Helium

A super cool commodity

An emerging investable universe in a niche growth market

In this report we provide a comprehensive overview of the helium market. We believe helium extraction is an exciting growth industry, with an expanding set of new exploration and production companies focused on this increasingly valuable commodity. We see recent pricing at around US$250-300/mcf for producers, with end users paying >$1,000/mcf, versus the US Henry Hub natural gas price of ~US$3/mcf. Therefore, we expect there to be various compelling investment opportunities in the market. There appears to be strong appetite for financing helium projects both on public and private markets. Five listed helium-focused upstream companies, with an aggregate market cap of ~US$250mm, have been extremely strong performers over the last year, with an average total shareholder return of 395%. The three pure-plays (Royal Helium, Desert Mountain and Blue Star) focused on primary helium extraction are up >650% on average. Helium One is the newest addition to the list.

A comprehensive look into this opaque sector with new and unique insights

The helium industry is a niche market with opaque data and one that suffers from a lack of detailed analysis. We believe that it falls between the cracks: too small a subsector for either traditional oil and gas analysts or industrial gases analysts to focus on. There are no independent organisations that track the helium market. From our research, we believe that much of the data in the market at present is stale and has relied on extrapolated trends from outdated information, and there has been a lack of bottom-up demand analysis. Most of the large helium producers provide little or no data on production and the offtakers of helium provide little data to help with demand analysis. We have created our own proprietary helium supply and demand balance, modelling existing projects, as well as future project potential. We have also completed some of the most comprehensive analysis into pricing, given the lack of any relevant spot market and a paucity of published helium price benchmarks.

Helium: a critical, irreplaceable element, essential to many sectors

Helium is a vital resource, essential in modern technologies with major critical uses throughout the science, medicine and manufacturing industries. It cannot be synthesised or substituted in many cases. The geological risks of finding helium are similar in many regards to finding natural gas. There is no direct carbon footprint associated with the use of helium, unlike burning fossil fuels. The helium market size is around 6bcf/y. Based on our upstream price assumption of US$250/mcf it is worth around US$1.5bn pa to the producers but based on end user pricing it is likely a 3-4x bigger market. Given the inability to substitute helium in many applications, we see demand as relatively price inelastic. As there is a finite amount of helium production, there has been a supply shortage of helium and there is not any significant commercial storage to draw on, it is hard to quantify the unmet or latent demand for helium.

Loosening supply and demand dynamics but we expect continued tightness

We expect that helium supply will grow at a CAGR of around 5-6% over the next five years based on all the current projects planned. However, we see risk skewed to the downside given the history of delays/ramp-up issues for new projects and also the risk of operational/geopolitical disruptions from existing projects. We expect that helium demand will grow in a range of 2-5% p.a., which suggests that some of the current tightness may be eased; however, if there is downward pressure on price from incremental supply, we see the potential for higher demand as companies look to secure supplies at lower prices and possibly also look to top up storage levels. The market is very susceptible to supply disruption as global supply is very concentrated, which has led to price spikes in the past as there is little in the way of spare storage or the ability to ramp production. There are numerous players involved in the helium market but just a handful of companies control the majority of supply and distribution.

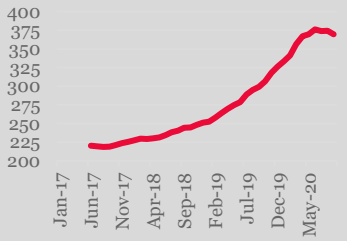
US$275/mcf

Our estimated average current upstream realised helium price

>$1,000/mcf

Price being paid for helium by some end users

Chinese 6m rolling average helium import price $/mcf



Source: Chinese Customs Data, H&P estimates

Anish Kapadia
Research Analyst
T +44 (0) 207 907 8500
E anish@hannam.partners

Jay Ashfield
Sales
T +44 (0) 207 907 2022
E ja@hannam.partners

H&P Advisory Ltd
2 Park Street, Mayfair
London W1K 2HX

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Overview

In this report we provide a comprehensive overview of the helium market. We believe helium extraction is an exciting growth industry, with growing set of new exploration and production companies focused on this increasingly valuable commodity. Therefore, we expect there to be various compelling investment opportunities in the market: listed helium companies have already performed well over the last year. Five listed helium-focused upstream companies, with an aggregate market capitalisation of ~US$250mm, have been extremely strong performers over the last year, with an average total shareholder return of 395%. The 3 pure-plays focused on primary helium extraction are up >650% on average. Helium One is the newest addition to the list.

