WYOMING STATE GEOLOGICAL SURVEY
Erin A. Campbell, Director and State Geologist

# Helium in Wyoming

Kelsey S. Kehoe

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*Cover photo: The Madison Limestone, which hosts reservoirs high in helium in the western part of the state, forms the core of the Rattlesnake Mountain Anticline at Cedar Mountain near Buffalo Bill Reservoir.*

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## INTRODUCTION

Helium has been recognized as a critical and strategic element since World War I. This noble gas is indispensable to a variety of industries ranging from healthcare to aerospace, but its supply is exhaustible. Currently, the only commercially viable helium accumulations are found in gas reservoirs, although very trace amounts also occur in groundwater, soils, and rocks. As a result, helium is produced as a by-product of natural gas, but only when it can be done economically, and supplies remain dependent on trends in the natural gas industry. Increasing demand coupled with major shifts in the helium industry, natural gas production, and global geopolitics have driven a series of worldwide supply shortages and price spikes over the past two decades. These shortages underscore the necessity of helium for advanced manufacturing and research, propelling a new wave of interest and exploration for this resource.

Much has changed across the industry since the Wyoming State Geological Survey last covered the subject in depth (Clark, 1981; De Bruin, 1995). The Shute Creek gas plant in western Wyoming has established itself as one of the world's largest, most reliable suppliers of refined helium. Globally, liquefied natural gas (LNG) has become another major source of helium, as the massive volumes of gas involved makes helium extraction from trace occurrences profitable. Lastly, federal helium operations are in the final stages of a decades-long privatization process, and the federal reserve of helium has been sold, marking the end of a program that held a dominant, often monopolistic position in the market.

The purpose of this publication is twofold: first, to make available a Wyoming-specific dataset of helium concentrations, with other gas analyses, from wells for use in future resource evaluation and exploration; and second, to provide a broad overview of the helium industry with a focus on factors influencing current trends.

## HELIUM'S MANY USES

Helium is a unique element with properties that are not easily replicated or substituted. Compared to other elements, it has the smallest atomic radius, the lowest boiling point, the second-lightest mass, high thermal conductivity, rapid diffusion, very low water solubility, and it is chemically inert. These properties make it a crucial component (table 1) in many commercial, industrial, and research applications (National Research Council, 2010). This report is concerned with naturally occurring helium, which dominantly consists of the stable isotope helium-4, and forms as a product of radioactive decay of uranium and thorium. The other stable helium isotope, helium-3, is very rare on Earth, and its supply has typically been the byproduct of nuclear weapons programs.

Helium was first detected in the sun's spectrum in 1868, and only later discovered on Earth in 1895. For the first few decades after its discovery, helium was little more than a scientific novelty. The liquefaction of helium, which requires extremely low temperatures, was first accomplished in 1908, and its cryogenic properties led to the discovery of superconductivity (Sears, 2012). Widespread interest in the element did not occur until later that decade during World War I, when its lighter-than-air density and non-flammability made it an appealing alternative to hydrogen for use as a lifting gas for military airships. Not long afterwards, a second use was found for helium—as a component of breathing mixtures for underwater diving, with the purpose of mitigating nitrogen toxicity, also known as "the bends" (Levitt, 2000).

The discovery of a process to create high-purity helium (greater than 99.0 percent pure, commonly referred to as Grade-A) in 1949 led to a rapid expansion of applications that took advantage of helium's inimitable properties (Sears, 2012). Many industries are reliant on a steady, stable supply of Grade-A helium, and shortages can impact electronics manufacturing, scientific research, and the medical and aerospace industries. While helium is still used as a lifting gas, in breathing mixtures, and in welding, the demand for these uses has largely been outpaced by demand in "high-technology" applications (Clarke and others, 2014). Beginning in the 1990s, widespread adoption of medical magnetic resonance imaging systems was a significant driver of increasing helium consumption. Currently, the greatest demand for helium is for use as a liquid refrigerant in medical magnetic resonance imaging systems, where the low boiling point of helium maintains the magnets at temperatures needed for superconductivity. Helium also plays an important role in manufacturing of both semiconductors and fiber-optic cables, where it is used as a controlled atmosphere which minimizes defects during growth of silicon and germanium crystals and prevents impurities in fiber-optic cable as it is formed. Helium is also a critical component of scientific research, where liquid helium cools superconducting magnets for particle physics experiments and nuclear magnetic resonance spectroscopy, and helium is used as a carrier gas for chromatography.

## HELIUM PRODUCTION

Helium is a trace component of most natural gas, but in some reservoirs it occurs at high enough concentrations to justify the installation of separation and purification equipment to produce helium as a by-product. For the majority of gas production though, helium extraction has not been an economical option, so it remains in the gas

**Table 1.** Uses of helium and relevant properties. Modified from Clark (1981), tables 9.2, 9.3, and 9.4 in Cai and others (2012), and Boreham and others (2018).

| Application | Applicable properties and benefits |
|---|---|
| Cryogen for superconductors used in magnetic resonance imaging systems, nuclear magnetic resonance spectroscopy, magnetometers, tokamaks, particle accelerators, particle detectors | Lowest boiling point of any element; remains liquid at absolute zero and atmospheric pressure; maintains conditions required for superconductivity |
| Cryogenics, other uses including high-sensitivity receivers and sensors, telescopes, cryo-electron microscopy | Lowest boiling point of any element; remains liquid at absolute zero and atmospheric pressure |
| Controlled atmosphere for semiconductor manufacturing | Inert, stable atmosphere; high thermal conductivity; ideal atmosphere for growing silicon and germanium crystals with minimal impurities |
| Optical fiber manufacturing | Inert, ultra-pure atmosphere; high thermal conductivity |
| Shield gas for arc-welding | Inert, ultra-pure atmosphere; high thermal conductivity; minimizes potential contaminants or defects in weld |
| Leak detection | Smallest atomic size; high permeation rate; low atmospheric concentration |
| Lifting gas for balloons and airships used in meteorology, defense, surveillance, parties, parades | Only hydrogen is lighter; inert; less reactive than hydrogen |
| Breathing mixtures for deep-sea diving | Low solubility in water |
| Medical treatments with helium-oxygen mixtures | Low gas density; decreased flow turbulence |
| Supersonic and hypersonic wind tunnels | Low liquefaction point |
| Helium-filled high-capacity hard drives | Decreased flow turbulence |
| Carrier gas for analytical instruments | Inert, low molecular weight |
| Propellant gas for metal spray coatings | High sonic velocity |
| Particle physics experiments | Superfluidity below -455.5°F |
| Heat transfer medium in gas-cooled nuclear reactors | High thermal conductivity; radiologically inert |
| Pressurizing and purging aerospace fuel systems | Inert; low solubility; low boiling point; high liquid-to-gas expansion ratio |

stream, escaping into the atmosphere during gas processing, transportation, or use. Once released into the atmosphere, helium resides there for a brief time, estimated on average one million years, before diffusing into space (Allègre and others, 1987). The low concentration of atmospheric helium, 5.2 parts per million (Holland and Emerson, 1987), makes its recovery from air extremely energy intensive and prohibitively uneconomic. Like the non-biogenic methane that helium mixes with in a gas reservoir, it is a non-renewable resource.

