

Information Circular 9342

Helium Resources of the United States, 1991

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Bcf billion cubic foot

MMcf million cubic foot

Btu British thermal unit

psia pound per square inch, absolute

°F degree Fahrenheit

Tcf trillion cubic foot

HELIUM RESOURCES OF THE UNITED STATES, 1991

By John E. Hamak¹ and Brent D. Gage¹

ABSTRACT

The U.S. Bureau of Mines estimates the identified helium resources of the United States at 630 Bcf as of December 31, 1990. This includes 295 Bcf of demonstrated reserves, 87 Bcf of demonstrated marginal reserves, and 42 Bcf of demonstrated subeconomic resources. The identified resources include 161 Bcf of helium in inferred and marginal reserves and 45 Bcf in inferred subeconomic resources. The identified helium resources contained on Federal lands are approximately 170 Bcf, including 32 Bcf in underground storage in the Cliffside Gasfield near Amarillo, TX. In addition to the identified helium resources, undiscovered helium resources in the United States are estimated at a most likely volume of 103 Bcf, with a maximum volume of 259 Bcf and a minimum volume of 41 Bcf. Also reported are 43 Bcf of helium in nonconventional and low-helium-content natural gases.

Current extraction of helium in the United States occurs mostly from natural gases produced from the Hugoton gas area in Kansas, Oklahoma, and Texas, and the Riley Ridge area in southwest Wyoming. Helium extracted from natural gas in the United States in 1990 was 2.5 Bcf. If current trends continue, some shortfalls in helium supply may occur in about 5 to 10 years.

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INTRODUCTION

The identified helium resources of the United States are estimated at 630 Bcf.² This includes both demonstrated and inferred helium contained in proved, probable, and possible natural gas resources.³ It also includes helium previously separated from natural gases and stored at the Cliffside Gasfield in Potter County, TX. The helium contained in other occurrences of natural gas in the United States is estimated at 43 Bcf; this includes helium in nonconventional gas reserves and low-helium-content natural gas. The undiscovered helium resources in the United States are estimated at a most likely value of 103 Bcf. This results in a total helium resource base of 776 Bcf.

This publication is the ninth in a series of reports on the helium resources of the Nation. The first of these reports gave information on helium resources as of January 1, 1973 (1).⁴ The reports have been published approximately every 2 years with the last circular reporting information as of January 1, 1989 (2-8).

The Bureau has been estimating the helium resources of the Nation for about 45 years in connection with a search for helium occurrences that has been conducted for over 75 years. These activities are carried on (1) to ensure a continuing supply of helium to fill essential Federal needs, (2) to provide information to the Secretary of the Interior so that helium resources reserved to the United States on Federal land can be properly managed, and (3) to provide the public with information on a limited natural resource that is often wasted.

The Mineral Lands Leasing Act of 1920 reserves to the United States all helium found on Federal lands leased under the provisions of that Act. The responsibility for ensuring a supply of helium to meet essential Federal needs was assigned to the Secretary of the Interior by the Helium Act of March 31, 1925. The latest legislation pertaining to helium is the Helium Act Amendments of 1960. The helium resource estimates and supply-demand forecasts presented in this report are realistic for the short term; however, as in all long-term forecasts, less reliance should be placed on the estimate toward the end of the forecast.

The estimate of the total helium resource base of 776 Bcf compares with 895 Bcf estimated as of January 1, 1989. The decrease is due to changes in estimates of natural gas resources by the Potential Gas Committee (PGC) (9), continued refinement in helium content

averages by the Bureau, and natural gas production during the last 2 years. The identified resources are classified based on degree of geological assurance of occurrence. This classification results in the categories termed "measured," "indicated," and "inferred" resources. Appendix A defines these terms and their relationship to the oil and gas industry terms of proved, probable, and possible. Measured resources, including storage, are 266 Bcf, indicated resources are 158 Bcf, and inferred resources are 206 Bcf.

The identified helium resources can be subdivided into three categories (fig. 1): (1) reserves containing 387 Bcf, which includes helium in underground storage, (2) marginal reserves containing 156 Bcf, and (3) subeconomic resources containing 87 Bcf. The helium resource base also includes approximately 43 Bcf of helium in other natural gas occurrences. These natural gas occurrences include coalbed methane and natural gas with very low helium contents, generally less than 0.05%. The undiscovered helium resources comprise the remainder of the helium resource base, and the estimate is based on the most likely speculative gas resource values provided by the PGC. The minimum value for the undiscovered resources is 41 Bcf, and the maximum value is 259 Bcf. The definitions for the above helium and natural gas resource terms are found in appendix A. The definitions and uses of the terms in this circular follow the general guidelines established by the U.S. Geological Survey (USGS) and the Bureau of Mines as published in USGS Bulletin 1450-A, *Principles of the Mineral Resource Classification System of the United States Bureau of Mines and the United States Geological Survey, 1976* and later revised in USGS 831 (1980).

The format for this information circular is different from that of past circulars on the subject. Previously, the helium resources were reported based on helium content of the natural gases. Natural gases containing greater than 0.30% helium (helium-rich) were considered most economically producible, and natural gases with less than 0.30% helium (helium-lean) were considered increasingly less economic as helium content decreased. No attempt was made to categorize the helium resources based on economic potential.

This report categorizes the resources on an economic basis. The helium content of the gases is still an economic consideration because the extraction costs generally decrease as helium content increases. However, other factors that affect the economic potential of helium deposits are also considered and included in classifying the helium resources. These factors include the average daily rate of processed gas, hydrocarbon recovery, life of the reserves, size of reserves, and proximity to the Government's helium storage system.

²All values in this report, unless otherwise stated, are at 14.65 psia and 60° F as of December 31, 1990.

³See appendix A for definitions of resource terms.

⁴Italic numbers in parentheses refer to items in the list of references preceding the bibliography at the end of this report.

IDENTIFIED RESOURCES ¹

	Demonstrated		Inferred	UNDISCOVERED RESOURCES			
	Measured	Indicated		Probability Range			
RESERVES	Storage 34	210	51	92	Minimum 41	Most Likely 103	Maximum 259
MARGINAL RESERVES	7		80	69	Other Occurrences		
SUB-ECONOMIC RESOURCES	15		27	45	Includes nonconventional and low-grade materials 43		

¹ A part of reserves or any resource category may be restricted from extraction by laws or regulations.

Figure 1.—Identified and undiscovered helium resources in the United States (billion cubic feet at 14.65 psia and 60° F). Modified from "Principles of a Resource/Reserve Classification of Minerals" (Geological Survey Circular 831, 1980).

IDENTIFIED HELIUM RESOURCES

Helium occurs as a constituent of natural gas, which is presently the only economical source, and is also present in the atmosphere. For this report, helium in the atmosphere is not considered as part of the helium resource base. The natural gas in which helium is found may be normal fuel gas, naturally occurring, low-Btu gas, or nonconventional gas resources such as coalbed methane and carbon dioxide gas. The helium contents of the natural gas resources are derived from Bureau records of

helium analyses of natural gas samples, which are a part of the Bureau resource data base. The analyses of natural gas and limited evaluations of helium resources started in 1917. Over 19,200 natural gas samples from wells and pipelines in the United States and other countries have been analyzed through 1991, and 15,433 of these analyses have been published in 38 Bureau publications. These publications are listed in the bibliography of this report.

HELIUM IN STORAGE

In 1961, the Government contracted to purchase helium from five extraction plants built by four private companies adjacent to large natural gas transmission pipelines. The gas, principally from the West Panhandle and Hugoton Gasfields in the Oklahoma and Texas Panhandles and in southwest Kansas, was being produced for fuel. As the gas was burned, the helium was released to the atmosphere and wasted. Using private funds, these companies constructed plants to extract crude helium for sale to the Government. The helium was delivered into a Government-owned pipeline that connected all plants with the Bush Dome in the Cliffside Gasfield near Amarillo, TX. Further information concerning the Government's helium purchases can be found in the first report of this series (7) and the section in this report on history and uses of helium.