The helium industry is a niche market with opaque data and one that suffers from a lack of detailed analysis. We believe that it falls between the cracks: too small a subsector for either traditional oil and gas analysts or industrial gases analysts to focus on. There are no independent organisations that track the helium market (such as the IEA in energy) and no significant industry bodies. Most of the large helium producers provide little or no data on production and the offtakers of helium provide little data to help with demand analysis. We have pieced together supply data and demand data from a variety of sources. For example, we have used customs data to understand trade flows and also give a sense of pricing.

We have created our own proprietary helium supply and demand balance, modelling existing projects, as well as future project potential. On the demand side, we have looked at the segments of the market that consume helium and usage by geography. Another piece of the analysis is looking at trade flows. We have also completed some of the most comprehensive analysis into pricing given the lack of any relevant spot market and a paucity of published helium price benchmarks.

We examine helium demand by usage type and by region. There are not many sources that provide demand data. From our research, we believe that much of the data in the market at present is stale and has relied on extrapolated trends from outdated information, and there has been a lack of bottom up demand analysis. For example, one of the widely quoted sources, the US Government data on helium consumption by sector, has not changed since 2016. We have looked at the different industries using helium and taken a bottom up approach to forecasting demand. Also, we have looked the geographies using helium with some help from import data.

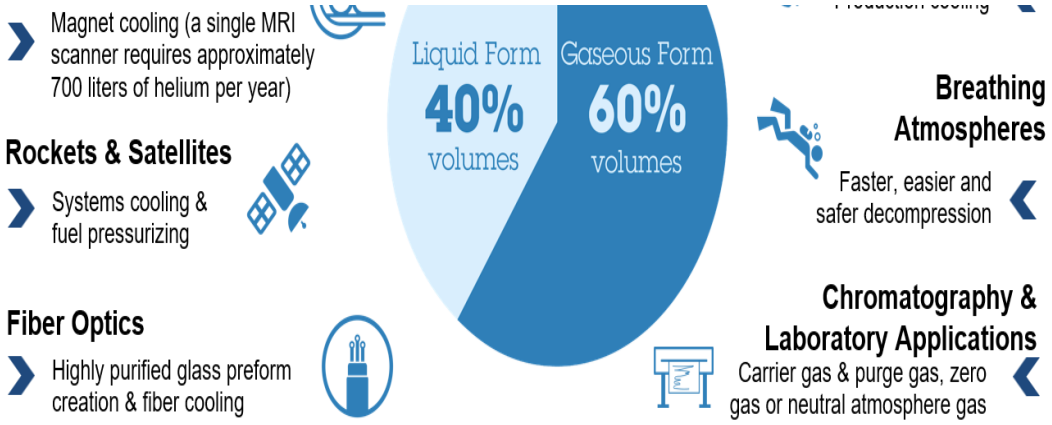
Helium: the key questions and answers

Why is helium an important commodity? Helium has several unique properties with numerous applications that make it an essential and irreplaceable element for many industries. This is because it cannot be synthesised, manufactured or substituted in many cases. Helium is listed on the critical materials lists for the US, EU, China and other major economies. Its key properties are that it is the second lightest element, it is the least reactive material known (inert), has the lowest boiling point and is one of the smallest elements. It is colourless, tasteless, odourless, non-toxic, non-flammable, has high sound, specific heat and thermal conductivity and extremely low solubility. Helium becomes a superfluid at temperatures close to absolute zero.

What is helium used for? Helium is a vital resource, essential in modern technologies with major critical uses throughout the science, medicine and manufacturing industries. It is an inert gas for cryogenic, heat transfer, shielding, leak detection, analytical and lifting applications. It is the most important element in studying super-cold conditions in low-temperature physics studies. It is a

critical component in the manufacturing process, specifically ones which serve unique high-tech applications in MRIs and semiconductor chip manufacturing. More recent uses include hybrid air vehicles, helium filled hard drives, nuclear fusion technology and Google X Project Loon.