For this reason, commercial helium production has largely been a by-product of natural gas production. A longstanding rule of thumb is that 0.3 percent helium content is the cutoff for a "helium-rich" gas, thus defining economic helium deposits (National Research Council, 2010).

More recently, there has been growing interest in gas reservoirs with concentrations below the 0.3 percent benchmark, thanks in part to advances in natural gas liquefaction technology. During this liquefaction process, one of the byproducts is a stream of non-condensable gas, consisting of mostly nitrogen, with minor amounts of noble elements including helium, which is concentrated relative to the raw natural gas. Often this tail, or purge, gas will be vented for disposal, but in some locations it has been redirected to become the feed gas at a helium plant. LNG facilities in Qatar, Algeria, and Australia have added helium plants to process tail gas. Qatar and Algeria have since become the second- and third-largest helium producers, respectively (Boreham and others, 2018). In Algeria the gas that feeds the LNG facilities is from the Hassi R'Mel field, with 0.19 percent helium (Reinoehl, 2012). At the Ras Laffin plant in Qatar, the original helium content of the produced gas is even lower, only 0.04 percent, but after liquefaction the tail gas contains 32 percent helium (Boreham and others, 2018). Qatar is one of the top three largest exporters of liquefied natural gas, and the sheer volume of gas processed at the Ras Laffin plant makes helium separation and refinement a valuable addition. A study by Boreham and others (2018) found that 14 out of 18 proposed or existing LNG facilities in Australia were likely to have tail gases with economic quantities of helium.

Domestically, the shift in natural gas exploration targets from conventional to shale gas impacted the helium supply in a few different ways. The abundance of cheaper shale gas has made some conventional gas deposits uneconomic, and that impacts co-production of helium— for example, the Keyes Field in Oklahoma, which is one of the longest-running helium-producing fields, has become uneconomic (Clarke and others, 2014). Vertical drilling in traditional reservoirs is more likely to yield elevated or economically viable concentrations of helium, whereas shale gas typically has lower helium concentrations, decreasing the likelihood of discovering new helium deposits (Anderson, 2018).

For these reasons, as well as the continued potential for further shortages, exploration that specifically targets helium-rich resources—pure helium plays—is on the rise. These target low-heating-value gas reservoirs that are primarily nitrogen or carbon dioxide, with helium content up to 10 percent (Tedesco, 2022). Some regions where this type of exploration is most active includes the Four Corners area, northern Montana, Saskatchewan, and Tanzania (Yurkowski, 2016; Wiseman and Eckels, 2020; Mtili and others, 2021; Halford and others, 2022).

## FEDERAL HELIUM PROGRAM

Over the decades, the United States Government has viewed helium strategically as a military advantage, a political tool, and as a driver of innovation in technologies for aerospace, physics, and medical industries (Levitt, 2000). The government's involvement in the helium industry began with interest from the military during World War I (Sears, 2012). Concerns about the dependency of helium supplies on natural gas production, combined with internal demand, laid the groundwork for creation of a federal helium program, which was responsible for managing and conserving the country's helium resources in order to ensure a continuous and reliable supply for federal agencies. For the majority of its existence, the federal helium program was run by the U.S. Bureau of Mines (USBM), and following that agency's elimination in 1996 it was transferred to the Bureau of Land Management (BLM). The program included helium separation and refining facilities, 450 miles of gas pipeline extending from Kansas through Oklahoma into Texas, long-term crude helium storage (the federal helium reserve at Cliffside Field in Texas), close tracking of remaining resources, research laboratories, and a long-running sampling program to identify new reservoirs. These developments positioned the U.S. Government to become the dominant producer of helium for the majority of the 20th century.

The origins and early years of the federal program through 1940 are covered in detail by Levitt (2000), while Sears (2012) provides an excellent overview of the federal program from its beginning through 2012, and is particularly insightful in the later decades of the program. Kornbluth (2015) discusses the federal helium program from 1990 through 2015 in the context of a growing private and international helium industry.

Here is only a short summary of the federal helium program, following the framework of Lacey and others (2020) which outlines the program's evolution in five major periods. The consolidation period, from World War I to the end of World War II, included restrictions on producing helium from federal lands by the Minerals Leasing Act of 1920, and gave the federal program a monopoly on helium production after passage of the 1937 Helium Act. During the early Cold War period, spanning 1945–1959, the government's monopoly continued while demand from both government agencies and the private sector grew dramatically, resulting in shortages during 1957 and 1958. The conservation period, 1960–1980, included the creation of the federal helium reserve at Cliffside Field, the successful reentry of private companies into the helium industry, and declines in government helium demand, which all contributed to the federal helium program's increasing debt. The privatization period, 1987–2013, began as private consumption started to outpace federal demand, and federal consumption continued to decline (Crawford, 1987; Sears, 2012). The passage of the Helium Privatization Act in 1996 outlined a process for the government to stop producing helium, sell the helium reserve in order to reduce debt incurred by the program, and eventually transition the program's facilities into private ownership. Sales of crude helium from the reserve began to undercut private producers in the mid-2000s, driving private companies out of the helium industry and leading to higher-than-predicted withdrawals from the reserve. In response to these negative impacts, the Helium Stewardship Act was passed in 2013, beginning the stewardship period, which aimed to minimize the effects of the reserve sales on the helium market and provided for a less aggressive timeline to complete the privatization process. The last of the federal helium reserve was auctioned in 2018. As of fall 2023, the General Services Administration is in the process of selling the remaining assets, including Cliffside Gas Plant, plant equipment, natural gas wells, the helium pipeline, and the Cliffside storage reservoir. The sale will likely be finalized in 2024.

Another longstanding complication hampering private development of helium was the process of producing helium from federal leases. The Minerals Leasing Act of 1920 kept helium under federal ownership if separated from the natural gas produced from federal lands. This required that any helium yielded from these leases had to be sold to the federal government at a fixed price, uninspiring terms which did little to encourage private production. Operators were also required to hold an active oil and gas lease for helium production. However, to hold such a lease, economic quantities of natural gas or oil had to be produced, posing a significant challenge for helium deposits found in gas reservoirs with low methane content. In 2019, passage of the John D. Dingell, Jr. Conservation, Management and Recreation Act (Public Law 116–9, sec. 1109) modified the Minerals Leasing Act so that federally owned helium resources could be leased via the same process as federal leases for oil and gas, without requiring a secondary oil and gas lease, creating a clearer pathway for helium development and exploration on federal lands.

## GLOBAL HELIUM MARKET

Prior to the 1990s, the United States dominated the global helium market. From 1937 to 1960, the only major producer of helium in the world was the USBM (Minarik and others, 1991). Private companies entered the domestic market in response to the 1960 amendments to the helium act and began contributing to the federal helium reserve. The first helium plant built internationally appears to have been a small plant near Swift Current, Saskatchewan, Canada, which began operating in 1963 (Sears, 2012). During the 1970s, France, Poland, and Russia also constructed helium plants. Although these plants produced relatively small volumes of helium, it was enough to begin exports (Sears, 2012). While the global market was beginning to diversify, United States exports continued to grow as domestic demand slowed.