The helium stored in Bush Dome totals 33.9 Bcf. Of this total, 32.4 Bcf was accepted by the Government from the conservation plants under contract or was produced by Government-owned helium extraction plants and was excess to Federal market demands. The other 1.5 Bcf is stored by the Government for private companies under separate storage contracts.

Bush Dome was the source of helium-bearing natural gas that was produced for helium extraction at the Government's Amarillo Helium Plant from 1929 until the plant ceased helium extraction operations in April 1970. About 105 Bcf of the natural gas has been produced from the field, and there is about 204 Bcf of remaining recoverable gas reserves. The natural gas averages about 1.86% contained helium; therefore, the remaining native helium reserves are about 3.8 Bcf. Since the Amarillo Helium Plant ceased helium extraction operations, natural gas has been produced from Bush Dome for fuel gas and helium extraction at the Government's Exell Helium Plant operations north of Amarillo, TX. Helium contained in the remaining native gas is included with the helium in proved natural gas reserves (measured helium reserves).

OTHER MEASURED HELIUM RESOURCES

Measured helium in proved natural gas reserves is estimated at 232 Bcf, not including storage and other occurrences of helium. The measured helium is subdivided into reserves, marginal reserves, and subeconomic resources. Presently, all measured reserves are in helium-rich natural gas. The marginal reserves and subeconomic helium resources are contained in both helium-rich and helium-lean natural gas. All gasfields known to contain at least 0.05% helium have been individually evaluated and are part of the demonstrated helium resources. Fields

containing less than 0.05% helium are not individually evaluated. The helium resources in these fields are estimated by using average helium contents of natural gas from representative fields and basins and applying those values to the Department of Energy-Energy Information Administration (DOE-EIA) reserve estimates (10). These helium resources, although they are contained in proved natural gas reserves, are reported as other occurrences of helium.

Measured Helium Reserves

The measured helium reserves are estimated at 210 Bcf. These reserves are located in 12 gas-producing areas in 8 States. The reserves by State and area are listed in table 1. The locations are shown in figure 2.

Since 1950, the Bureau has been making estimates of the helium resources of the Nation, although for several years the estimates included only the fields that contained major deposits of at least 0.30% helium. These fields were the Hugoton in southwest Kansas and the Oklahoma and Texas Panhandles, West Panhandle in Texas, Greenwood in Kansas, Keyes in Oklahoma, and Cliffside in Texas. Even today these fields are estimated to contain approximately 31%, or 65 Bcf, of the measured helium reserves. The natural gas from all these fields is being produced for fuel, and the helium that is not extracted is lost as the natural gas is burned. Bush Dome in Cliffside Gasfield is being produced only for the Federal Government's helium program needs and for redelivery of helium stored under contract.

As the helium resources evaluation program progressed, more comprehensive data were collected and the estimates were improved. In 1961, a major improvement in the program took place when, for the first time, helium reserves were estimated for all fields from which samples containing more than 0.30% helium had been analyzed in connection with the gas-sampling program. Available data for many of these smaller fields were limited for the first evaluation efforts; however, over the intervening years, data have been collected from all known, available sources. This has resulted in a comprehensive assessment of the total helium reserves of the country.

Before the implementation of crude helium purchases in late 1962, all of the previously mentioned gasfields with large helium reserves were being produced for fuel. The resultant loss of helium amounted to approximately 8 Bcf per year. Under the crude helium purchase program, approximately 3.5 Bcf of the helium that would otherwise have been wasted was saved annually from 1963 through November 12, 1973, when acceptance of helium from the private conservation plants ceased.

Table 1.—Measured helium reserves
(Volumes are in million cubic foot, as of December 31, 1990)

State and area	Total		Total		Total	
	Helium reserves	Federally owned	Marginal helium reserves	Federally owned	Subeconomic helium resources	Federally owned
Arizona: Apache County	2,792	0	0	0	0	0
Arkansas: Arkansas Valley	0	0	1,535	117	0	0
Colorado:						
Baca County	0	0	389	54	0	0
Douglas Creek Arch	0	0	769	731	0	0
McElmo Dome	0	0	0	0	6,500	5,011
Miscellaneous	0	0	254	165	304	169
Las Animas Arch	906	0	0	0	0	0
Total	906	0	1,412	950	6,804	5,180
Kansas:						
Hugoton	55,279	1,394	0	0	0	0
Other areas	181	0	1,045	0	589	31
Total	55,460	1,394	1,045	0	589	31
Montana:						
Rudyard-Utopia	ND	0	0	0	0	0
Other areas	0	0	189	0	1,023	164
New Mexico:						
Chaves County	2,403	1,514	0	0	0	0
Northwest NM	907	32	0	0	2,000	1,040
Total	3,310	1,546	0	0	2,000	1,040
Oklahoma:						
Guymon Hugoton	5,049	29	0	0	0	0
Keyes gas area	1,275	16	0	0	0	0
Other areas	0	0	0	0	1,020	4
Total	6,324	45	0	0	1,020	4
Texas:						
Cliffside area native gas	3,847	3,847	0	0	0	0
District 10	12,817	12	0	0	0	0
Other areas	0	0	0	0	2,491	23
Total	16,664	3,859	0	0	2,491	23
Utah:						
Lisbon area	1,564	1,361	0	0	0	0
Other areas	0	0	1,541	1,521	0	0
Total	1,564	1,361	1,541	1,521	0	0
Wyoming:						
Riley Ridge	121,841	113,807	0	0	0	0
Church Buttes	1,412	720	350	148	0	0
Washakie Basin	0	0	541	201	146	130
Total	123,253	114,527	891	349	146	130
Other States	0	0	0	0	672	0
Total United States	210,273	122,732	6,613	2,937	14,745	6,572

Some of the gasfields that contain measured reserves of helium are not being produced, and the helium is not being wasted. These are classified as nondepleting helium reserves. There are 38 fields in 7 States that are nondepleting. These nondepleting fields contain both reserves and marginal reserves of helium. Table 2 lists the nondepleting and depleting resources by category.

There are various reasons why these fields are not being produced. Some are located in remote areas where pipeline connections are not presently available. In other cases, the gas is being used in pressure-maintenance operations to produce associated oil. In the majority of these fields, however, the helium is in natural gas that has a low heating value and thus is not suitable for fuel.

Fields in the first two groups will be put on production eventually, and the helium reserves moved to the depleting category. An example of this is the Lisbon Field in south-east Utah. The field has been under pressure maintenance and secondary recovery operations since 1969 and will begin blowdown operations in 1993. As part of this blowdown, Unocal Corp. has installed a helium recovery unit that will extract helium during this phase of operations. As natural gas prices rise, some of the fields with low-heating-value gas will be put on production. During 1986, one major field in this group began production from the Madison Formation of the Riley Ridge Field in Sublette County, WY. This transferred approximately 71 Bcf of helium from the nondepleting to the depleting category of measured helium reserves.

Table 2.—Depleting and nondepleting helium reserves
(Volumes are in billion cubic foot at 14.65 psia and 60° F)

	Total		Total	
	Deplet- ing	Fed- eral	Nonde- pleting	Fed- eral
Measured reserves ¹	158	77	52	46
Indicated reserves	23	0	28	11
Measured marginal reserves . . .	5	2	2	1
Indicated marginal reserves . . .	77	<1	3	1
Measured subeconomic	14	<1	1	<1
Indicated subeconomic	27	0	0	0
Total	304	79	86	59

¹Does not include 34 Bcf in storage, of which 32 Bcf is owned by the Federal Government.

