

FIELDNOTES

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HELIUM: *Origin, Use, Supply and Demand*

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INTRODUCTION

Most people give little thought to helium gas except when it is used to inflate children's balloons at circuses or parades, or when its properties are revealed in a high school chemistry class. Helium is actually a unique and indispensable natural resource that is crucial for many industrial and research activities. The following narrative describes the geologic occurrence and physical properties of helium, outlines the history of its discovery and development as a natural resource, and examines possible future uses of helium as well as the consequences of its depletion.

Several natural gas fields in the United States contain most of the world's known helium reserves. Most natural gas contains small amounts of helium which, unless extracted from the natural gas, are lost to the atmosphere when the gas is burned. Roughly 14 billion cubic feet of helium (about one-tenth of a cubic mile) are contained in natural gas produced domestically each year. About one billion cubic feet of this helium is extracted and sold commercially, while the rest is dissipated into the atmosphere. The atmosphere is a virtually limitless and renewable source of helium, but the cost of atmospheric recovery of helium is

high due to the increased energy requirement for extraction from such a dilute source (five parts helium per million parts air). It is estimated that it would cost \$2,000-\$6,000 to extract a thousand cubic feet of helium from the atmosphere, compared to less than \$13 for extraction of the same quantity from natural gas containing more than 0.3 percent helium (3,000 parts per million) (Peach, 1981).

The importance of helium to industry and scientific research, and its possible importance to future energy-related industries, has long been recognized. As a result, efforts have been made to extract helium from natural gas and to pump it underground into depleted natural gas reservoirs where it can be stored indefinitely. About 40 billion cubic feet of helium have been stored in the Cliffside reservoir in northern Texas by the U.S. Bureau of Mines before federal funding for helium extraction and storage was terminated in 1973 for budgetary reasons. Despite legislative attempts to revive the helium conservation program, it is not likely to be renewed in the near future. At current rates of helium production and discovery, the world's underground helium reserves will be depleted by the middle of the 21st century. However, as helium-intensive energy technologies become practical and helium reserves are depleted, the debate over the merits of federally funded helium conservation will intensify. Advanced electric power generation, storage, and



The Goodyear "blimp"—one of four lighter-than-air craft in the Goodyear fleet today. Since 1917 Goodyear has built more than 300 helium-filled dirigibles; 60 of these have been used as commercial airships which also promote community activities and public service throughout the U.S. and Europe. A "blimp" is 192 feet long, 59 feet high and weighs 9,500 pounds when empty; it travels 35-50 mph at heights of 1,000-10,000 feet, and can carry a maximum load of 2,820 pounds. Photo courtesy of Goodyear Aerospace Corporation.

transmission devices, now in research and development, may require large amounts of helium in the future.

ORIGIN OF HELIUM

Helium is the second element on the periodic table of the chemical elements and is the second most abundant element in the universe. Only hydrogen, the first element on the periodic table, is more abundant. The sun's energy is derived almost entirely from fusion of hydrogen nuclei into helium nuclei. In fact, the sun and stars can be regarded as enormous helium factories.

On Earth where temperatures and pressures are far too low for nuclear fusion, much smaller amounts of helium are produced by radioactive decay of uranium and thorium. A single atom of uranium 238, the most abundant isotope of uranium, produces eight helium nuclei during its long decay into lead. Over millions of years, trillions of cubic feet of helium have been produced by radioactive decay of uranium and thorium in the Earth's crust. Helium produced in the Earth is initially trapped in the rocks and minerals in which it is formed. Large amounts of helium eventually escape into the atmosphere, and from there escape into outer space. Smaller amounts, however, accumulate in underground geologic reservoirs. Both natural gas and helium accumulate in porous and permeable sedimentary rocks overlain by impermeable strata, although the two types of gas are derived from different sources. Helium is derived from rocks rich in uranium, whereas natural gas is derived from rocks rich in organic matter. The two types of gas are typically found together in underground reservoirs, although the relative concentration of each varies greatly because of differences in the concentrations of uranium and organic matter in source rocks.

DISCOVERY AND EARLY USES OF HELIUM

Helium was discovered simultaneously by British astronomer Norman Lockyer and French astronomer Pierre Janssen in 1868. Lockyer noticed that a bright yellow spectral line which appeared in light emitted from the sun's corona was an element not known on Earth. He later named the element "helium", from the Greek word for sun, *helios* (Seibel, 1968).

Twenty-three years later (1895) in a London laboratory, professor William Ramsay dissolved one gram of the uranium-bearing mineral cleveite in acid and obtained a gas which he purified and examined spectroscopically. Because he did not recognize the gas, Ramsay sent a sample to Sir William Crooke, a noted spectroscopist, who identified it as helium. Within a few years of this discovery, helium had been found in a variety of uranium and thorium-bearing minerals, and in the air.