In the 1990s, technological advances, particularly in magnetic resonance imaging systems, drove helium demand higher (Kornbluth, 2015). By 1994 U.S. exports comprised two-thirds of helium purchases worldwide (Lacy and others, 2020). The following year, a helium plant at Algeria's Arzew LNG facilities came online and became the first to process helium from LNG tail gas (Reinoehl, 2012). This production represented the first significant source of helium outside of the United States (Mohr and Ward, 2014).

Supply-side shortages emerged as a major issue around the turn of the 20th century, and prices began climbing upwards (U.S. Geological Survey [USGS], 2019b). In 2003, the BLM began to sell crude helium (containing 50–80 percent helium) from the Federal Helium Stockpile to keep private helium refining plants operating at capacity (Kornbluth, 2015). This delayed, but did not prevent, looming shortages. In 2006, new plants in Algeria and Qatar experienced delays while starting, triggering a brief global shortage in helium (Cai and others, 2010). A few years later, production shortfalls once again drove a major global helium shortage from 2011 into 2014 (Kornbluth, 2015).

Following this unprecedented shortage, global demand for helium was slow to recover (Anderson, 2018). Additional shortages followed: first, in 2018–2020, in part due to the Qatar trade embargo, which forced Qatar—supplier of about 30 percent of global helium—to temporarily shut down its helium plants due to the blockade of export routes by neighboring countries (Lacy and others, 2020). In 2022, more supply shortages were driven by an unexpected six-month shutdown of facilities at the BLM's Helium Operations in Texas (USGS, 2023) and issues at a new Russian plant, which experienced catastrophic fires shortly after coming online (Kornbluth, 2022).

Each of these shortages impacted the wide range of helium consumers through steep price increases and rationing. At present, safeguarding the U.S. supply of helium against future shortages is of critical concern for the industry.

## HELIUM PRODUCTION IN WYOMING

ExxonMobil's LaBarge-Shute Creek Treating Facility (Shute Creek), in Lincoln County, has become a major supplier of Grade-A refined helium since it began operations in October 1986 (fig. 1). The plant's production catapulted Wyoming to the second-largest producer of refined helium in the country (Minarik and others, 1991). Since then, Shute Creek has only increased its market share. In the past few years, helium production at Shute Creek accounted for about 25 percent of global totals (National Minerals Information Center, 2022, 2023).

In addition to helium, Shute Creek separates for sale carbon dioxide and methane, and previously produced elemental sulfur (Wyoming Oil and Gas Conservation Commision [WOGCC], 2023). The incoming gas stream at Shute Creek consists of 65 percent carbon dioxide, 22 percent methane, 7.4 percent nitrogen, 5 percent hydrogen sulfide, and 0.6 percent helium (Jensen and others, 2018). The natural gas is produced from deep wells (greater than 15,000 feet) in the Mississippian-age Madison Limestone at a structural high known as the LaBarge platform. The LaBarge platform is part of the Moxa Arch, a basement involved anticline along the western margin of the Greater Green River Basin; the platform is along the northern end of the arch, where it passes beneath the eastern extent of the Wyoming Overthrust Belt. The LaBarge platform hosts two structurally separate, and compositionally distinct, petroleum systems: a shallow system hosted in Mesozoic and Cenozoic strata and a subjacent system hosted in deep Paleozoic strata, in association with the west-vergent basement-involved thrusts near the crest of the Moxa Arch (Johnson, 2005; Becker and Lynds, 2012). It is these deeper, older reservoirs that contain helium- and carbon dioxide-rich natural gas. Additional detailed information on the geology of the LaBarge platform and the Paleozoic reservoirs may be found in Kraig and others (1987), Stilwell (1989), Royse (1993), Johnson (2005), Lynds and others

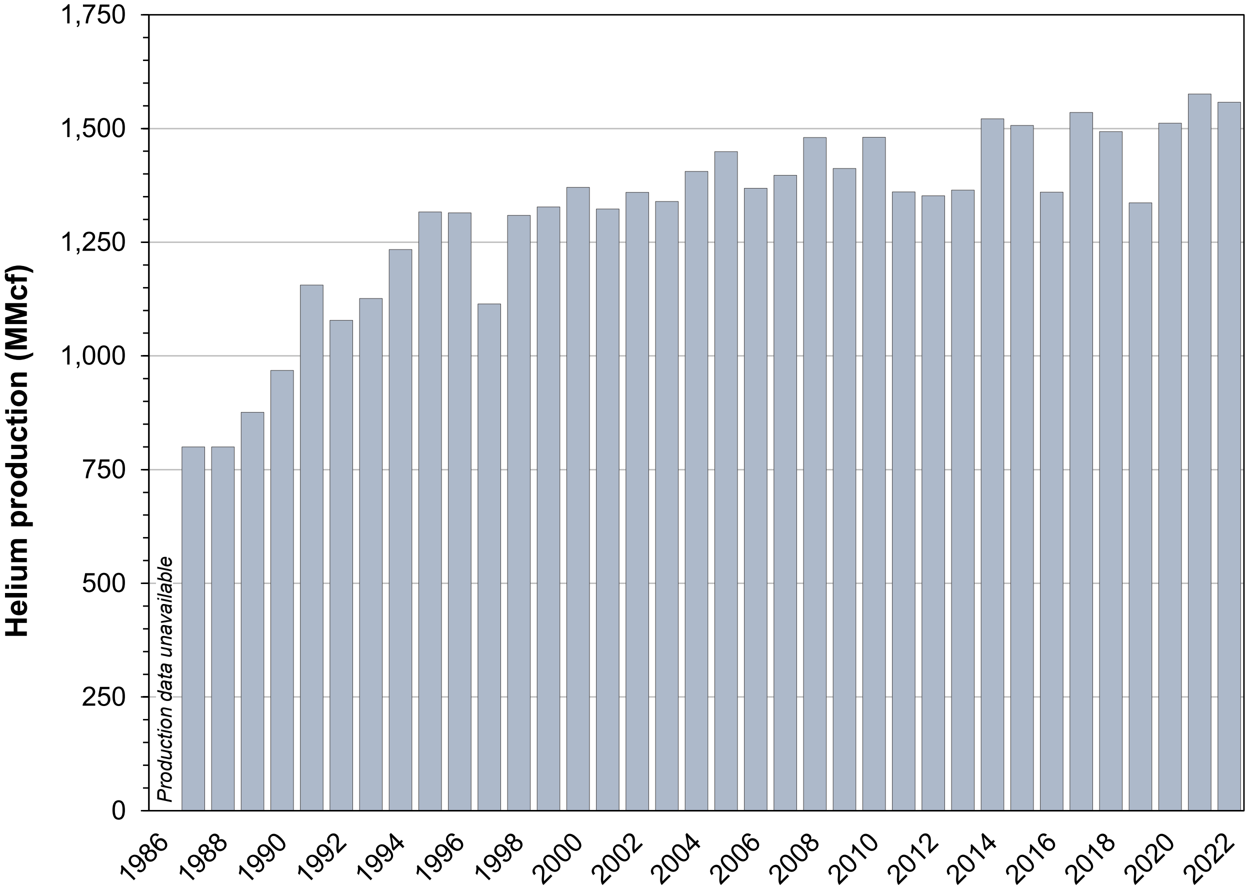

**Figure 1.** Graph of annual helium production at Shute Creek gas plant. Production in million cubic feet (MMcf). Production for 1986 was unavailable. Totals for 1987 and 1988 are estimated based on Hamak (1989) and annual Mineral Yearbook reports for Wyoming (Rice and Glass, 1989; Starch and others, 1990). For the remaining years, production volumes are from individual gas plant volumes and Form 9 filings from the Wyoming Oil and Gas Conservation Commission data site (WOGCC, 2023).