Uses of gaseous versus liquid helium



Source: Air Liquide

Helium market size and opportunities? The helium market is around 6bcf/y. Based on our upstream price assumption of US$250/mcf it is worth around US$1.5bn pa to the producers but based on end user pricing it is likely a 3-4x larger market. We see the key uses of helium coming from MRI/NMR machines at 20% of demand; around 15% each for the lifting, scientific and semiconductors categories; around 8-9% for both welding and fibre optics; and 5% or less for leak detection, space and diving.

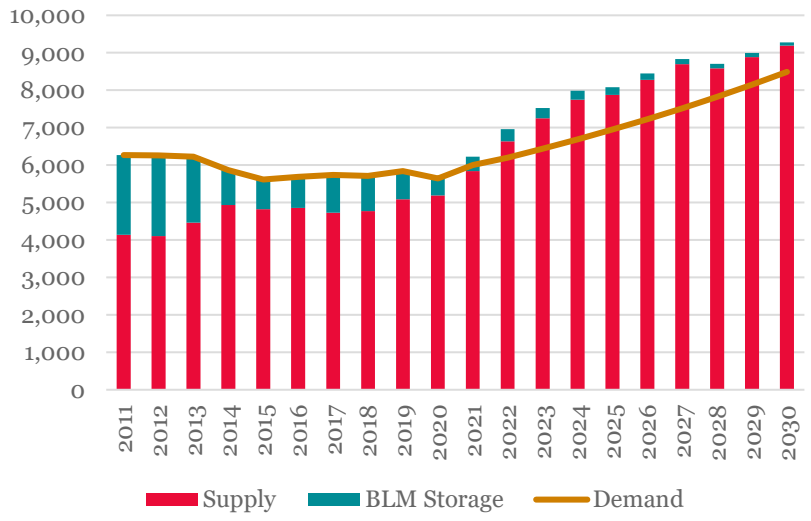
What units are used to refer to helium? Helium pricing is referred to in various units: either per thousand cubic feet (mcf), per litre (l) or per kilogram (kg). Our base case price estimate of US$250/mcf is the equivalent of US$7/l or US$53/kg.

Who are the main players? There are numerous players involved in the helium market but just a handful of companies control the majority of supply and distribution. For example, on the supply side Qatargas, the US Government (through its strategic storage), Sonatrach in Algeria and Exxon produce the majority of supply and will be joined by Gazprom as it ramps up production in the next few years. There are a handful of mainly US focused midstream companies operating helium purification plants. There are now around 20 independent E&P companies globally that either have helium production or are looking to develop helium. These are generally relatively new companies that have emerged over the last few years to capitalise on rising helium prices. Finally, there are the industrial gas companies that buy the helium: Linde, Air Liquide and Air Products are the main players. As with other commodities, we believe there is a good chance that China will look to stockpile helium (build storage similar to the US Bureau of Land Management) and also look to acquire helium resources globally. There is room for smaller players - for example, the CEO of Weil Group, which is the only small player to export helium from North America to Asia, has said that his company is operating effectively outside the oligopoly, establishing relationships with unique customers who are “tired of the unpredictability and unreliability of supply”.

How is helium formed and produced? Although helium is the second most abundant element in the Universe, it is found in very low concentrations in the earth's atmosphere. Most helium on earth is formed through the radioactive decay of uranium in the earth's crust that makes its way into underground gas reservoirs. The geological risks of finding helium are similar in many regards to finding natural gas. The requirements for success are the same, namely having source, migration, reservoir, trap and seal; however, the mechanisms are somewhat different. The vast majority of helium is produced as a by-product of natural gas production, with generally a few percent or less helium content, but more recently companies have been looking at extracting helium from non-hydrocarbon sources if it is found in high concentrations >5%. Globally, Tanzania has emerged as an extremely promising area for primary helium production with some of the highest global concentrations of helium in surface seeps.