In 1905 Dr. H.P. Cady of the University of Kansas analyzed gas from a natural gas well in Dexter, Kansas, and discovered that it contained almost two percent helium. Afterward, Cady and his colleague, Dr. D.F. McFarland, analyzed 44 samples from natural gas wells in Kansas, and recognized the widespread occurrence of helium in natural gas. Cady spoke wisely when he stated: ". . . helium is no longer a rare element, but a very common element,

existing in goodly quantity for the uses that are as yet to be found for it" (Seibel, 1968).

Techniques for large-scale extraction of helium from natural gas were developed for military purposes. The Germans made much use of hydrogen-filled zeppelins during World War I. These lighter-than-air vehicles could drop bombs from 16,000 feet, which was higher than airplanes of the time could fly. Using rockets that exploded in a shower of sparks, the British learned that a single spark could send a zeppelin crashing to the ground as flaming wreckage. The advantages of using nonflammable helium became obvious, and, by 1917, the U.S. Bureau of Mines was financing research and development of helium-extraction plants. The first significant quantities of helium were not available until the end of World War I. However, research and development continued, and large quantities of helium were available for use as a lifting gas in airships during World War II. Many new uses for helium, some of them related to national defense, were found during the years immediately following the second world war.

HELIUM CONSERVATION

In a 1954 report prepared for the U.S. Bureau of Mines, the need for helium conservation was addressed:

Since the helium occurs in mixture with the natural gas . . . present reserves of helium are being dissipated every day as a part of the large natural gas deliveries to the fuels markets. . . . The alternatives to permitting the rapid disappearance of the helium reserves is to institute an active program for conservation of a large quantity of helium as a national asset for the more distant future [Henrie and others, 1978].

Following this and later studies of helium supply and demand, the federal government passed the Helium Act Amendments of 1960. This act authorized the Bureau of Mines to enter into contracts for the purchase of helium during the following 25 years.

Shortly after the passage of the Helium Act Amendments, several companies constructed helium extraction plants and began selling helium to the U.S. Bureau of Mines under contract agreements. The Bureau pumped the helium into the Bush Dome at its Cliffside-field subsurface geologic storage reservoir near Amarillo, Texas. The helium was injected into the center of the domal-shaped reservoir rock, while natural gas was pumped from the margins. When helium purchases were terminated in 1973, 36 billion cubic feet of helium had been extracted and stored at a cost of more than \$300 million.

HELIUM PROPERTIES AND USES

Helium has a number of unique properties that make it useful in a variety of applications. Originally used only as a lighter-than-air lifting gas, it now has over 75 uses, most of which were developed after World War II. Three major uses—cryogenics, heliarc welding, and purging and pressurizing—account for about two-thirds of domestic helium uses (Figure 1; Table 1).

The following description of helium uses is based on reports by Davis (1980), Henrie and others (1978), and Midwest Research Institute (1977):

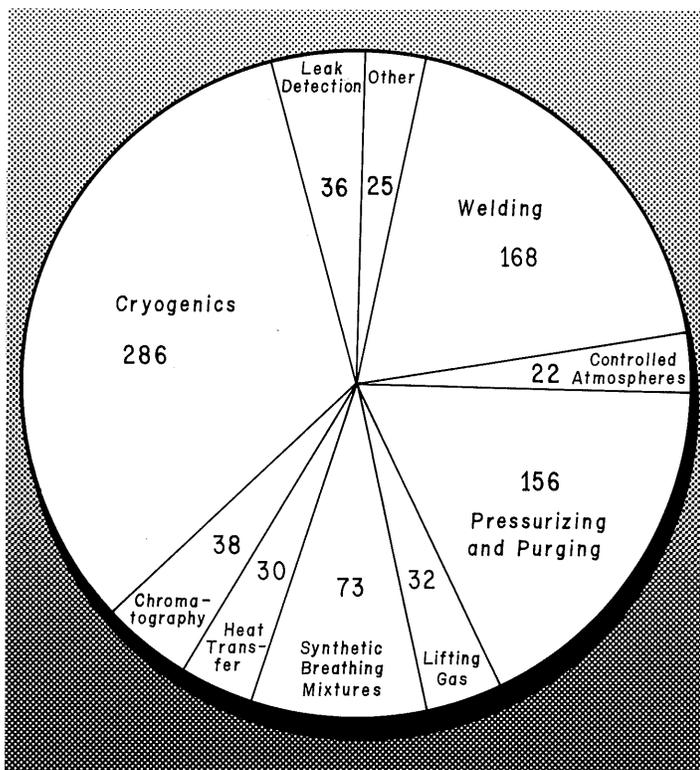


Figure 1. Uses of helium in the United States in 1981, based on U.S. Bureau of Mines data (Tully, 1982). Total helium used in the U.S. was about 866 million cubic feet.