(2010), King and others (2013), and Merrill and others (2014, 2015).

Beginning in the 1920s, intermittent oil and gas development at the LaBarge platform focused on the shallow, younger system, producing from sandstones in the "Almy" member of the Eocene Wasatch and Paleocene Evanston formations (Dunnewald, 1969; McDonald, 1973) and later from Cretaceous strata. Over the first few decades of activity, limited access to markets was a significant factor curbing gas production (Shipp and Dunnewald, 1962). That changed with plans for the Pacific Northwest Pipeline, which would pass through the southwestern corner of Wyoming as it transported natural gas from New Mexico and Colorado to major cities in Washington, Oregon, and Idaho. Beginning in 1952, exploration at the LaBarge platform ramped up in anticipation of pipeline construction. Within a few years, enough reserves had been identified in Paleogene and Cretaceous reservoirs to justify construction of a 60-mile-long lateral connecting with the main pipeline at Opal (Krueger, 1955).

Successful development at the LaBarge platform led to targeting of older and deeper strata. In the early 1960s, wells drilled into Paleozoic formations found multiple showings of non-flammable, sour gas. A large Paleozoic gas system had been discovered, but the gas was unmarketable—it had high concentrations of carbon dioxide and hydrogen sulfide, and low heating value. Most of these early deep wells were plugged back and recompleted in shallower Cretaceous reservoirs for commercial gas production (Shipp and Dunnewald, 1962).

In the early 1980s, Exxon began developing the Madison Limestone's gas resources, the largest reservoir in the Paleozoic system at the LaBarge platform (Hunter and Bryan, 1987; Stilwell, 1989). This was motivated by two factors: gas processing technology had advanced to the point that methane could be economically extracted from this sulfurous, non-flammable gas stream, and the rise of enhanced oil recovery techniques involving carbon dioxide injection created a market for the associated carbon dioxide (Hunter and Bryan, 1987). Other gas components also held potential value—sulfur could be recovered from the hydrogen sulfide, and the helium could be refined for sale as high-purity liquid helium. However, the extraction of helium from the LaBarge platform required extensive negotiations with the federal government because gas production at this location was from federally owned minerals, and due to specific stipulations in the Minerals Leasing Act of 1920, the U.S. government was guaranteed rights to all helium produced on leased federal land (Sears, 2012).

While methane and carbon dioxide appear to have been the primary products driving development at Exxon's Shute Creek plant, the company recognized early on that the large quantity of helium they could produce as a by-product would make them a major supplier (Hunter and Bryan, 1987). As the market for carbon dioxide slowed (Gill, 1992; Parker and others, 2011), natural gas prices dropped (Crawford, 1987), and the sulfur market weakened (Wall and Kenefake, 2005), helium became the primary product of the plant.

Initially, the plant had the intake capacity of 480 million cubic feet per day (MMcf/day) natural gas, with outputs of 114 MMcf/day methane, 250 MMcf/day carbon dioxide, and 2.2 MMcf/day equivalent liquid helium (Hunter and Bryan, 1987). In 1987, the plant operated at capacity, processing 179 billion cubic feet (Bcf) of natural gas to produce approximately 120 Bcf carbon dioxide (DeBruin, 1989) and 800 MMcf helium (Hamak, 1989). Over the course of that first year, gas was produced from 15 wells in three lease areas—the Fogarty Creek, Lake Ridge, and Graphite units (WOGCC, 2023).

Since initial operations, upgrades to the plant and "debottlenecking" processes have resulted in a doubling of helium production (Jensen and others, 2018; WOGCC, 2023;) despite numerous challenges, including the plant's remote location, as well as the acidic, corrosive composition of the gas due to high carbon dioxide and hydrogen sulfide content, and sulfur deposition in wellbores (Hunter and Bryan, 1987; Voorhees and others, 1991; Wall and others, 2005; Martin and others, 2008; Parker and others, 2011). In 2022, the plant processed 243 Bcf of natural gas from the same 15 wells (WOGCC, 2023), producing 163 Bcf carbon dioxide and 1.56 Bcf helium.

Construction of a second helium plant, Riley Ridge, began in 2010 to process natural gas from the Madison Limestone in the Riley Ridge field, just north of the fields feeding Shute Creek. Denbury became the full owner and operator of the wellfield and the under-construction plant in 2011. The plant would send crude helium to a nearby helium refining unit being constructed by Air Products & Matheson Tri-Gas, which had contracted for deliveries of crude helium from Riley Ridge. The Riley Ridge plant came online in 2014 after construction delays; soon after, sulfur deposition began slowing well flows. After purifying 25.4 MMcf of helium in the first half of the year, the sulfur issues became insurmountable and the Riley Ridge wells were shut in (WOGCC, 2023). In the summer of 2023 ExxonMobil announced its acquisition of Denbury, including the Riley Ridge field and plant. As of this report's publication in October 2023, the purchase has not yet been completed.

## DATA COMPILATION

In order to provide a comprehensive, single dataset for helium in Wyoming, table A1 of the appendix contains 1,204 natural gas analyses, reported in mole percent (hereafter referred to as percent), that were compiled from multiple public sources, primarily the USGS, USBM, and WOGCC. The majority of analyses are from the Federal Helium Program's national surveying program, run by USBM and later by the BLM, from 1917 through 2007. This program was created to identify new helium resources in natural gas reservoirs. Sample acquisition relied primarily on the donation of gas samples from petroleum operators. Using in-house instruments, USBM compiled thousands of natural-gas analyses from wells and pipelines in a large number of gas fields across the country. Results of these gas analyses were released in a series of publications from 1951 through 2008 (Anderson and Hinson, 1951; Boone, 1958; Munnerlyn and Miller, 1963; Miller and Norrell, 1965; Moore, 1982; Moore and Sigler, 1987; Hamak and Sigler, 1991; Hamak and Gage, 1992; Hamak and Sigler, 1993; Sigler, 1994; Hamak and Driskill, 1996; Gage and Driskill, 1998, 2003, 2005; Driskill, 2008). These helium survey analyses were recently digitized by the USGS in preparation for a national helium assessment (Brennan and others, 2021c). In 2021, USGS released two datasets (Brennan and others, 2021a, 2021b) that incorporated USBM and BLM survey results, plus additional analyses from an internal BLM database and USGS Energy Geochemistry Database (USGS, 2019a).

The dataset provided in Appendix table A1 contains Wyoming-specific analyses of samples from wells and pipelines (Brennan and others, 2021a, 2021b) plus gas analyses from the WOGCC that included measurements for helium. These data have been through a process of verification, including cross-checking between datasets, removing duplicates, verifying well existence using WOGCC data, and correcting sample or well information as possible.