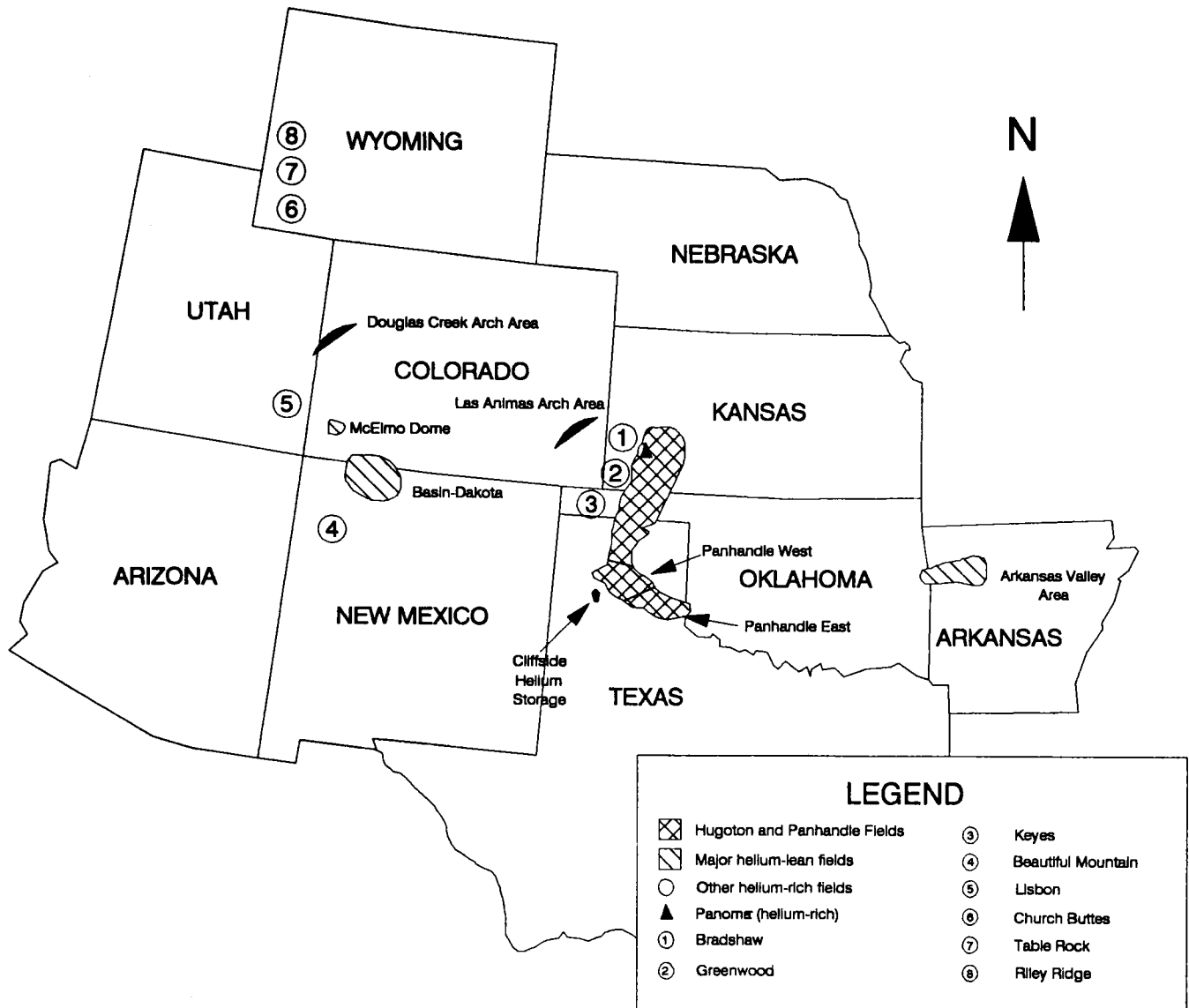


Figure 2.—Location of major helium-bearing gasfields.

The Mineral Lands Leasing Act of 1920 reserves the ownership of all helium in natural gas found on Federal lands to the Federal Government. In this report, the term "Federal lands" applies to those lands on which the Government owns the gas rights. Under these provisions, the United States is estimated to own 123 Bcf of helium found in measured helium reserves on Federal lands. The measured helium reserves are comprised of 77 Bcf of depleting and 46 Bcf of nondepleting reserves (table 2). The nondepleting reserves on Federal lands may serve as a backup to the helium stored by the Government and are an integral part of the Government's helium conservation efforts.

Measured Marginal Helium Reserves

The measured marginal helium reserves are approximately 7 Bcf. These marginal reserves are found in nine gas-producing areas in six States (table 1). A portion of these marginal helium reserves are found in different geologic formations in fields containing measured helium reserves or in proximity to these reserves. They are classified as marginal helium reserves because the size of the resource is small or the helium content is lean (appendix B).

Most of the measured marginal reserves, 5 Bcf, are contained in helium-rich gasfields. These resources are classified as marginal reserves because of their small size, generally less than 0.5 Bcf of helium. About 2 Bcf of helium is found in helium-lean gasfields. Almost all of this is in the Arkansas Valley area in the Arkoma Basin. The fields in this area are small and produce from various zones of Pennsylvanian Age. Gas samples from various zones in many of these fields have been analyzed by the Bureau. These analyses show similar gas and helium contents with very little variation. Since the fields are in close proximity to each other and the gas is eventually gathered by only two major pipeline companies, the resources in the Arkansas Valley area have been combined and are considered marginal helium reserves, whereas individually they would be classified as subeconomic helium resources.

Measured Subeconomic Helium Resources

This category is made up of both helium-rich and helium-lean gasfields. All helium-rich gasfields containing less than 100 MMcf of helium and all helium-lean gasfields containing less than 1 Bcf of helium are included, with the exception of McElmo Dome in southwest Colorado. The measured subeconomic helium resources are

estimated at approximately 15 Bcf. Most of these resources are in helium-lean gasfields, with less than 0.5 Bcf in helium-rich gasfields. Nearly all of these resources are depleting. These helium resources are listed by State in table 1.

Although it is possible to extract helium from gasfields in this category, it is unlikely. These gasfields are isolated from current helium extraction facilities and contain small amounts of helium. The exception is the McElmo Dome Field. This field contains about 6 Bcf of helium in 7 Tcf of carbon dioxide gas. The gas is being produced for use in secondary recovery operations in Texas. The field is not classified as a marginal helium reserve because the helium content is only 0.07%, which would make extraction much more costly than extraction from other helium-lean fields with higher helium contents.

INDICATED HELIUM RESOURCES

The indicated helium resources of the United States are (1) 51 Bcf of reserves, (2) 80 Bcf of marginal reserves, and (3) 27 Bcf in subeconomic resources. The indicated helium resources are derived from the PGC's estimate of probable resources of natural gas. The average helium contents are estimated for each PGC region or basin and used to determine the amount of indicated helium in each basin. Figure 3 is a general map of PGC regions. The assumption is that probable gas resources in a basin will have helium contents similar to those of proven gas reserves. However, some basins not previously containing significant helium could contain helium in the future and vice versa. In addition, some basins contain indicated helium that has been evaluated in conjunction with individual gasfield evaluations. This helium is included as part of the PGC derived value, not added to it, except for low-Btu gases that are not included in the PGC's estimate.

The indicated helium reserves contain 23 Bcf of depleting helium and 28 Bcf of nondepleting helium.⁵ About 11 Bcf of this, all of which is nondepleting, is contained on Federal land. The indicated marginal helium reserves contain 77 Bcf of depleting helium and 3 Bcf of nondepleting helium. Only about 1 Bcf of this is known to be on Federal land. The indicated subeconomic resources are all in depleting reservoirs; none are on Federal land.

⁵Technically, all indicated helium is nondepleting because these resources are not developed or actually producing. The terms "depleting" and "nondepleting," as used here, show that the helium is associated with currently depleting or nondepleting fields.