Cryogenics

Cryogenics refers to scientific and engineering work performed at temperatures below about -232°F (-153°C) and above absolute zero, -459°F (-273°C). [It is theoretically impossible to reach absolute zero, although scientists have come extremely close]. Helium is the only known substance that remains liquid at extremely low temperatures and can be used as a coolant to achieve and maintain temperatures within 14°C (25°F) of absolute zero. [Hydrogen, the closest competitor of helium, freezes at -259°C (-434°F)].

At temperatures within a few degrees of absolute zero, some substances become superconductive, a condition in

which the resistance to the flow of electricity is zero. Achieving superconducting temperatures is one of the most important uses of helium, although some materials become superconductive above the freezing temperature of hydrogen. Superconducting electromagnets, for example, produce intense magnetic fields at about one-tenth the operating cost of conventional electromagnets. A major use of superconducting magnets at present is in particle physics research. Research is being done to develop superconducting magnets for magnetic-confinement fusion power generation, MDH (magnetohydrodynamic) power generation and magnetic electricity-storage devices. Superconducting generators and motors are also being studied. Widespread commercial use of these technologies is unlikely for at least the next 20-30 years.

Superconductivity is also important for a number of electronic instruments, including masers (microwave equivalent of lasers) for microwave communications with satellites, highly sensitive infrared detectors for military observation satellites and astrophysical research, and NMR (nuclear-magnetic resonance) imaging, a technique that may replace X-rays in medical applications. Research on superconducting computer elements, and a whole variety of scientific instruments based on superconductivity, could lead to dozens of new uses for helium as a refrigerant.

Welding

Many metals, such as aluminum, magnesium, and stainless steel, cannot be welded together by arc welding under normal atmospheric conditions because the molten metal reacts with oxygen and nitrogen in the atmosphere. These metals can be welded, however, by use of inert-gas-shielded arc welding. In this technique, the electrical arc providing heat to the metal is surrounded by a jet of inert gas that shields the arc and the metal from reactive gases in the atmosphere. Helium is preferred over argon in most situations because it improves weld penetration and appearance, and allows greater welding speed.

Pressurizing and Purging

Helium has a number of properties, including chemical inertness, very low boiling point, low solubility, and low density, that make it ideal for pressurizing and purging such things as rocket fuel tanks. NASA has been the primary

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
WORLD PRODUCTION											
United States	760	647	577	627	647	699	745	808	947	1,001	1,062
Rest of World	90	90	112	122	132	140	146	146	149	149	181
Total World Production*	850	737	689	749	779	839	891	954	1,096	1,150	1,243
U.S. DEMAND PATTERN											
Purging and pressurizing	271	219	164	180	149	116	109	114	140	146	147
Controlled atmospheres	78	63	46	52	53	63	16	19	21	21	21
Welding	72	58	52	57	91	106	97	102	151	157	158
Lifting gas	51	41	23	25	11	11	23	25	29	30	30
Leak detection	48	38	32	36	30	37	25	25	32	34	34
Cryogenics	112	90	104	113	123	127	207	223	258	268	270
Chromatography	16	13	19	21	21	21	25	25	33	35	36
Heat transfer	10	8	9	10	16	37	24	25	27	28	28
Breathing mixtures	5	5	14	16	27	32	55	57	65	68	69
Other uses	7	7	7	5	9	20	20	19	23	24	24
Total U.S. Demand*	670	542	470	515	530	570	601	634	779	811	817

*Estimated Amounts

Table 1. U.S. and world production of helium, and U.S. demand pattern, 1969-1979 (Davis, 1980).

consumer of helium for this purpose. Helium is the only gas that can be used to pressurize liquid hydrogen in rocket fuel tanks because all other gases freeze at liquid hydrogen temperatures.

Breathing Mixtures

Compared to other gases, helium is relatively insoluble in liquids and, therefore, relatively insoluble in human blood. Deep-sea divers, using helium-oxygen breathing mixtures at depths greater than 100-200 feet, can return to the surface much more rapidly than divers using conventional nitrogen-oxygen breathing mixtures. Because nitrogen is more soluble in blood than helium, it will form bubbles upon rapid decompression, a potentially fatal condition known as the "bends." Helium is widely used for breathing mixtures by companies involved in offshore oil and gas exploration and production, and by U.S. Navy divers.