**Table 2.** Distribution of gas samples collected from wells and pipelines by Wyoming county and helium concentration.

| County | Total samples | Number of samples | | | |
|---|---|---|---|---|---|
| | | No reported helium value | Less than 0.05% He | 0.05–0.29% He | 0.3% helium and greater |
| Albany | 1 | 0 | 0 | 1 | 0 |
| Big Horn | 32 | 18 | 8 | 6 | 0 |
| Campbell | 110 | 83 | 25 | 1 | 1 |
| Carbon | 93 | 44 | 34 | 15 | 0 |
| Converse | 17 | 5 | 8 | 4 | 0 |
| Crook | 4 | 3 | 1 | 0 | 0 |
| Fremont | 160 | 47 | 104 | 7 | 2 |
| Hot Springs | 15 | 3 | 4 | 8 | 0 |
| Johnson | 25 | 12 | 12 | 1 | 0 |
| Lincoln | 62 | 8 | 40 | 11 | 3 |
| Natrona | 48 | 22 | 19 | 5 | 2 |
| Niobrara | 45 | 25 | 6 | 8 | 6 |
| Park | 76 | 28 | 33 | 14 | 1 |
| Sheridan | 7 | 7 | 0 | 0 | 0 |
| Sublette | 157 | 23 | 53 | 10 | 71 |
| Sweetwater | 268 | 81 | 130 | 33 | 24 |
| Teton | 1 | 0 | 0 | 0 | 1 |
| Uinta | 69 | 20 | 33 | 16 | 0 |
| Washakie | 10 | 4 | 6 | 0 | 0 |
| Weston | 4 | 1 | 3 | 0 | 0 |

Appendix table A2 includes well header information, sourced from WOGCC and Wyoming State Geological Survey (WSGS) data, for sampled wells in table A1 (Toner and others, 2016; WOGCC, 2023). Two additional tables are included in the appendix: table A3 contains analyses of samples from sources other than oil and gas wells, such as natural springs or water wells; and table A4 contains a list of the samples that were excluded from table A1 because major aspects of the sample information could not be verified—in most of these cases, well information could not be confidently matched to WOGCC data or historic card files.

The resulting Wyoming dataset (Appendix table A1) contains samples primarily from individual oil and gas wells, while 15 samples were from pipelines and represent a bulk mixture of multiple wells. Samples are from most of the basins across the state and from 20 out of 23 counties (table 2). No analyses were found for the Denver Basin and Goshen Hole in Goshen, Laramie, and Platte counties. Other counties with sparse data include Albany, Crook, Sheridan, Teton, and Weston counties. Samples are from 327 different oil and gas fields (fig. 2) and 22 samples are from wildcat wells (fields follow WSGS field designations from Toner and others, 2016).

Due to the multiple data sources and the timespan over which analyses were conducted, there are some minor internal inconsistencies in the Wyoming dataset, including results reported to different significant figures and variations in the suites of components analyzed.

Over the course of the USBM's helium survey program, analyses were collected with evolving instrumentation as technology improved. Initially, helium content was measured using a specialized helium apparatus developed by USBM personnel (Anderson and Hinson, 1951; Boone, 1958). In 1978, the program began using a gas chromatograph (Moore and Sigler, 1987). An Orsatz apparatus was the primary instrument used to measure the other gas components until 1949, at which point the program switched to mass spectrometry (Moore and Sigler, 1987). Further details about the program's sampling and analytical methods are explained in USBM publications by Boone (1958) and Moore and Sigler (1987). Due to limitations of the Orsatz method, analyses made before 1949 have some shortcomings, and a greater degree of uncertainty should be considered when evaluating these older results, as thoroughly explained by Anderson and Hinson (1951). Quirks of the early data include probable overestimates of calculated carbon dioxide concentrations due to

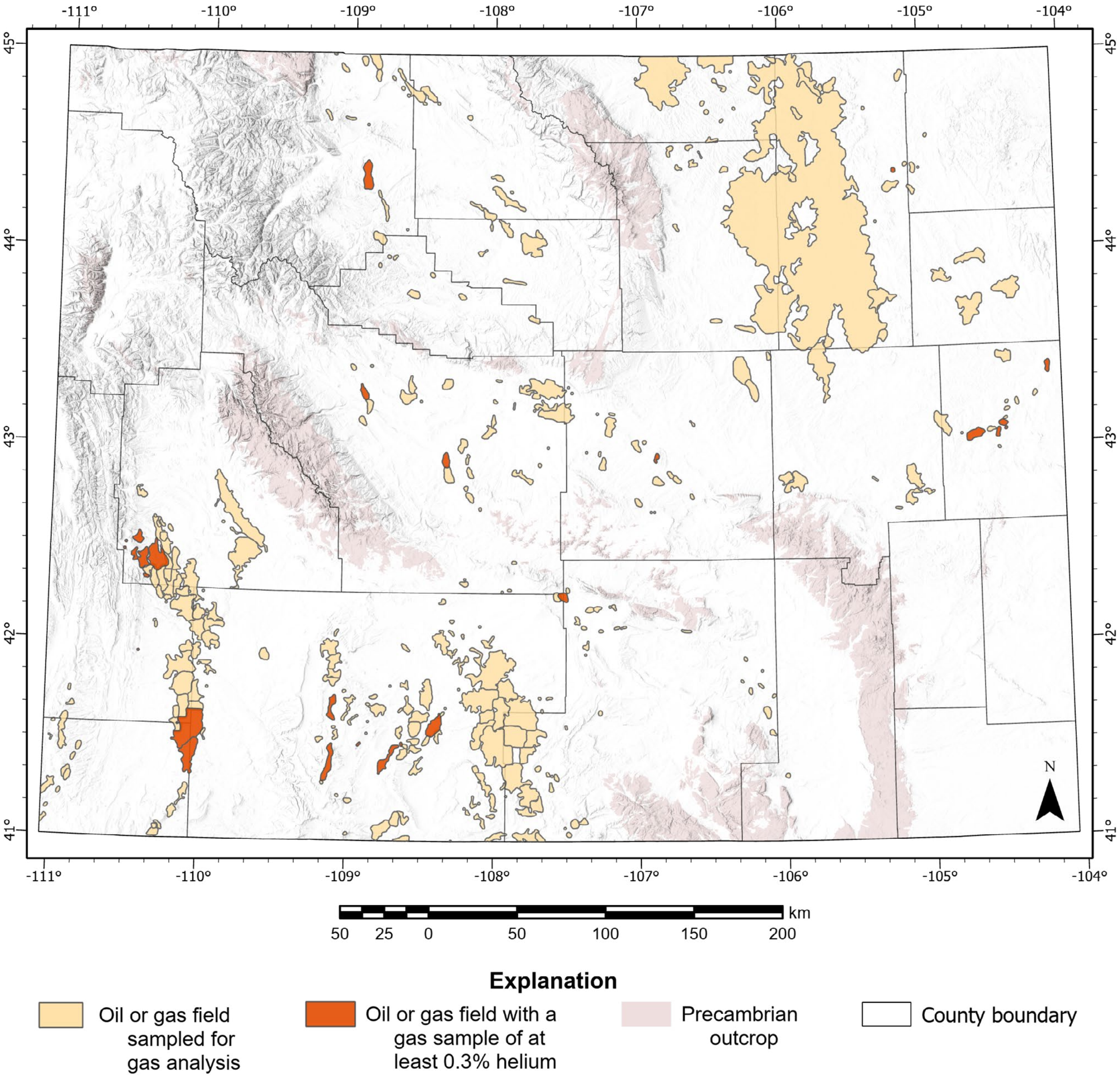

**Figure 2.** Map of Wyoming showing locations of sampled oil and gas fields. Fields where a sample contained 0.3% or greater helium are in orange.

the absorption of other acidic gases like hydrogen sulfide during carbon dioxide measurement; and limited hydrocarbon differentiation—although the total hydrocarbon measurement is accurate, the method only determines the correct amount of methane, reporting all heavier hydrocarbons with ethane.