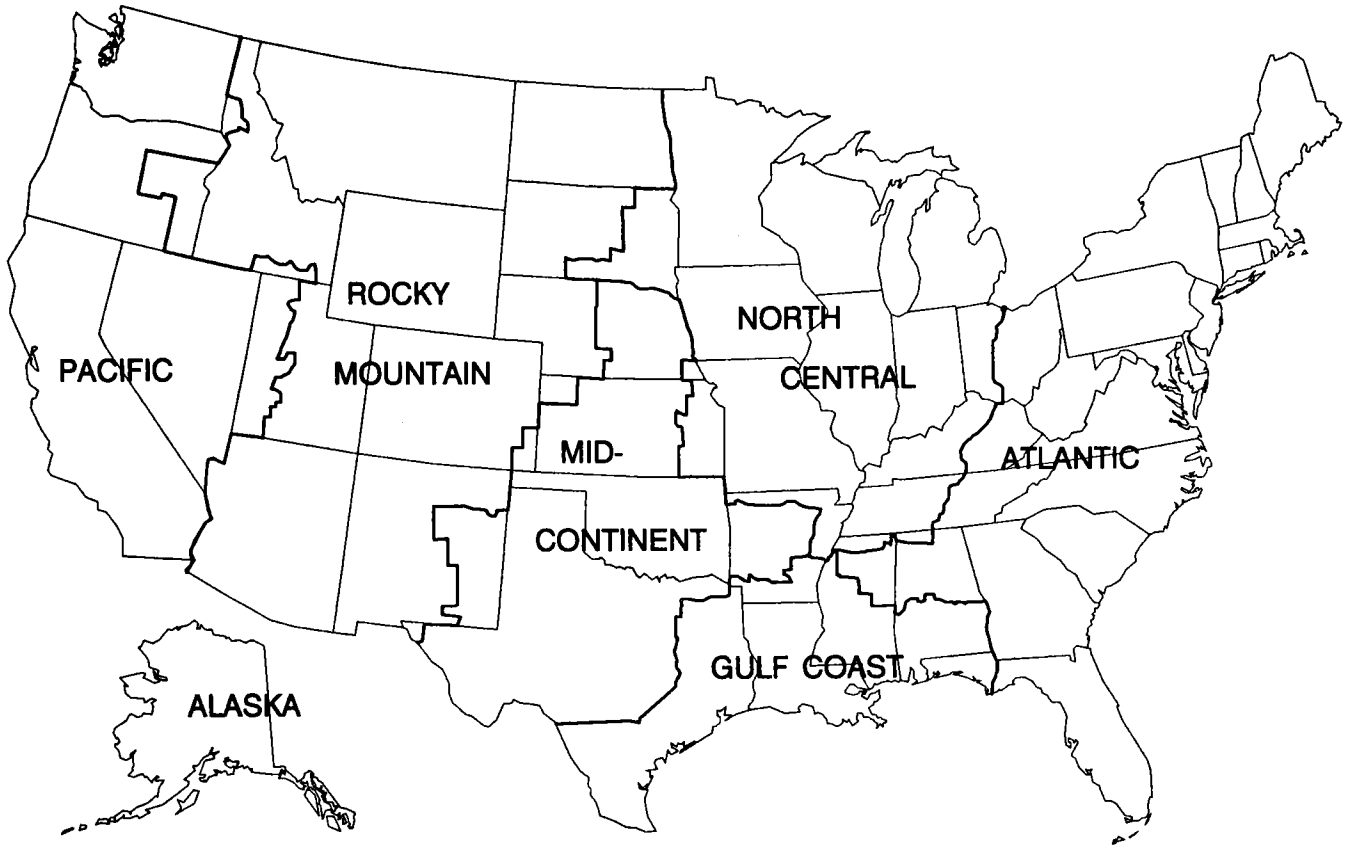


Figure 3.—Map of Potential Gas Committee Regions.

Approximately 33 Bcf of the indicated helium is associated with individually evaluated gasfields. Of this, 28 Bcf is contained in helium reserves and 5 Bcf is contained in marginal helium reserves. The remainder, 125 Bcf, of the indicated resources is derived from the PGC's probable gas resources estimates. Because more importance is placed on reserves and marginal reserves, only gasfields containing helium reserves and marginal helium reserves are individually evaluated for indicated resources. In the subeconomic category, all indicated resource estimates are derived from the PGC probable gas resource values.

Table 3 shows the average helium contents by PGC region as projected by the Bureau. The estimated indicated helium resources for each PGC area have been placed in a resource category based on size and helium content. The same criteria used in determining resource placement for the measured reserves are applied to the indicated resources. These resource estimates are shown on table 4.

INFERRED HELIUM RESOURCES

The inferred helium resources of the United States are (1) 92 Bcf associated with helium reserves, (2) 69 Bcf associated with marginal helium reserves, and (3) 45 Bcf associated with subeconomic helium resources. The inferred helium resources are derived from the PGC's estimate of possible gas resources. As with indicated helium resources, estimates are made of the average helium contents of the possible gas resources for the PGC areas and basins. The average helium contents are based on helium contents of proven reserves, and all areas have potential for significant helium finds in the future. All basins and areas studied, except the Gulf Coast and Pacific areas, have contained some helium-rich natural gas. Possible Federal ownership of the inferred resources was not estimated. Table 5 shows the estimated inferred helium resources for each PGC area and the category in which the resources are placed.

Table 3.—Estimated average helium contents of gas resources
by PGC region and basin

<i>Region and basin</i>		<i>Average helium content, %</i>
Alaska ¹		0.0111
Atlantic: ¹		
P-100	New England and Adirondack Uplift	.0233
P-110	Atlantic Coastal Basin	.0233
P-120	Appalachian Basin	.0497
P-130	Piedmont-Blue Ridge Province	.0497
P-140	South Georgia-Peninsular Florida	.0150
P-150	Black Warrior Basin	.0100
Gulf Coast: ¹		
P-300	Louisiana-Mississippi-Alabama Salt	.0430
P-310	Louisiana Gulf Coast Basin	.0020
P-320	East Texas Basin	.0017
P-330	Texas Gulf Coast Basin	.0020
P-930	Eastern Gulf Shelf	² .0014
P-931	Eastern Gulf Slope	.0014
P-935	Louisiana Shelf	² .0014
P-936	Louisiana Slope	² .0014
P-940	Texas Shelf	² .0014
P-941	Texas Slope	² .0014
P-945	Gulf of Mexico Outer Continental Slope	.0014
Mid-continent: ¹		
P-400	Central Kansas Uplift, Salina Basin	.2081
P-410	Arkoma Basin	.0110
P-420	Anadarko, Palo Duro Basins, etc.	.2081
P-430	Fort Worth and Strawn Basin, Bend Arch	.2550
P-440	Permian Basin	.0282
North Central ¹		.0371
Pacific ¹		.0069
Rocky Mountain: ¹		
P-500	Williston Basin	.0802
P-510	Powder River Basin	.0793
P-515	Big Horn Basin	.0490
P-520	Wind River Basin	.0417
P-530	Greater Green River Basin < 15,0	.0760
P-530	Greater Green River Basin > 15,0	³ .5190
P-535	Denver Basin, Chadron Arch	.0642
P-540	Uinta-Piceance, Park and Eagle Basins	.1720
P-545	San Juan Mountains; San Luis and Raton	² .0230
P-550	Paradox Basin	.4150
P-555	San Juan Basin	.0228
P-560	Southern Basin and Range Province	² .0150
P-565	Plateau Province, Black Mesa Basin	² .0070
P-570	Sweetgrass Arch	.1602
P-575	Montana Folded Belt	.1602
P-580	Snake River Basin	.0275
P-590	Wyoming-Utah-Idaho Thrust Belt	.0824

¹Unless otherwise indicated, the average helium content is weighted based on the number of gas samples from each formation and field combination in the region.

²The average helium content is derived from pipeline gas surveys carried out by the Bureau and is weighted based on gas volumes flowing through gas plants in the region.

