (Sable Island), while the latter transports natural gas from western Canada to the same general service territory.

Although Corridor 6, which links the Western Region to Canadian supplies, did not have as large a percentage increase in compressor station capabilities as the other import corridors, six new compressor stations were added and installed horsepower increased by 43 percent. The several systems that bring natural gas from Alberta and British Columbia, Canada, through the States of Washington, Idaho, and Oregon to termination points in Nevada and California increased installed horsepower by 267,000 and throughput capacity by 10 percent, or 0.6 Bcf per day, from 1996 to 2006.[15]

The Midwest Region was the major benefactor of Canadian export expansion

The steady growth in natural gas demand in the Midwest Region between 1996 and 2006, largely to support the increasing natural-gas-fired electric generating capacity in the region, was mainly satisfied through an expansion of natural gas import transportation capacity.[16] Between 1996 and 2006, natural gas pipeline capacity on Corridor 7 more than doubled, rising from 4.4 Bcf per day in 1996 to 7.4 Bcf per day in 2006.

Driving this growth was the addition of 27 new compressor stations, which created an 89-percent increase in total installed compressor station horsepower between Canada and the Midwest Region. Moreover, average horsepower per station increased from 12,878 in 1996 to 17,293 in 2006, up 34 percent, while throughput capacity per station increased from 701 MMcf per day to 918 MMcf per day, up 31 percent (Table 2).

Major contributions to these increases included the tripling of both capacity and installed horsepower on the Northern Border Pipeline system (import) between 1996 and 2006, adding 10 new compressor stations, and upgrading the remaining 7 stations, which significantly increased transportation of western Canadian natural gas supplies to the Midwest Region. The addition of the Alliance Pipeline system in 2000, with its seven compressor stations, increased the installed horsepower and throughput capacity along Corridor 7 by an additional 27 percent (Table 1).

Today, as a result of the expansion of natural gas pipeline import capacity into the Midwest Region, the combined capabilities of the natural gas pipelines operating along Corridor 7 currently rank fourth among all corridors (sixth in 1996) in installed horsepower and throughput capacity. Indeed, during the 10-year period, throughput capacity along Corridor 7 increased 85 percent while installed horsepower rose 89 percent (Figure 5).

Expansion of Natural Gas-Fired Electric Generating Capacity

A driving force behind the expansion of interstate natural gas pipeline systems and the upgrading of many compressor stations during the past 10 years has been the installation of new natural gas-fired electric generating plants throughout the United States. Spurred by the relatively low cost level of new gas burning facilities and the low natural gas prices in the mid- and late-1990s, coupled with the desire to build more environmentally-friendly, low-emission facilities, the number of natural-gas-fired electric generating units grew by about 820, with total nameplate capacity increasing by 225,000 megawatts between 1996 and 2006.[17] That represented an increase of more than 103 percent in natural-gas-fired generating capacity over what was in place in 1996.

It is estimated that the creation of this amount of additional generating capacity necessitated an increase in overall natural gas pipeline capacity on the interstate network of approximately 31.5 Bcf per day.[18] This figure accounts for about one-third of the approximately 100 Bcf per day total new capacity added to the national natural gas pipeline network between 1996 and 2006.[19]

The use of natural gas to generate electric power increased from 13 percent of total electricity generation in 1996 to about 19 percent in 2005. Among the largest users of natural gas for power generation currently are the States of Texas, California, Florida, Louisiana, New York, and Illinois. The vast majority of natural-gas-fired electric generating plants, with the exception of those in Texas and Louisiana, are almost totally dependent upon the interstate natural gas pipeline network for their supplies of natural gas. New York

[14]The Portland Natural Gas System does not include any compressor stations of its own and is therefore not included in Table 1. System pressure is maintained by compression from the upstream TransCanada Pipeline system, which delivers supplies into its system at the Canadian border.

[15]At the U.S./Canada border imports are transferred to Northwest Pipeline Company (in Washington State) and Gas Transmission Northwest (in Idaho). The two pipelines operate a total of 49 compressor stations with an installed horsepower of 896,000 horsepower and a combined throughput capacity of 44 Bcf per day.

[16]The Midwest Region receives its natural gas supplies from four separate supply areas: the Gulf Coast, the Texas Panhandle, the Rocky Mountain area, and Canada. By far the largest current source of supply for the region remains the Gulf Coast.

[17]About 2,095 new natural-gas-fired units were added during the period but 1,276 smaller, less efficient, units were also retired. See Energy Information Administration, Form EIA-867, "Annual Nonutility Power Producer Report" and Form EIA-860, "Annual Electric Generator Report," for 1996 and Form EIA-860, "Annual Electric Generator Report," for 2006 (preliminary data).

[18]This estimate is based on the assumption that each additional 100 megawatt generating unit will require approximately 14 million cubic feet per day of natural gas to operate at an assumed capacity factor of 60 percent.

[19]Energy Information Administration, Natural Gas Division, Gas Transportation Information System, Natural Gas Pipeline Projects database.

natural-gas-fired electric generating facility users depend on supplies of natural gas from the Southwest Region, via Corridor 2, and, to a lesser degree, on Canadian supplies off Corridor 8.