How is helium extracted? The process to upgrade low concentration helium in a gas stream to high purity helium is as follows: the raw gas is first pre-treated, then either distillation of gas takes place or membrane separation, to produce crude helium and finally purification using a method called pressure swing adsorption. This produces pure helium (99.99%) which can be compressed and sold as a gas or put through a bed of activated charcoal to remove trace impurities before being liquefied. Helium projects have rarely been delivered on time due to the complexity of the projects (often the wider gas projects that the helium projects form a small part of) or due to issues with gas supply and pipeline infrastructure.

Estimated supply demand balance for helium (mmcf/y)



Source: H&P estimates

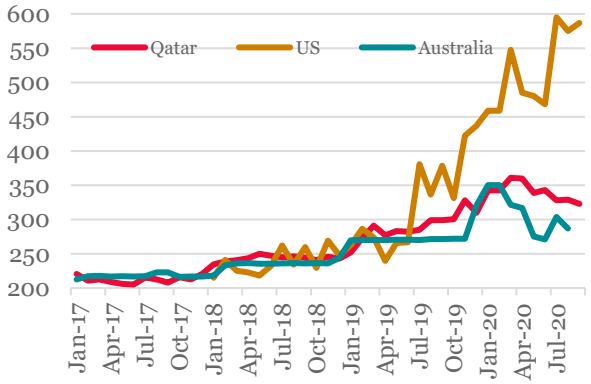
What does the supply and demand balance look like? We expect that helium supply will grow at a CAGR of around 5-6% over the next five years based on all the current projects planned. However, we see risk skewed to the downside given the history of delays/ramp-up issues for new projects and also the risk of operational/geopolitical disruptions from existing projects. We expect that helium demand will grow in a range of 2-5% p.a., which suggests that some of the current tightness may be eased; however, if there is downward pressure on price from incremental supply, we see the potential for higher demand as companies look to secure supplies at lower prices and possibly also look to top up storage levels.

How is helium priced? Market pricing for helium is difficult to ascertain as it is not a traded commodity and pricing is normally based on long-term,

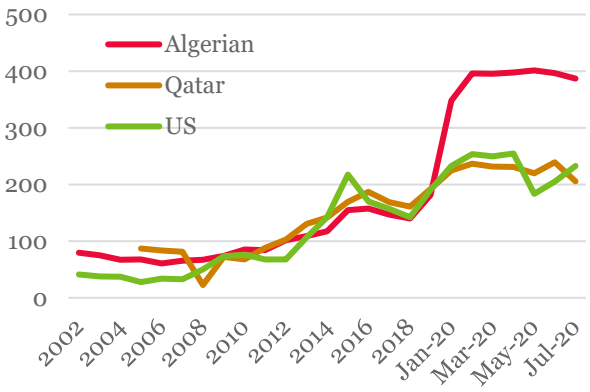
confidential contracts, resulting in opaque pricing given there are only a few key suppliers and industrial gas buyers. Many helium users tend to be price insensitive as there are no substitutes for helium in many cases, making them price-takers. This is another reason for long-term contracts as security of supply is crucial to many users. Therefore, spot or current pricing is not overly relevant for producers and means production is more bankable given security of cash flows. The market is very susceptible to supply disruption, which has led to price spikes in the past. It has been estimated that around 10% of global helium demand was lost in 2011-13 due to shortages and pricing doubling.

What is current helium pricing? We see recent pricing at around US$250-300/mcf for producers. For example, the majority of imports into Europe have recently been around US$250/mcf and imports into China at US$300/mcf based on the data available to us. The latest US auction pricing (back in 2018) was at US$280/mcf. Gazprom has apparently been selling individual cargoes of helium for ~US$700/mcf. From the data we have seen, when cargoes are being sold in single ISO sized containers (1mmcf) they appear to be selling for well over US$500/mcf. To put these prices in context, end users such as universities have been paying >$1,000/mcf.