³The average helium content is weighted heavily to the high-helium-bearing gas in the Riley Ridge Field. The helium contents of other gases in the area also are considered.

Table 4.—Indicated helium resources by PGC basin

(Volumes are in billion cubic foot at 14.65 psia and 60° F)

PGC basin	Re-serves	Marginal reserves	Subeconomic resources
P-530 Greater Green River Basin > 15,000 ft.	21.92	0	0
P-550 Paradox Basin83	0	0
P-400 Central Kansas Uplift, Salina Basin.	0	0.84	0
P-420 Anadarko, Palo Duro Basins, etc.	0	51.05	0
P-430 Ft. Worth and Strawn Basins, Bend.	0	5.13	0
P-540 Uinta, Piceance Basins	0	14.19	0
P-570 Sweetgrass Arch	0	3.70	0
Less individually evaluated fields.	0	(.20)	0
P-120 Appalachian Basin . . .	0	0	10.23
P-500 Williston Basin	0	0	.66
P-510 Powder River Basin . .	0	0	.88
P-515 Big Horn Basin	0	0	.44
P-530 Greater Green River Basin < 15,000 ft.	0	0	7.18
P-535 Denver Basin, Chadron Arch.	0	0	1.87
P-590 Wyoming-Utah-Idaho Thrust Belt.	0	0	6.05
Total	22.75	74.71	27.31

Where the average helium content of the possible gas resources is estimated to be less than 0.05%, the resources are placed in the subeconomic category rather than with other occurrences, as they are with probable resources. The reason for this is that the criteria for reserves, marginal reserves, and subeconomic resources will likely change in the future. What are presently considered low-grade or other occurrences may be considered subeconomic or even marginally economic. As helium-rich supplies of helium are depleted, the selling price will rise; in turn, lower grade helium will become more economic.

Table 5.—Inferred helium resources by PGC basin

(Volumes are in billion cubic foot at 14.65 psia and 60° F)

PGC basin or region	Re-serves	Marginal reserves	Subeconomic resources
P-530 Greater Green River Basin > 15,000 ft.	88.19	0	0
P-550 Paradox Basin	4.17	0	0
P-400 Central Kansas Uplift, Salina Basin.	0	0.21	0
P-420 Anadarko, Palo Duro Basins, etc.	0	50.95	0
P-430 Ft. Worth and Strawn Basins, Bend.	0	3.85	0
P-540 Uinta, Piceance Basins	0	8.79	0
P-570 Sweetgrass Arch	0	3.37	0
P-575 Montana Folded Belt . .	0	1.61	0
Alaska	0	0	3.25
P-120 Appalachian Basin . . .	0	0	3.75
P-150 Black Warrior Basin . .	0	0	.07
Gulf Cost Region (onshore and offshore).	0	0	5.38
P-410 Arkoma Basin	0	0	.30
P-440 Permian Basin	0	0	9.22
North Central Region	0	0	1.95
Pacific Region	0	0	1.06
P-500 Williston Basin	0	0	.53
P-510 Powder River Basin . .	0	0	1.83
P-515 Big Horn Basin	0	0	.59
P-520 Wind River Basin	0	0	4.03
P-530 Greater Green River Basin < 15,000 ft.	0	0	8.71
P-535 Denver Basin, Chadron Arch.	0	0	1.36
P-545 San Juan Mountains, San Luis/Raton Basin.	0	0	.09
P-555 San Juan Basin	0	0	.11
P-560 Southern Basin and Range Province.	0	0	.21
P-590 Wyoming-Utah-Idaho Thrust Belt.	0	0	2.98
Total	92.36	68.78	45.42

OTHER HELIUM OCCURRENCES

Other occurrences of helium include helium contained in nonconventional natural gas and extremely lean (low-grade) helium occurrences. All proven reserves of natural gas that contain less than 0.05% helium are in this category. In addition, helium in coalbed methane and some carbon dioxide occurrences are also included. The helium resources in other occurrences are about 43 Bcf.

An average helium content is applied to the DOE-EIA reserves of natural gas less the evaluated natural gasfields

containing measured helium to arrive at a value for helium contained in the remaining gas reserves. The average helium contents are derived from the helium survey analyses of gas wells and the continuing survey of gas transmission pipelines and are weighted based on flow through the pipelines. The total helium in other occurrences from this source is about 23 Bcf.

Also part of the other occurrences of helium are coalbed methane resources and some carbon dioxide

resources. Helium content data are available only for one large coalbed methane area and one carbon dioxide gas-field. The coalbed methane resources in the Black Warrior Basin are estimated at about 15 to 20 Tcf. The Bureau has estimated that this methane contains about 6 Bcf of helium. The helium resources in the carbon dioxide gases of the Sheep Mountain area of Colorado are less than 1 Bcf. Other carbon dioxide-producing fields have significant helium contents and are categorized as helium reserves (Riley Ridge Field) and subeconomic (McElmo Dome) as previously discussed.

The last source of helium in this category consists of certain estimates from the PGC probable gas resource category. Basins and areas that contain probable gas resources with average helium contents of less than 0.05% are also placed in the other occurrences category and are approximately 14 Bcf. Table 6 lists all estimates of helium in other occurrences.

Table 6.—Helium in other occurrences

(Volumes are in billion cubic foot at 14.65 psia
million cubic foot as of December 31, 1990)

Coalbed methane:	
Black Warrior Basin	5.9
CO ₂ resources:	
Colorado-New Mexico5
DOE-EIA	23.0
From PGC—probable:	
Alaska	3.76
P-150 Black Warrior Basin05
Gulf Coast Region	3.13
P-410 Arkoma Basin39
P-440 Permian Basin	3.86
North Central Region06
Pacific Region11
P-520 Wind River Basin	1.95
P-555 San Juan Basin34
Total	43.05

UNDISCOVERED HELIUM RESOURCES

The undiscovered helium resources in the United States are estimated at a most likely value of 103 Bcf, with a minimum value of 41 Bcf and a maximum value of 259 Bcf. The estimates are based on the PGC's minimum, most likely, and maximum speculative gas resources combined with the Bureau's estimate of average helium contents. The same average helium contents that are used for indicated and inferred helium resources are used for undiscovered resources. No attempt was made to estimate the minimum and maximum helium contents because for most basins the helium contents fall within a very narrow range of values. For example, the offshore Gulf Coast area has never contained gas with greater than 0.05% helium. In areas such as the Mid-continent, where the helium

contents have a wider range of values, statistical analysis showed no pattern to the helium contents based on size of reservoir or discovery. The authors considered arriving at and applying a minimum and maximum helium content to the PGC's minimum and maximum gas resource values; however, after careful consideration, it was decided to use only the average values. The reason for this decision is that larger gas discoveries do not necessarily translate into greater helium contents for the gas. Further, studies of proven gas reserves by basin and helium contents studies by basin and reservoir (11) show that gases in most basins and reservoirs contain helium contents within a narrow range of values. Also, new discoveries within these basins follow the helium content pattern of past discoveries.

PRODUCTION AND EXTRACTION

BACKGROUND

The Bureau's role in helium dates to World War I, when the Army and Navy became interested in using helium as an inert lifting gas and contacted the Bureau for assistance because of its natural gas expertise. The Helium Act of 1925 officially placed the helium program under Bureau control. The Bureau built a large-scale helium extraction and purification facility and began operations in 1929. During World War II, demand increased significantly, and four more small Government plants were built.

Increased helium demand in the 1950's led to the construction of the Keyes, OK, helium plant in 1959.

Dwindling Mid-continent natural gas supplies aroused concerns that no economic source of helium would exist by the turn of the century and led to the passage of amendments to the Helium Act of 1925. The Helium Act Amendments of 1960 provided for the conservation of helium for essential Government needs and also was intended to promote the development of a private helium industry. The Act directed the Secretary of the Interior to purchase and store helium for future use and to maintain helium production and purification plants and related helium storage, transmission, and shipping facilities.