In the Northeast Region, Pennsylvania led the way

Compressor station expansion on Corridor 2 between 1996 and 2006 was particularly dynamic, with a significant portion associated with the addition of new natural-gas-fired electric generating capacity in the Northeast Region. While New York and New Jersey, the locations for the majority of the natural gas-fired generating units in the Northeast Region, increased their number and overall generating capacity in their respective States, only Pennsylvania exhibited a major shift in electric generation resources. Between 1996 and 2006, natural-gas-fired generating capacity in the State grew from 3,600 megawatts to 11,000 megawatts, increasing by 197 percent.

The established natural gas pipeline systems along Corridor 2 responded to this need mainly by adding compression and looping along their existing routes. Actively expanding its compressor station base along this corridor was the Texas Eastern Transmission Company. During the 10-year span, the company added seven new compressor stations to its system while upgrading eight more. At least four of the nine expansion projects it completed in Pennsylvania during the period were associated with installing deliverability to new natural-gas-fired electric generating plants.

The Transcontinental Gas Pipeline Company, which not only extends into the Northeast Region but is also a major deliverer of natural gas to the coastal States of Georgia and the Carolinas in the Southeast Region, completed a total of 18 natural gas pipeline expansion projects during the period, encompassing both regions. These projects included upgrades to 17 of its existing 36 compressor stations and the installation of 11 new stations (Table 1). Ten of these expansion projects increased capacity to or within States in the Southeast Region while eight increased capacity to or within the Northeast Region.

Regional demand in the Southeast Region fostered major compression additions

The largest regional increase in natural-gas-fired electric generating capacity between 1996 and 2006 occurred in the 10 States that comprise the Southeast Region (Figure 1). More than 62,000 megawatts of generating capacity, a 182 percent increase, were added within the region. In fact, all 10 States more than doubled, and some tripled, their natural-gas-fired generating capacity, with Georgia and Kentucky showing the largest percentage increases. Florida, Georgia, and Mississippi showed the largest absolute gains in generating capacity within the region.

Growing consumer demand and new natural-gas-fired electricity generating capacity in the Southeast Region during the period are reflected in the changes that occurred in the level of compressor station capabilities along Corridor 1 (Figure 5). Between 2001 and 2004, Florida Gas Transmission Company completed six projects that added more than 1 Bcf per day of capacity on its system between Texas and Florida. This expansion included the installation of 6 new compressor stations, and upgrades to 10 others, along the extent of its system.

Also initiating deliveries of natural gas to the Florida marketplace was the new subsea Gulfstream Natural Gas system that runs between the Alabama/Mississippi coastlines to Florida via the Gulf of Mexico. Although the Gulfstream system currently has only one compressor station, located in Alabama, that station has the largest installed horsepower of any single station in the lower 48 States, 113,000 horsepower.[20] A major portion of the Gulfstream system is dedicated to supplying natural-gas-fired electric generating plants in central Florida.

Midwest and Western regional systems also benefited

The Midwest Region experienced the third largest increase in added natural-gas-fired electric generating capacity in the Nation between 1996 and 2006, increasing more than 300 percent while adding almost 42,000 megawatts of nameplate capacity. This explains in large part why the region was a key recipient of increased natural gas import capacity from Canada. The State of Illinois, a key delivery point for several major natural gas import pipelines such as the Northern Border Pipeline and Alliance Pipeline systems, and the home of the Chicago (natural gas) Hub, installed almost 13,200 megawatts of natural-gas-fired generating capacity, a 341 percent increase over its 1996 capacity level.

While overall natural-gas-fired electric generating capacity in the Western Region increased by a relatively low 78 percent, increasing from 40,000 megawatts in 1996 to 70,000 in 2006, additions in the State of Arizona exceeded 300 percent. This growth in natural-gas-fired electric generating capacity resulted in additional demand for shipping capacity on the Transwestern Gas Pipeline and the El Paso Natural Gas systems, the two major operating natural gas pipelines in the State. Although not all of the compressor upgrades made by these two natural gas pipeline systems between 1996 and 2006 can be attributed to satisfying this demand sector, 14 of their compressor stations in New Mexico and Arizona were upgraded overall. In addition, the Questar Southern Trails Pipeline, which flows from the San Juan Basin to the California State border and which does not have any compressor stations of its own, delivers a major portion of its

[20] The station includes three compressor units, two of which are usually operating while the other is on standby.

87 MMcf per day capacity to natural-gas-fired electric generating customers in Arizona.

Retrofitting and Replacement

In addition to upgrading their compressor stations to increase overall system capacity, natural gas pipeline companies also find it necessary to retrofit their older compressor stations periodically and put in more efficient and environmentally-friendly technology. Indeed, the vast majority of mainline compressor stations currently in operation are at least 30 years old.[21] Although scheduled routine maintenance (e.g., parts replacement) is all that is usually needed to maintain operational status, in many instances natural gas pipeline operators will also upgrade an older station to improve its reliability and potential.