Estimated Chinese helium import prices by region, $/mcf



Estimated European import pricing by region, €/mcf



Source: Chinese Customs Data, Eurostat, H&P estimates (2020 for January and February is averaged as only aggregate data reported)

What is the outlook for helium prices? Our base case helium price forecast on an ex-plant basis for Grade A liquid helium is US$250/mcf. While this is significantly lower than some of the prices seen over the last few years, we believe this to be a suitably conservative price to factor in the potential oversupply situation for a couple of years from 2022 until this is digested by the market. We have modelled out a helium development in Tanzania and based on this we see a breakeven helium price of ~US$100/mcf required to generate a double digit IRR. This is based on a relatively high percentage of helium in the gas produced so other projects may have higher break-evens. The cash cost of production is estimated at US$20/mcf.

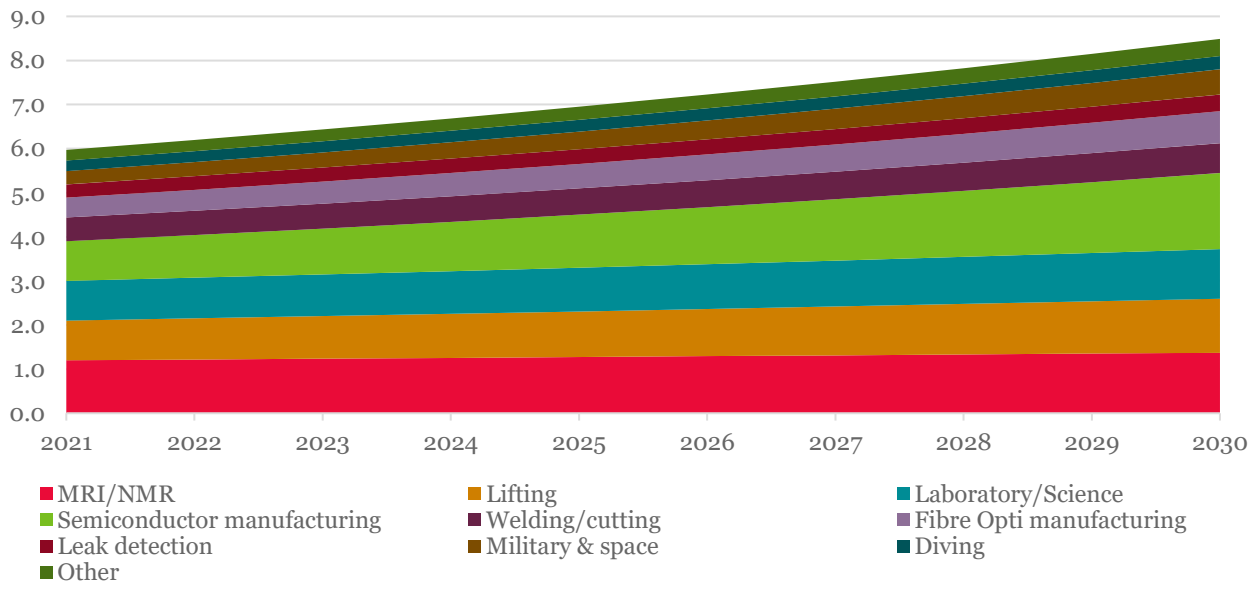
Where has helium supply come from? Global helium supply is currently very concentrated with the US and Qatar alone currently accounting for ~75% of world supply. There are two notable projects that supply >50% of world demand: the LaBarge field in the US and the North Field in Qatar. Both are supergiant fields where production can be maintained for decades to come (with further growth in the case of Qatar). As such, there is not as much of an issue with replacing underlying decline as there is with hydrocarbon production. In aggregate we see existing production declining at around 2-3% per annum or

excluding these fields at around 7% per annum. We estimate that US BLM still accounted for around 8% of supply in 2020 (~450mmcf/y) but this is expected to fall sharply over the coming years as storage is gradually depleted.

What is the supply outlook for helium? We have created our own proprietary supply model for helium on a bottom up basis. Most companies and countries do not disclose production or sales data, so we have had used multiple sources and made our own assumptions to derive our forecasts. We expect that helium supply will grow at a CAGR of around 5-6% over the next 5 years based on all the current projects planned. However, we see risk skewed to the downside given the history of delays/ramp-up issues for new projects and also the risk of operation/geopolitical disruptions from existing projects. We estimate that 2020 helium supply (including production out of storage) was 5.9bcf/y. We believe the fall in demand for, and in turn reduced global production of, LNG due to the Covid-19 pandemic is likely to have had a knock-on impact on helium production.