Purchases for the conservation program were made from private companies, which added crude helium extraction plants to existing gas-processing facilities. The

Bureau built a high-pressure pipeline to transport the helium from Bushton, KS, and intermediate points to the Bureau-owned Cliffside Gasfield for storage. In 1973, the contracts with private companies were canceled because of cutbacks in the space program and because the Secretary determined that the long-term needs of the Government were adequately fulfilled. In the mid-1970's, the Bureau began accepting privately owned crude helium for storage at the Cliffside Gasfield. Private industry currently has about 1.5 Bcf of helium stored at Cliffside.

Presently, the helium needs of Federal agencies are being met, and there is adequate helium in storage to meet these needs well into the future. The entire Federal helium demand is now supplied by the Exell Helium Plant.

USES OF HELIUM

Helium is chemically inert, which means that no other element will combine with it at any temperature or pressure. Helium is the second lightest element, hydrogen being the lightest. Helium liquefies at approximately -452° F, making it useful in cryogenics, the study of the behavior of matter and energy at temperatures below -270° F. These properties make helium an element that can be used in a variety of applications.

Since helium will not burn or react with other substances, it is used to shield reactive metals, such as aluminum, from contamination by other elements during arc welding. The inert characteristics of helium keep it from reacting in the body, which allows it to be used in breathing mixtures supplied to some undersea explorers and operating-room patients. Helium is seven times lighter than air and is nonexplosive, making it applicable as the lifting gas inside high-altitude weather and research balloons, children's toy balloons, and lighter-than-air craft.

Helium is used to control atmospheric conditions in special chambers where silicon crystals used in electronic applications are grown. The display case in the National Archives building in Washington, DC, that houses the first and last pages of the Constitution of the United States uses helium as an atmosphere control. Helium's immunity to radioactivity led to its use as a heat-transfer medium in gas-cooled nuclear power reactors. The molecular size of helium allows it to escape through the tiniest holes, making it useful for detecting leaks during the manufacture of sealed fluid systems like those used in refrigerators and vacuum systems. The very low temperature at which helium liquifies causes certain metals to become superconductors, losing all resistance to the flow of electricity. This made possible the construction of powerful magnets that can be used to monitor physical and chemical conditions inside the human body, and to accelerate subatomic particles to velocities near the speed of light for experiments in high-energy physics.

The development of liquid-fueled rockets increased the uses for helium in space exploration and missile technology. The Atlas, Saturn V, and Space Shuttle have applied the technology developed for helium used in space travel. The fuel tanks of all these spacecraft are pressurized by helium to push the fuel into the pumps feeding the rocket engines and to provide pressure, enabling thin-walled tanks to resist collapse when empty. The Space Shuttle also uses helium in the orbital-maneuvering-system engines that enable the shuttle to change the shape and altitude of its orbit. Figure 4 shows the uses of helium in 1990.

SUPPLY AND DEMAND

Historical production and extraction of helium in the United States are shown on figure 5. The figure indicates a steady growth in helium recovered and sold since 1971, with greater percentage increases from 1986 to 1988 and smaller growth from 1988 to 1990. The growth increased dramatically in 1986 when Exxon Corp. began extracting helium from the Riley Ridge Field, WY, at the Shute Creek plant. The plant extracts about 1 Bcf of pure helium per year, which is about plant capacity. Most of the growth in helium recovery since 1986 has been from the Mid-continent area's extraction plants. These plants extracted about 900 MMcf of helium in 1987; in 1990, they extracted about 1,500 MMcf of helium, which computes to an average annual growth of 18% (12).

Figure 6 shows the projected production and extraction of helium from the Mid-continent area through the year 2010. Riley Ridge area helium production and extraction were not included in this projection because helium extraction at the Shute Creek plant is near capacity. Any growth in helium extraction from the area would require investment in another processing train. Since helium is only one of several products (carbon dioxide, sulfur, and methane) processed at the plant, the addition of a processing train would require some growth in demand for the other products. With the current low oil prices, an increased demand for carbon dioxide, which is used in secondary recovery processes, is unlikely. Demand for sulfur is experiencing some growth (13); however, the permit and application process in this environmentally sensitive area is lengthy, and sales of the products would have to be assured in advance. Any scenario for further development of Riley Ridge must take those factors into account.

The curves shown in figure 6 are projected helium production, maximum pure helium extraction capacity, and three helium demand growth curves. The helium production curve is based on projected deliverabilities of gas from the helium-rich natural gasfields in Kansas, Oklahoma, and Texas. These fields include Bradshaw,

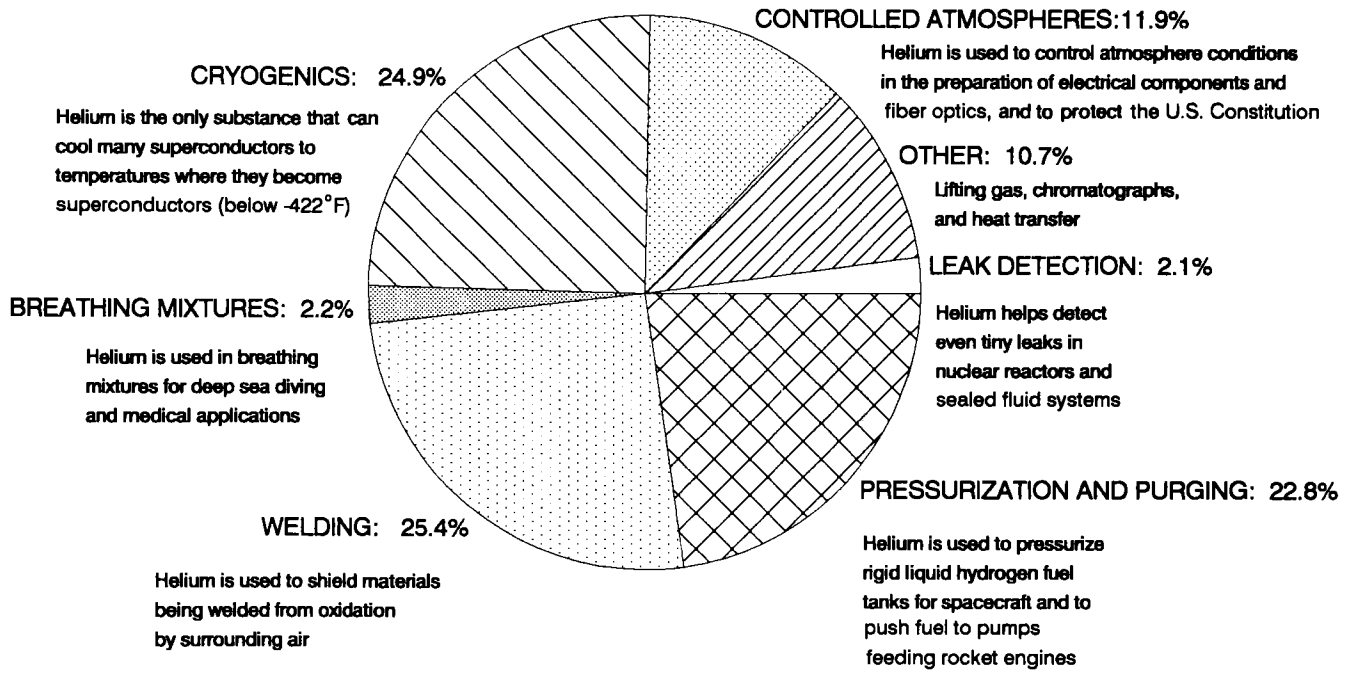


Figure 4.—Uses of helium, 1990.