## OCCURRENCES OF HELIUM IN WYOMING

Of the 1,204 natural gas samples in the dataset (Appendix table A1), 770 samples (64 percent) contained measurable quantities of helium (table 2), and concentrations of 0.3 percent and above were found in 111 samples (9.2 percent of all samples). The remaining 434 samples have no value reported for helium, which indicates that the sample was either not analyzed for helium or helium was not detected during analysis. These blanks are artifacts of the original datasets.

Helium-rich samples (0.3 percent helium or greater) are concentrated in 24 of the sampled fields. These fields are listed in table 3 to show the distribution of helium-rich samples by formation in each field. Some of the fields have been depleted, abandoned, or shut in since sampling, and the current status of each field is reported in table 4.

Not unexpectedly, the most heavily sampled helium-rich fields—Fogarty Creek, Lake Ridge, Riley Ridge, and Tip Top—are those located at the LaBarge platform, where exploration for helium resources has been most concentrated. These analyses show other Paleozoic units also host helium-rich gas, including the Amsden Formation, Bighorn Dolomite, Darby Formation, and Phosphoria Formation (table 5). However, the Madison Limestone is by far the biggest helium reservoir at the LaBarge platform—Debruin (1995) estimated the recoverable helium resources in the Madison are one to two orders of magnitude larger than those in the other Paleozoic units.

Beyond the helium-rich LaBarge platform, there are a handful of other helium occurrences worth highlighting. The three highest helium concentrations in Wyoming come from gas samples in the Mule Creek West Field in the southeastern Powder River Basin (table 4). The Pennsylvanian Amsden Formation was sampled twice in one well from this field, and the helium in the samples measured 1.82 and 1.4 percent. A gas sample from the Pennsylvanian Minnelusa Formation collected from a second well in that field had 1.5 percent helium. However, the reservoirs at Mule Creek West Field are reportedly depleted (Clark, 1981). Further south in the Powder River Basin a cluster of four helium-rich gas samples were collected from Pennsylvanian strata in the Buck Creek, Kuehne Ranch Southeast, Lance Creek, and Little Buck Creek fields (table 4).

In the eastern Wind River Basin, helium-rich gases were sampled from the Pennsylvanian Tensleep Formation and the Permian Embar (Phosphoria) Formation at Pine Mountain Field. Other high helium samples collected in the Wind River Basin are from the Tensleep Formation at Riverton Dome East Field and the Amsden Formation at Steamboat Butte Field.

One helium-rich gas sample was collected in the Bighorn Basin from the Cambrian Gros Ventre Formation in the Oregon Basin Field. Only one sample was collected in Jackson Hole, a helium-rich gas from a wildcat well in the Triassic Dinwoody Formation.

The Greater Green River Basin hosts six helium-rich fields separate from those at the LaBarge platform. Along the southern half of the Moxa Arch are the Church Buttes and Bruff fields, which both have a helium-rich gas sample from the Madison Limestone. Based on these data, DeBruin (1995) estimated 3.30 Bcf of recoverable identified helium resources in the Madison at Church Buttes Field. In the center of the Rock Springs Uplift, helium-rich gases were collected from the Madison Limestone and Weber Sandstone in the Baxter Basin North Field and from the Cretaceous Dakota (Cloverly) Formation in the Baxter Basin South Field. In the eastern half of the Greater Green River Basin, gas samples from the Nugget Formation in the Brady Field and the Madison Limestone in the Table Rock Field were helium-rich. One wildcat well in Sweetwater County is associated with a helium-rich sample from the Phosphoria Formation.

In the Overthrust Belt, helium-rich samples were found in two fields—one from the Madison Limestone in the Hoback III Field and one from the Amsden Formation in the Horse Trap Field. Both fields have been abandoned, and it is unclear if the Hoback III Field ever produced from the Madison. Additionally, a sample from the Madison Formation in a wildcat well in Lincoln County contained more than 0.3 percent helium.

**Table 3.** Fields with gas samples containing 0.3% helium or higher, showing the number of samples collected from each formation and the the elevated helium value(s). Region abbreviations: Bighorn Basin (BHB), Greater Green River Basin (GGRB), Jackson Hole (JH), LaBarge platform (LBP), Overthrust Belt (OB), Powder River Basin (PRB), Wind River Basin (WRB).

| Fields | Region | Formation sampled | Total samples | Samples with 0.3% helium and greater | Concentration(s) of helium-rich samples |
|---|---|---|---|---|---|
| Baxter Basin North | GGRB | | 9 | 2 | |
| | | Dakota | 3 | 0 | |
| | | Frontier | 1 | 0 | |
| | | Madison | 1 | 1 | 0.64 |
| | | Morrison | 1 | 0 | |
| | | Sundance | 1 | 0 | |
| | | Weber | 1 | 1 | 0.64 |
| | | No formation reported | 1 | 0 | |
| Baxter Basin South | GGRB | | 19 | 12 | |
| | | Dakota | 16 | 12 | 0.71–0.9 |
| | | Frontier | 3 | 0 | |
| Brady | GGRB | | 18 | 1 | |
| | | Almond | 1 | 0 | |
| | | Dakota | 3 | 0 | |
| | | Frontier | 1 | 0 | |
| | | Madison | 1 | 0 | |
| | | Nugget | 4 | 1 | 0.34 |
| | | Weber | 8 | 0 | |
| Bruff | GGRB | | 16 | 1 | |
| | | Dakota | 2 | 0 | |
| | | Frontier | 11 | 0 | |
| | | Madison | 2 | 1 | 1.52 |
| | | Morgan | 1 | 0 | |
| Buck Creek | PRB | | 6 | 1 | |
| | | Minnelusa | 6 | 1 | 0.76 |
| Camel Rock | GGRB | | 3 | 3 | |
| | | Dakota | 2 | 2 | 0.76–0.78 |
| | | Frontier | 1 | 1 | 0.43 |
| Church Buttes | GGRB | | 10 | 1 | |
| | | Dakota | 1 | 0 | |
| | | Frontier | 3 | 0 | |
| | | Madison | 2 | 1 | 0.35 |
| | | Morgan | 3 | 0 | |
| | | No formation reported | 1 | 0 | |