Such improvements are reflected most often in an adjustment in installed horsepower and/or change in the number of compressor units, without any design change in throughput capacity. For instance, adding multiple units to replace larger single units at a compressor station can often provide additional operational flexibility to match variations in flow demands. Moreover, the newer units are usually more efficient, using less fuel in their operations.

These newer units are usually markedly quieter, thus reducing noise pollution. In addition, these units produce less greenhouse gas emissions, thereby avoiding the need to add separate emission abatement equipment. Other changes that also may be undertaken to mitigate environmental problems include changes in the type of engine lubricants and improvements to cooling apparatus.

In most instances, minor improvements can be undertaken during periods of routine maintenance allowed under a "blanket certificate" granted by the Federal Energy Regulatory Commission (FERC), as long as the estimated cost does not exceed $10 million.[22] However, upgrades such as modifying unit arrangements or replacing units, with an estimated cost between $10 and $28 million, are subject to prior-notice review procedures. Prior-notice procedures give the FERC and other interested parties an opportunity make certain that the project does not negatively affect rates and services or have an adverse effect on the environment, while allowing the company to proceed quickly. However, if the total cost of the proposed upgrade exceeds $28 million, the company must file a formal certificate application with the FERC and undergo the full review process before gaining approval to incorporate the design changes and proceed with the upgrade.

It is difficult to pinpoint precisely how many compressor stations were upgraded without expansion during the past 10 years. Most often these types of improvements do not necessarily translate into increased installed horsepower and/or throughput capacity. However, at least 57 compressor stations had changes in installed horsepower without any change in throughput capacity. In those cases, most likely newer compressor units were installed to replace older models but overall station capabilities (design flow capacity) did not change. Furthermore, it is likely that at least some fraction of the 732 compressor stations (of the 1,047 existing compressor stations) where no change in either installed horsepower or throughput capacity was indicated underwent some non-identifiable upgrading during the period.

Conclusion

Mainline natural gas pipeline compressor stations (Figure 6) constitute a very significant portion of the infrastructure that makes up the national interstate natural gas pipeline network in the lower 48 States. Indeed, in 2005, the interstate natural gas pipelines that owned and/or operated mainline compressor stations reported plant costs or investment expenditures of more than $15 billion for compressor station equipment, second only to the $50 billion they reported as invested in natural gas transmission pipeline.[23] (Interstate operators also reported investments of more than $1.7 billion in underground storage compressor equipment and $66 million in field and plant compressor equipment).

Since 1996, when reported investment in mainline compressor equipment stood at only $9.4 billion, the number of interstate natural gas pipeline compressor stations has increased from approximately 1,047 mainline compressor stations to 1,201 (in 2006). This installation of new compressor stations and the expansion and upgrade of more than 250 existing stations created a 26-percent increase in installed horsepower and a 19-percent increase in throughput capacity during the period (Table 1).

Further increases in compressor station infrastructure are expected over the next several years. For instance, based upon the more than 182 natural gas pipeline projects currently (as of August 2007) proposed for completion between the end of 2007 and 2010, 42 new compressor stations and 53 expansions of existing stations may be finished during the period.[24] Of the 182 projects, 36 of these affect interstate compressor stations and, although there are

[21] Compressor and Pump Station Research Report Forum December 11-12, 2003, Washington, DC, http://primis.phmsa.dot.gov/rd/mtgs/121103/Facilities/RD_Forum_12-11-03_Facilities_PRCI_Compressor.pdf

[22] A blanket certificate is granted to pipeline companies that previously obtained a certificate of public convenience and necessity under section 7 of the Natural Gas Act. Blanket certificates allow a pipeline company to improve or upgrade its existing facilities, or construct certain new facilities, without the need for further case-by-case certificate authorization.

[23] Federal Energy Regulatory Commission (FERC), FERC Form 2 & 2A, 2005 & 1996 Databases. http://www.ferc.gov/docs-filing/eforms/form-2/data/2005/gas-plant.xls

[24] Energy Information Administration, Natural Gas Division, Gas Transportation Information System, Natural Gas Pipeline Projects database.

no final design specifications on horsepower or individual station throughput capacity yet available on most of these proposed compressor station updates, the overall expansion capacity of the associated projects will be approximately 17 Bcf per day.

Even though all of the proposed projects are not directly associated with interstate natural gas pipelines, six of the 182 projects are intrastate natural gas pipeline projects being developed in conjunction with expansions to the interstate network. These intrastate natural gas pipeline projects are located in east Texas and in the Rocky Mountain area of Wyoming and Colorado where natural gas production levels are steadily expanding. The additional compression that will be installed as part of these projects will help transport more natural gas production from the Barnett Shale play in east Texas, the Piceance/Unita Basin of western Colorado, and the Green River/Powder River basins of Wyoming to an expanding interstate pipeline system network.

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Figure 6. Intake View of a Large-Scale Natural Gas Compressor Station

Mainline natural gas pipeline entering the Gallion Compressor station near DeMopolis, Alabama, with a view of the scrubber towers and filter units used to eliminate contaminates prior to compression operations.
Courtesy Southern Natural Gas Company, El Paso Corporation.