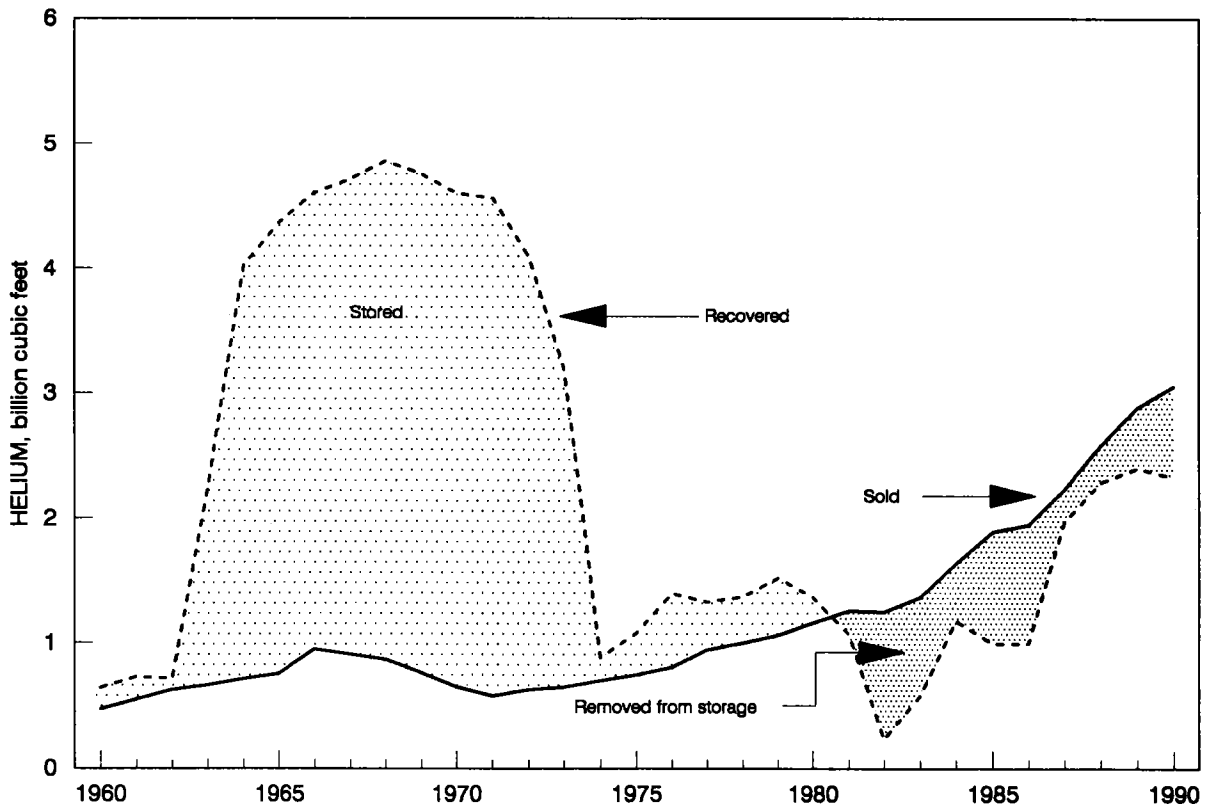


Figure 5.—Production and extraction of helium in the United States.

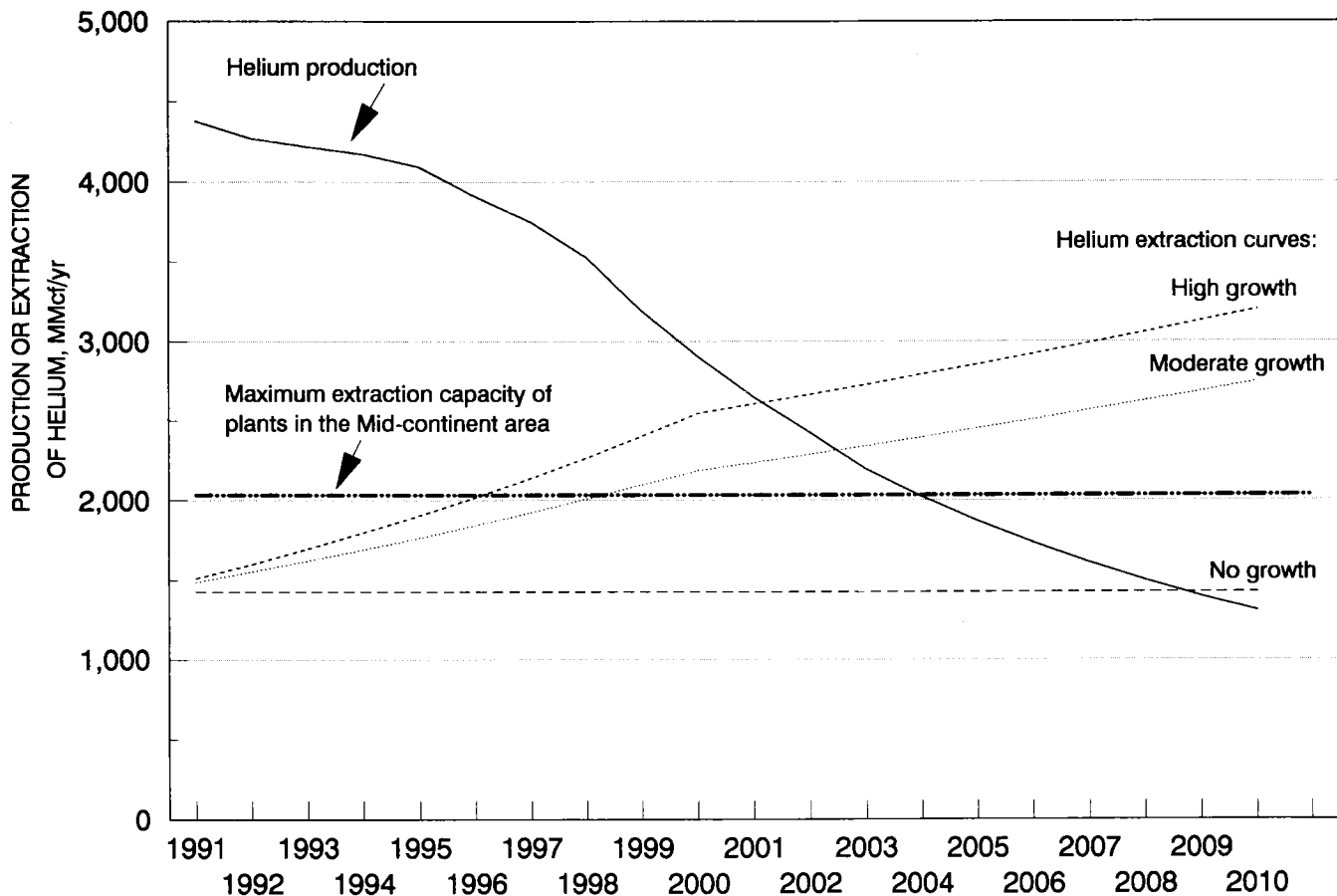


Figure 6.—Supply and demand forecasts for helium from the Mid-continent area (volumes at 14.65 psia and 60° F).

Greenwood, Kansas Hugoton, and Panoma in Kansas; Guymon-Hugoton and Keyes in Oklahoma; and West Panhandle and Texas Hugoton in Texas. The maximum plant capacity curve shows the pure helium extraction capacity of the private plants in the Mid-continent area. Lastly, a set of curves presents three possible helium demand scenarios for the helium produced in the Mid-continent area. The "no growth" curve assumes that demand for helium from these plants will remain steady, and growth in total demand will be taken up by a combination of new facilities in other areas, lower exports, and increased capacity at Riley Ridge. The "high growth" curve assumes 6% annual growth to 2000 and 2.3% growth beyond 2000. This curve is based on growth in helium sales since 1971; it is assumed that sales will level off eventually. The "moderate growth" curve assumes 4.4% annual growth to 2000 and 2.3% beyond. This curve is based on most recent sales showing moderate growth. Again helium usage is expected to eventually level off.

Data from figure 6 suggest that with both moderate and high growth of helium sales, extraction capacity will be reached as early as 1996 and not later than 1999.