**Table 3** Continued

| Fields | Region | Formation sampled | Total samples | Samples with 0.3% helium and greater | Concentration(s) of helium-rich samples |
|---|---|---|---|---|---|
| Fogarty Creek | LBP | | 22 | 19 | |
| | | Bighorn | 1 | 1 | 0.63 |
| | | Frontier | 2 | 0 | |
| | | Madison | 19 | 18 | 0.50–0.64 |
| Graphite | LBP | | 2 | 1 | |
| | | Madison | 2 | 1 | 0.63 |
| Hoback III | OB | | 2 | 1 | |
| | | Madison | 1 | 1 | 0.64 |
| | | Mowry | 1 | 0 | |
| Horse Trap | OB | | 1 | 1 | |
| | | Amsden | 1 | 1 | 0.31 |
| Kuehne Ranch Southeast | PRB | | 1 | 1 | |
| | | Minnelusa | 1 | 1 | 0.8 |
| Lake Ridge | LBP | | 14 | 14 | |
| | | Madison | 14 | 14 | 0.43–0.61 |
| Lance Creek | PRB | | 16 | 1 | |
| | | Dakota | 3 | 0 | |
| | | Lakota | 1 | 0 | |
| | | Minnelusa | 6 | 1 | 1.01 |
| | | Muddy | 2 | 0 | |
| | | Sundance | 3 | 0 | |
| | | No formation reported | 1 | 0 | |
| Little Buck Creek | PRB | | 3 | 1 | |
| | | Dakota | 1 | 0 | |
| | | Minnelusa | 1 | 1 | 0.6 |
| | | Muddy | 1 | 0 | |
| Mule Creek West | PRB | | 3 | 3 | |
| | | Amsden | 2 | 2 | 1.4–1.82 |
| | | Minnelusa | 1 | 1 | 1.5 |

**Table 3** Continued

| Fields | Region | Formation sampled | Total samples | Samples with 0.3% helium and greater | Concentration(s) of helium-rich samples |
|---|---|---|---|---|---|
| Oregon Basin | BHB |  | 11 | 1 |  |
|  |  | Chugwater | 4 | 0 |  |
|  |  | Cloverly | 1 | 0 |  |
|  |  | Embar | 1 | 0 |  |
|  |  | Flathead | 2 | 0 |  |
|  |  | Gros Ventre | 1 | 1 | 0.57 |
|  |  | Morrison | 1 | 0 |  |
|  |  | Tensleep | 1 | 0 |  |
| Pine Mountain | WRB |  | 2 | 2 |  |
|  |  | Embar | 1 | 1 | 0.66 |
|  |  | Tensleep | 1 | 1 | 0.79 |
| Riley Ridge | LBP |  | 9 | 9 |  |
|  |  | Madison | 9 | 9 | 0.482–0.60 |
| Riverton Dome | WRB |  | 32 | 1 |  |
|  |  | Cody | 7 | 0 |  |
|  |  | Dakota | 3 | 0 |  |
|  |  | Frontier | 7 | 0 |  |
|  |  | Lakota | 1 | 0 |  |
|  |  | Mesaverde | 7 | 0 |  |
|  |  | Muddy | 3 | 0 |  |
|  |  | Tensleep | 1 | 1 | 0.61 |
|  |  | Wind River | 1 | 0 |  |
|  |  | No formation reported | 2 | 0 |  |
| Steamboat Butte | WRB |  | 4 | 1 |  |
|  |  | Amsden | 1 | 1 | 0.43 |
|  |  | Frontier | 2 | 0 |  |
|  |  | No formation reported | 1 | 0 |  |
| Table Rock | GGRB |  | 17 | 3 |  |
|  |  | Almond | 3 | 0 |  |
|  |  | Blair | 2 | 0 |  |
|  |  | Frontier | 1 | 0 |  |
|  |  | Madison | 5 | 3 | 0.30–0.33 |
|  |  | Mesaverde | 1 | 0 |  |
|  |  | Nugget | 2 | 0 |  |
|  |  | Wasatch | 2 | 0 |  |
|  |  | Weber | 1 | 0 |  |

**Table 3** Continued

| Fields | Region | Formation sampled | Total samples | Samples with 0.3% helium and greater | Concentration(s) of helium-rich samples |
|---|---|---|---|---|---|
| Tip Top | LBP | | 40 | 27 | |
| | | Adaville | 1 | 0 | |
| | | Baxter | 2 | 0 | |
| | | Bighorn | 4 | 4 | 0.80–1.32 |
| | | Commingled deep zones | 2 | 2 | 0.61 |
| | | Darby | 2 | 2 | 0.66 |
| | | Frontier | 6 | 0 | |
| | | Frontier, Muddy | 2 | 0 | |
| | | Madison | 7 | 7 | 0.51–0.78 |
| | | Muddy | 1 | 0 | |
| | | Phosphoria | 8 | 8 | 0.48–0.65 |
| | | Tensleep | 4 | 4 | 0.56–0.80 |
| | | No formation reported | 1 | 0 | |
| Wertz | GGRB | | 5 | 1 | |
| | | Cloverly | 1 | 0 | |
| | | Dakota | 1 | 0 | |
| | | Frontier | 1 | 0 | |
| | | Sundance | 1 | 0 | |
| | | Tensleep | 1 | 1 | 1.3 |
| Wildcat | JH | Dinwoody | 1 | 1 | 0.52 |
| Wildcat | OB | Madison | 1 | 1 | 0.43 |
| Wildcat | GGRB | Phosphoria | 1 | 1 | 0.92 |

**Table 4.** Details of fields with gas samples containing 0.3% helium or higher. Region abbreviations: Bighorn Basin (BHB), Greater Green River Basin (GGRB), Jackson Hole (JH), LaBarge platform (LBP), Overthrust Belt (OB), Powder River Basin (PRB), Wind River Basin (WRB). Field designations: Abandoned field, no production for 10 years (A); coalbed natural gas (CM); carbon dioxide ($CO_2$); gas disposal (GD); gas storage (GS); helium (HE); heavy oil, less than 20°API gravity (HO); Hydrogen sulfide ($H_2S$); Other disposal well, either Class I and/or V (OD); Shut-in field, last production within three to nine years (SI); Produced water disposal (WD). Data from the 2023 update of WSGS interactive oil and gas map (Toner and others, 2016; WOGCC, 2023).