What is the outlook for helium demand? Our bottom up estimates result in an overall CAGR of 4% over the forecast period, with demand growing from 6bcf/y in 2021 to 8.5bcf/y in 2030. We see major growth potential for helium in space travel, near space travel in balloons, semiconductors and other electronics applications. The future growth of helium is expected to be driven by demand from electronics manufacturers in Asia. Semi-conductor, flat-panel display, and optical fibre manufacturing are all significant consumers of helium in Asian markets. We also think there will be new uses for helium emerging that we have not considered yet or markets that grow quicker than expected such as quantum computing or fusion.

Forecast helium consumption by industry 2021-2030E, bcf/y



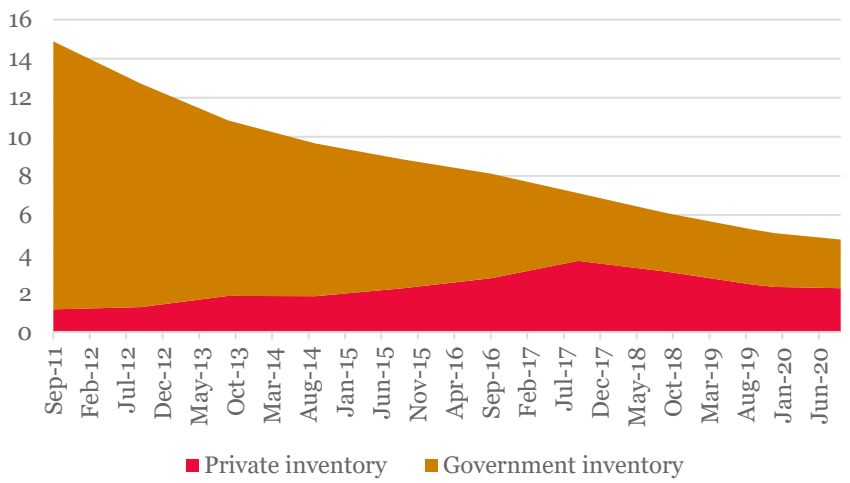
Source: H&P estimates

What are the regional trends in demand? The general trend in the helium market has been a fall in demand from the US and Europe over the last decade, which has been offset by growth in China and Asia. This is because of the faster growth rate of MRI usage in Asia than the west, and also due to technology growth industries for helium such semi-conductors and fibre optics being centred in China and the Far East. As with so many commodities, China is the most important growth market for helium, in our view. It has already doubled its

helium consumption over the last decade and is almost completely dependent on imports given a lack of a domestic helium industry. We expect Chinese helium demand to be around 1bcf/y in 2021, 16% of the total global market, and expect demand to grow at 100mmcf/y.

What is the sensitivity of demand to pricing? Given the inability to substitute helium in many applications, we see demand as relatively price inelastic. With prices already significantly higher than at the beginning of the decade, most of the price elastic demand has most likely already been eliminated. In fact, if there are periods of lower pricing there is likely to be latent, more price-sensitive demand that could return to the market. Given that there is a finite amount of helium production, there has been a supply shortage of helium and there is not any significant commercial storage to draw on, it is hard to quantify what the unmet or latent demand for helium is. If more helium supply was to come on to the market, we believe demand would likely come out of the woodwork.

US BLM inventories 2011-2020, bcf



Source: BLM, H&P estimates

What does global storage look like for helium? The main site for storage of helium and the only real buffer for the helium market is the US BLM Government storage facilities. There is minor storage elsewhere (e.g. Air Liquide has a site in Germany) but this is small in the scheme of things. However, we would not be surprised if some of the large producers (e.g. Russia) or large buyers (e.g. China) would look to build their own storage in order to ensure security of supply. This could be positive for demand and offset the upstream capacity growth over the coming years. We believe that the dramatic fall in the production capacity and the total reserves in the BLM storage should ensure a structurally higher price for helium in the future. Buyers that cannot substitute helium would be willing to sign long-term contracts with a diversified set of suppliers, in order to ensure security of supply, even if this entails higher pricing, as the cost of not having helium could be multiple times higher.