Chromatography

Gas chromatography is an analytic process by which volatile substances can be separated into individual components by flowing the sample and a carrier gas through an adsorbant medium. Helium is preferred as a carrier gas in most cases because of its high thermal conductivity, low solubility, and chemical inertness. About 80 percent of the 40,000 chromatographs in operation today employ helium as a carrier gas.

Leak Detection

Helium is used to detect and locate minute leaks in pressure and vacuum systems because it has the highest diffusion coefficient of any gas (i.e., the ability to go through microscopic holes and to diffuse throughout a medium), and it can be easily detected. Helium detectors are now sufficiently sensitive to detect a leak with a flow rate such that one tablespoon of helium would take 100,000 years to pass through an opening. Leak detection capability has been of great value to the semiconductor, nuclear, aerospace, refrigeration, and food canning industries, as well as to many scientific laboratories.

Lifting Gas

The dangers of using hydrogen as a lifting gas are exemplified by the explosive fire that destroyed the hydrogen-filled dirigible "Hindenberg" in 1937. Helium has 93 percent of the lifting power of hydrogen, but no explosive potential. Primary uses of helium as a lifting gas include weather balloons, upper-atmosphere research balloons, blimps used for advertising (see cover photo), and balloons used to transport logs from inaccessible logging areas to collection points.

Heat Transfer

Helium is an ideal heat transfer medium because it has a high thermal conductivity and high heat capacity, and is chemically inert. Helium is used as the primary coolant in some gas-cooled nuclear reactors. In addition to the properties mentioned above, the high resistance of helium to neutron bombardment makes it ideally suited for this application. Several high-temperature, gas-cooled nuclear reactors (HTGRs) in this country and Europe have demonstrated the benefits of this design over conventional water

or steam-cooled reactors. The Fort St. Vrain Nuclear Generating Station, a 330 megawatt HTGR in Colorado, is this country's only large helium-cooled reactor. Unlike conventional water-cooled reactors, helium-cooled HTGRs use large, massive graphite cores to contain the nuclear fuel. In the event of a total coolant loss, serious damage and potential meltdown of the core of a water-cooled reactor begins to occur within 1-2 minutes, whereas at least 10 hours is required to reach critical temperatures in a helium-cooled HTGR. This feature of HTGRs, plus their greater energy efficiency and reduced nuclear waste generation, should make them attractive to public utilities if and when the utilities resume ordering nuclear power plants (Agnew, 1981).

Controlled Atmospheres

A helium atmosphere is used as an inert environment for the growth of high-purity crystals needed by a variety of industries. Germanium and silicon crystals grown in helium atmospheres are used in transistors and other semiconductors, and other crystals with special optical properties are grown for use in lasers and masers. Helium is also used for the purification of rare metals, such as titanium, and in super-high-speed wind tunnels.

Other Uses

There are numerous other small-volume uses of helium which include medical applications, where helium is used as a carrier gas for potentially explosive anesthetics, and for diagnosis and treatment of respiratory disorders. Other miscellaneous uses include lasers, gas-lubricated bearings and high-speed gyroscopes, particle physics research, and improved light sources.

FUTURE SUPPLY AND DEMAND

With the exception of helium stored in the Cliffside reservoir, almost all of the world's economic helium reserves are mixed with natural gas, and most of these helium-rich natural gas fields are in four states (Texas, Oklahoma, Kansas, and Wyoming). Gas from these fields contains about one-half percent helium, while most other gas fields around the world contain helium in considerably lower concentrations. "Economic", or helium-rich natural gas, is generally considered to be gas with more than 0.3 percent helium. Helium can be recovered from natural gas with less than 0.3 percent helium, but the energy requirements, and therefore the costs, are greater.

Because the demand for helium is small relative to the amount of helium pumped from the ground, helium is not generally extracted from helium-rich natural gas, and is lost to the atmosphere when the gas is burned. As long as excess helium is being pumped from underground natural gas fields, there will be no shortage of helium. When demand can no longer be met by extracting helium from natural gas in pipelines, helium will be available from the Bureau of Mines' helium reservoir. At present rates of helium consumption (about one billion cubic feet per year), helium in the federal storage reservoir could supply helium needs for 35-40 years.