Thereafter, the plants would produce at capacity to about 2004, when the maximum extraction curve intersects the helium production curve. At that point the Mid-continent helium plants would lose sales, and some shortages of helium would occur. If additional purification capacity is added in the Mid-continent area, the moderate and high growth curves will intersect the helium production curve sometime after 2001. This assumes that the plants would be able to extract all helium produced. However, the more likely scenario suggests that no more than 75% of the helium could be made available to existing plants because of such factors as plant location, pipeline location, and natural gas sales contracts. There is a possibility that the helium production decline curve will not be as steep as projected owing to in-fill drilling and other technology. However, a less steep slope will only increase the time to crossover by about 5 to 10 years.

There are crude helium plants in the Mid-continent area with ample extraction capacity, about 3 Bcf per year. In addition, more crude helium plants are planned for operation by 1994. All the crude plants are connected to the Bureau's crude helium pipeline and are currently storing

1.5 to 2.0 Bcf of helium at the Cliffside storage field. This storage is utilized in the summer months, when natural gas demand is slack, to allow the pure helium plants to meet customer demand, which generally is not seasonal. For the pure helium plants to meet expected future demand, other Mid-continent sources of helium

must be discovered, or private storage of crude helium must be increased and used for a private reserve to meet future demand. In either instance, more purification capacity will be needed in the near future to meet anticipated demand.

SUMMARY

Previous Bureau reports on helium resources listed helium resources based solely on helium content. This report uses other criteria in addition to helium content to determine reserves, marginal reserves, and subeconomic resources. Refinements in evaluating other occurrences of helium and undiscovered resources also have been made for this report. In previous Bureau reports, it was concluded that relatively large volumes of helium would be available from natural gas through 2020, although that helium would probably be in gases with leaner concentration than those being processed today. This report does not estimate nationwide projections for helium in natural gas production. Rather, it focuses on short-term supply and demand for helium and examines the possible repercussions of various growth-in-demand scenarios. These scenarios suggest a need for private producers in the

Mid-continent to begin to store crude helium and increase purification capacity to provide for expected shortages of produced helium. If shortages and loss of sales occur in the short term (within 15 years), helium production in the Mid-continent will decline to below extraction capacity, causing a further decline in the Mid-continent helium industry.

Currently, there is 33.9 Bcf of helium stored in Bush Dome at the Cliffside Gasfield. The Bureau owns 32.4 Bcf, and 1.5 Bcf is owned by private companies. There is also approximately 3.8 Bcf of helium contained in the natural gas in Bush Dome. This reserve of helium and the helium on Federal lands in nondepleting fields will fulfill the Bureau's mission of supplying helium to meet all essential Government needs for several decades.

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APPENDIX A.—GLOSSARY OF RESERVE AND RESOURCE TERMS

The following definitions are based on definitions found in *Principles of a Resource/Reserve Classification of Minerals*, Geological Survey Circular 831, 1980, with additions and revisions where necessary to accommodate for helium.

Resource.—A concentration of naturally occurring solid, liquid, or gaseous material in or on the Earth's crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

Identified Resources.—Resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence. Identified Resources include reserves, marginal reserves, and subeconomic resources components. To reflect varying degrees of geologic certainty, these economic divisions can be subdivided into measured, indicated, and inferred.¹

Demonstrated.—A term for the sum of measured and indicated.

Measured.—The quantity is computed from dimensions revealed by actual gas analyses, production or formation tests, electric logs, and core analyses; and/or is delineated by drilling and defined by fluid contacts or undrilled areas that can be reasonably judged as commercially productive on the basis of geologic and engineering data.

Indicated.—Quantity and quality are computed from information similar to that used for measured resources, but the amounts are less certain and can be estimated with a degree of certainty sufficient to indicate they are more likely to be recovered than not. In general they include reserves in formations that appear to be productive based on log characteristics but that lack core data or definitive tests, and reserves that will be found by field extensions, in-fill drilling, or improved recovery methods.

Inferred.—Estimates are based on an assumed continuity beyond measured and/or indicated resources, for which there is geologic evidence. Inferred resources may or may not be supported by analyses or measurements.

Reserve Base.—That part of an identified resource that meets specified minimum physical and chemical criteria related to current drilling and production practices, including those for quality, porosity, permeability,

thickness, and depth. The reserve base is the in-place demonstrated resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology, thickness, and depth. The reserve base is the in-place demonstrated resource from which reserves are estimated. It may encompass those parts of the resources that have a reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics. The reserve base includes those resources that are currently considered reserves and marginal reserves, and some of those considered subeconomic resources. For helium, the measured portion of subeconomic resources is included in the reserve base, but not the indicated portion.

Inferred Reserve Base.—The in-place part of an identified resource from which inferred reserves, marginal reserves, and subeconomic resources are estimated. Quantitative estimates are based largely on knowledge of the geologic character of a reservoir, for which there may be no gas analyses or measurements.

Reserves.—That part of the reserve base that could be economically extracted or produced at the time of determination. The term "reserves" need not signify that extraction facilities are in place and operative. Reserves include only recoverable materials; thus, terms such as "extractable reserves" and "recoverable reserves" are redundant and are not a part of this classification system.

Marginal Reserves.—That part of the reserve base that, at the time of determination, borders on being economically producible. Its essential characteristic is economic uncertainty. Included are resources that would be producible, given postulated changes in economic or technologic factors.

Subeconomic Resources.—The part of identified resources that does not meet the economic criteria of reserves and marginal reserves.

Other Occurrences.—Resources that are contained in extremely low-helium-content natural gases or nonconventional natural gas reserves. Only "proved" and "probable" natural gas reserves of this type are evaluated and included in the classification.

Undiscovered Resources.—Resources, the existence of which are only postulated, comprising deposits that are separate from identified resources. The undiscovered resources of helium are postulated based on the "speculative" resources reported by the PGC.

¹The terms "proved," "probable," and "possible," which are commonly used by industry in economic evaluations of ore or mineral fuels in specific deposits, reservoirs, or districts, have been loosely interchanged with the terms measured, indicated, and inferred. The former terms are not a part of this classification system.

APPENDIX B.—GUIDELINES FOR DETERMINING HELIUM RESERVES AND RESOURCES

The following guidelines apply for determining helium reserves, marginal helium reserves, and subeconomic helium resources as contained in this publication. The

guidelines also are helpful for determining undiscovered resources.

INDIVIDUAL FIELD RESERVES AND RESOURCES

Helium content, %	Contained helium in field area	Category
> = 2.00	> = 100 MMcf	Reserves.
0.30-2.00	> = 1 Bcf	Reserves.
> = .30	100 MMcf to 1 Bcf	Marginal reserves.
> = .30	10 to 100 MMcf	Subeconomic resources.
.10-.30	> = 5 Bcf	Reserves.
.10-.30	1 to 5 Bcf	Marginal reserves.
.10-.30	100 MMcf to 1 Bcf	Subeconomic resources.
.10-.30	10 to 100 MMcf	Other occurrences.
.05-.10	> = 5 Bcf	Subeconomic resources.
.05-.10	10 MMcf to 5 Bcf	Other occurrences.
<.05	Large coalbed methane or carbon dioxide resources with > 5 Bcf contained helium	Other occurrences.

The above guidelines also apply for areawide classifications. In addition, the following guidelines are applied to basinwide resources. An average helium content is used for each basin, and the reserves and/or resources are determined by applying the average helium content to the

basin's gas resource estimate for probable and possible categories. For the undiscovered resources, the average helium content is applied to minimum, most likely, and maximum speculative PGC gas resource numbers.

AREAWIDE CLASSIFICATIONS

<0.05	All DOE-EIA reserves after subtracting computerized data base measured reserves.	Other occurrences.
<0.05	PGC probable gas resources in a basin or region.	Other occurrences.
<0.05	PGC possible gas resources in a basin or region.	Subeconomic resources.