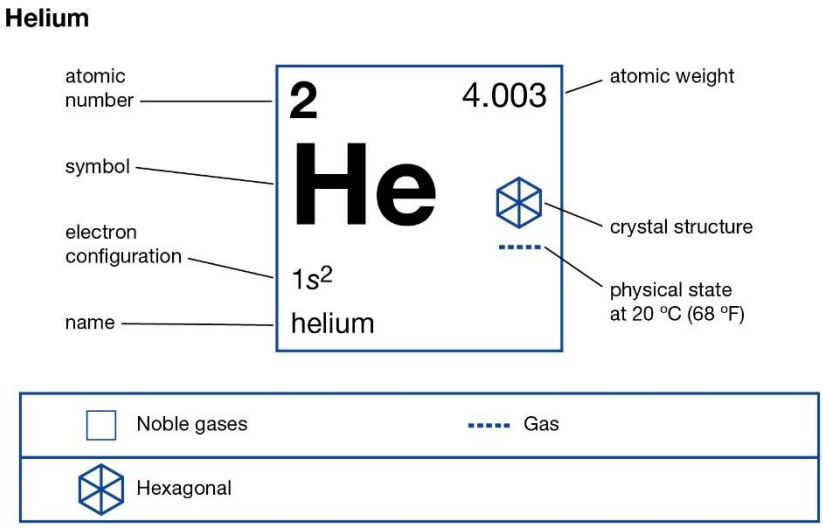
What is financing availability like and deal structuring: There appears to be strong appetite for financing helium projects given that there are plenty of privately funded helium companies, e.g. North American Helium raised C$123mm, and public markets have strongly rewarded listed pure-play helium companies (stocks up >650% over the last year). There have been significant

asset-based lending transactions (e.g. Nasco raised $83mm investment grade financing against its helium assets in the US). In 2019 Riviera Resources raised US$82mm through a volumetric production payment transaction (VPP) monetising 23% of its helium reserves at a 5% discount rate.

What is the carbon footprint and environmental impact of helium?
Helium does not suffer from environmental criticism, pipeline constraints, regulatory burdens and excess taxes. There is no direct carbon footprint associated with the use of helium, unlike burning fossil fuels, which is another attraction for increasingly ESG savvy investors. Producing helium as a standalone product rather than as a by-product of natural gas production is another benefit.

Unique properties of helium

Properties of helium



Source: Encyclopaedia Britannica

Helium has several unique properties with numerous applications that make it an essential and irreplaceable element for many industries. This is because it cannot be synthesised, manufactured or substituted in many cases. The main characteristics are:

- The stable isotopes of helium are helium-3 and helium-4. The isotopic abundances of helium-3 is 0.00014% and helium-4 is 99.99986%. Helium-3 is composed of 2 protons and 1 neutron. Helium-4 is composed of 2 protons and 2 neutrons.
- Monatomic noble gas: atoms are not bound to each other. The only chemical elements that are stable single atom molecules at standard temperature and pressure are the noble gases.
- Colourless, tasteless, odourless, non-toxic.
- Second lightest element (importantly seven times lighter than air) with a molecular weight of four atomic mass units.
- Small size: Helium is one of the smallest molecular compounds of any gas or liquid fluid and can therefore 'fit' in places that other molecules cannot, including in the porous voids of some solid materials. It also means that it can penetrate most rocks, so from an exploration perspective, trapping mechanisms are critical to retain it in host rocks.
- Inert (will not react with other substances) makes for an effective purging agent. It is the least reactive material known. No helium-containing compounds have been synthesised.
- Lowest boiling point of 4.2 Kelvin (-268.9C) amongst all elements: The reason that helium is irreplaceable and highly sought after in certain industries is due to its extremely low temperature required to turn into a

solid. When you liquefy helium, it is the coldest substance known to man.