Estimating the present volume of total helium reserves and the rate of helium depletion is subject to many uncertainties. Volumes of known natural gas and helium reserves are only approximately known, and estimates of

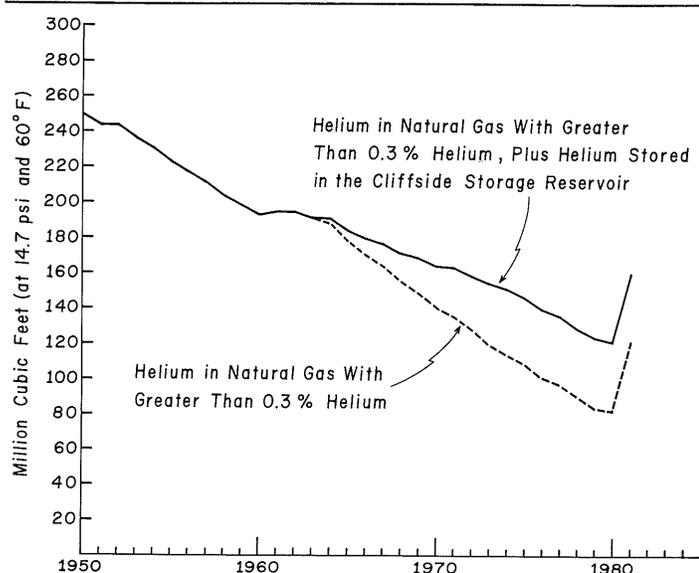


Figure 2. Measured helium reserves in helium-rich natural gas (>0.3 percent helium), in the United States and in the Cliffsides storage reservoir (Hertweck and Miller, 1983). Note that new discoveries have not kept up with depletion of producing gas fields. The large increase in helium reserves in 1981 is due to increased estimates of the amount of helium in the Tip Top field of southwestern Wyoming.

the size and helium content of undiscovered natural gas fields are highly speculative. The U.S. Bureau of Mines reported that U.S. helium reserves, as of January 1, 1979, totaled 743 billion cubic feet. This amount includes 141 billion cubic feet of "measured" (proved) and "indicated" (probable) reserves, 40 billion cubic feet in the Cliffsides reservoir, and 562 billion cubic feet of "hypothetical" (possible) and "speculative" reserves (Davis, 1980). It is predicted that the *helium-rich* natural gas reserves in the U.S. will be depleted within about 30 years, based on rates of discovery and depletion of proven helium-rich natural gas fields (Figure 2; Cook, 1979). *Helium-lean* natural gas will become an economic source of helium at this time, although the cost of recovery will be substantially larger. By the year 2030, the world's natural gas reserves might be nearing exhaustion. At this point, the only remaining sources of helium will be stored helium, and the atmosphere.

Estimating the future demand for helium is also subject to considerable uncertainty. Millions of dollars are spent each year on research and development of helium-intensive energy technologies that, if developed on a large scale, could involve the consumption of large amounts of helium in the early part of the next century. It is ironic that there may be little helium left if and when new helium-intensive, energy-producing technologies become feasible, and conventional energy sources such as natural gas near depletion.

CONCLUSION

The question of helium conservation is well-stated by Cook (1979): "How [do we] decide whether it is worthwhile to pay a present tangible and calculable cost to conserve a finite resource for uncertain and partly intangible benefits that will accrue mainly to future generations?" Efforts during the past decade to revive the helium conservation program have been unsuccessful.

Given current economic problems, it is unlikely that the program will be revived in the near future.

Fortunately, a substantial amount of helium can be conserved without the large expenditure of tax dollars that would be required to revive the helium extraction plants which supply the federal storage reservoir. The Tip Top natural gas field in Wyoming is estimated to contain at least 54 billion cubic feet of helium at a concentration of 0.8 percent (Clark, 1981). Mobil Oil Corporation may soon begin producing natural gas from this field, which will result in loss of its helium reserves. Ninety-five percent of these reserves lie under federal land, and thus, the federal government could require extraction and storage of helium from this gas field, or it could prohibit production until the helium is needed.

As long as our technological civilization exists, helium is likely to be a useful and, in some cases, essential resource. If energy becomes cheap and plentiful in the future, helium can always be extracted from the atmosphere. Should energy become more expensive, as it may if fossil fuels are depleted and other energy sources prove to be costly, helium will be prohibitively expensive for all but the most crucial uses. Given the many unique and outstanding properties of helium, it might be a wise and practical investment in our future to conserve this valuable resource while it is relatively inexpensive to do so.

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LOCAL EVENTS

On October 21, 1983, there will be a symposium on Land Subsidence in Phoenix. Contact Lewis Scott, Arizona Consulting Engineers Association, Suite 111, 3625 N. 16th St., Phoenix, AZ 85016; 602/968-8778.

The 30th Annual Tucson Gem and Mineral Show will be held during February 9-12, 1984 at the Tucson Community Center. For further information, contact the Tucson Gem and Mineral Committee, PO Box 42543, Tucson, AZ 85733.