| Field name | Field type | Total wells | Field designation(s) | Year of first well spud | Year of most recent well spud | Abandoned | Shut-in | Year last produced (if abandoned or shut-in) | Primary reservoir age | Producing reservoir(s) | Region |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Baxter Basin North | Gas | 39 |  | 1926 | 2009 | N | N |  | Lower Cretaceous | Frontier, Muddy, Dakota, Lakota, Morrison, Sundance, Nugget | GGRB |
| Baxter Basin South | Gas | 62 |  | 1921 | 2009 | N | N |  | Upper Cretaceous | Frontier, Dakota | GGRB |
| Brady | Gas | 95 | (CM)($H_2S$)(WD) | 1960 | 2004 | N | N |  | Pennsylvanian | Mesaverde, Almond, Blair, Baxter, Frontier, Dakota, Entrada, Nugget, Phosphoria, Weber | GGRB |
| Bruff | Gas | 495 | ($H_2S$) | 1961 | 2012 | N | N |  | Upper Cretaceous | Frontier, Muddy, Dakota, Morgan | GGRB |
| Buck Creek | Oil | 34 | (WD) | 1958 | 2017 | N | N |  | Permian-Pennsylvanian | Dakota, Minnelusa | PRB |
| Camel Rock | Gas | 3 |  | 1979 | 1980 | Y | N | 1984 | Upper Cretaceous | Frontier, Dakota | GGRB |
| Church Buttes | Gas | 185 | ($H_2S$)(WD) | 1945 | 2011 | N | N |  | Upper Cretaceous | Frontier, Dakota, Morgan | GGRB |
| Fogarty Creek | Gas | 25 | ($CO_2$)(HE)(H2S) | 1964 | 2004 | N | N |  | Mississippian | Frontier, Madison | LBP |
| Graphite | Gas | 4 | ($H_2S$) | 1980 | 2004 | Y | N | 1997 | Mississippian | Mesaverde, Madison | LBP |
| Hoback III | Gas | 1 |  | 1969 | 1969 | Y | N | pre-1978 | Lower Cretaceous | Muddy | OB |
| Horse Trap | Gas | 1 |  | 1982 | 1982 | Y | N | 1992 | Mississippian | Amsden, Madison | OB |
| Kuehne Ranch Southeast | Oil | 11 |  | 1966 | 1985 | N | N |  | Permian-Pennsylvanian | Minnelusa | PRB |
| Lake Ridge | Gas | 9 | ($CO_2$)(HE)($H_2S$) | 1980 | 2004 | N | N |  | Mississippian | Madison | LBP |
| Lance Creek | Oil | 371 | (WD) | 1918 | 1996 | N | N |  | Permian-Pennsylvanian | Muddy, Dakota, Lakota, Morrison, Sundance, Spearfish, Minnelusa | PRB |
| Little Buck Creek | Oil | 37 |  | 1944 | 1998 | N | N |  | Permian-Pennsylvanian | Muddy, Dakota, Lakota, Minnelusa | PRB |

**Table 4** Continued

| Field name | Field type | Total wells | Field designation(s) | Year of first well spud | Year of most recent well spud | Abandoned | Shut-in | Year last produced (if abandoned or shut-in) | Primary reservoir age | Producing reservoir(s) | Region |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mule Creek West | Oil | 90 |  | 1919 | 2013 | N | N |  | Lower Cretaceous | Dakota, Lakota, Minnelusa | PRB |
| Oregon Basin | Oil | 763 | (GD)(HO)($H_2S$)(WD) | 1912 | 2022 | N | N |  | Pennsylvanian | Frontier, Mowry, Muddy, Cloverly, Dakota, Lakota, Sundance, Chugwater, Phosphoria, Tensleep, Darwin, Madison, Gros Ventre, Flathead | BHB |
| Pine Mountain | Oil | 25 | (HO) | 1926 | 1983 | N | Y | 2014 | Pennsylvanian | Sundance, Phosphoria, Tensleep | WRB |
| Riley Ridge | Gas | 20 | (CM)($CO_2$)(GD)(HE)($H_2S$)(WD) | 1961 | 2013 | N | Y | 2014 | Mississippian | Mesaverde, Frontier, Madison | LBP |
| Riverton Dome | Gas | 74 | (CM)(WD) | 1948 | 2003 | N | N |  | Upper Cretaceous | Fort Union, Lance, Mesaverde, Cody, Shannon, Frontier, Muddy, Dakota, Lakota, Phosphoria, Tensleep | WRB |
| Steamboat Butte | Oil | 108 | ($H_2S$) | 1942 | 2011 | N | N |  | Pennsylvanian | Frontier, Muddy, Dakota, Lakota, Curtis, Nugget, Crow Mountain, Dinwoody, Phosphoria, Tensleep, Amsden | WRB |
| Table Rock | Gas | 178 | ($H_2S$)(WD) | 1946 | 2012 | N | N |  | Upper Cretaceous | Wasatch, Lewis, Mesaverde, Almond, Ericson, Rock Springs, Blair, Baxter, Frontier, Dakota, Nugget, Weber, Madison | GGRB |
| Tip Top | Gas | 413 | (GD)(HE)(WD) | 1925 | 2009 | N | N |  | Upper Cretaceous | Wasatch, Almy, Mesaverde, Baxter, Frontier, Muddy, Bear River, Dakota, Nugget, Madison | LBP |
| Wertz | Oil | 178 | ($CO_2$)($H_2S$) | 1919 | 1989 | N | N |  | Pennsylvanian | Frontier, Muddy, Cloverly, Dakota, Lakota, Tensleep, Darwin, Madison, Flathead, Precambrian | GGRB |

**Table 5.** Distribution of gas samples with helium concentrations of 0.3% and higher by age of sample formation.

| Formation age | Formation sampled | Number of samples with 0.3% helium or greater |
|---|---|---|
| Cretaceous | Dakota | 14 |
| Cretaceous | Frontier | 1 |
| Jurassic | Nugget | 1 |
| Permian | Dinwoody | 1 |
| Permian | Embar | 1 |
| Permian | Phosphoria | 9 |
| Permian-Pennsylvanian | Minnelusa | 5 |
| Pennsylvanian | Amsden | 4 |
| Pennsylvanian | Madison | 1 |
| Pennsylvanian | Tensleep | 7 |
| Pennsylvanian | Weber | 1 |
| Mississippian | Madison | 56 |
| Devonian | Darby | 2 |
| Ordovician | Bighorn | 5 |
| Cambrian | Gros Ventre | 1 |
| Paleozoic, multiple | Commingled deep zones | 2 |

## SUMMARY

Wyoming is and continues to be a significant player in the global helium market. A series of recent global shortages, and the confluence of other supply- and demand-side developments, underscore the need for additional helium production. Multiple avenues of exploration and production are promising, and warrant further investigation—exploration for pure-helium plays, the addition of small helium recovery units at existing gas plants to capture additional value, and the potential for processing LNG tail gases. With the goal of providing a foundation for further work, this study revisits existing data for helium occurrences throughout the state.

The dataset associated with this publication comprises natural-gas analyses and associated well data compiled from the USBM, BLM, USGS, and WOGCC. Analytical results represent 1,189 well samples and 15 pipeline samples from 327 gas fields throughout Wyoming. Most helium samples collected in the past several decades have been limited to the LaBarge platform area. Public data for other potential helium reservoirs throughout the state remain scarce.

Overall, helium plays an indispensable role in various sectors of national importance. Given the increasing diversification of the global helium market, shifting involvement of the federal government in helium production and conservation, and developments in the natural-gas industry since the shale gas revolution, further evaluation of U.S. and Wyoming helium resources is critical.

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# APPENDIX

## DATASET OF NATURAL GAS COMPOSITIONS

This appendix is a spreadsheet of all compiled natural gas analyses and sample information. It is available as part of this publication's zipped document on the WSGS publications webpage (https://www.wsgs.wyo.gov/wyoming-geology/mapping.aspx). The results of samples from oil and gas wells can be viewed on the WSGS Interactive Oil and Gas Map of Wyoming (https://portal.wsgs.wyo.gov/arcgis/apps/webappviewer/index.html?id=d42f571b87fa4234b03d66ca7ae311a4) .