- Helium becomes a superfluid at temperatures close to absolute zero. A superfluid is a fluid with a viscosity of zero, so the superfluid flows up and over the walls of containers. The state of superfluid is called Helium II. Other known elements do not become superfluid at temperatures close to absolute zero.
- Non-flammable (This contrasts with hydrogen, the lightest element, which is highly flammable).
- High specific heat and thermal conductivity makes for a uniquely powerful heat absorber. Helium can convectively remove heat faster than any other molecular compound.
- Ionisation potential: Helium requires the most amount of energy to ionise (remove) one of its electrons of any molecule. Ionised helium is therefore a highly reactive material.
- Helium has a sound velocity of 970 m/s, so helium conducts sound three times faster than air.
- Helium does not become radioactive under irradiation (radiologically inert).
- Very low solubility means it is suitable as a gas for diving.
- Liquid helium can be transported to port via ISO containers mounted onto trucks with no pipelines necessary.
- Used helium escapes into space and is lost.

A critical commodity, officially

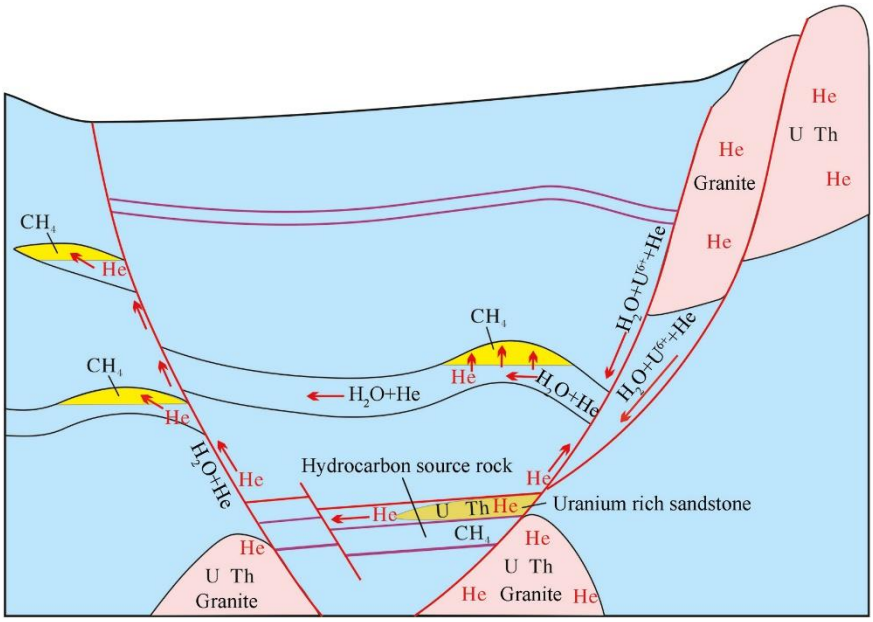
Helium is critical to innovation in science. It has supported work leading to >5,000 patents. Multiple Nobel Prizes have been awarded to discoveries that relied on liquid helium including, but not limited to, the Josephson effect (1973), superfluidity (1978, 1996), the quantum Hall effect (1985) and quantum computing (2012).

Without helium, much scientific research would come to a halt. Liquid helium has enabled breakthrough discoveries in medicine, national security, computer technology, and fundamental science. These breakthroughs have spawned billion-dollar industries. Examples include magnetic resonance imaging, semiconductor devices, fibre-optic telecommunications, and space propulsion.

Helium is listed on the critical materials list for US, EU, China and other major economies. Helium was added to the EU's Critical Raw Minerals list in 2017, which means it is considered critical for the EU because it is at high risk of supply shortage and any shortages could have a significant impact on the economy. In May 2018, the U.S. Department of the Interior included helium on its list of 35 critical minerals.

Helium Formation

Helium accumulation model



Source: https://www.sciencedirect.com/science/article/pii/S2468256X1830004X

Helium is the second most abundant element in the Universe, where it makes up around a quarter of the total elemental mass but it is found in very low concentrations in the earth's atmosphere: less than 0.001% in air (around 5ppm). In seawater the concentration is miniscule at 4 parts per trillion. Cosmic helium was formed after the Big Bang during fusion reactions in the stars.

There are two sources of helium on earth: primordial, part of the original formation of the planet or from the radioactive decay of the heaviest natural elements, Uranium and Thorium over aeons, deep in the earth's crust and mantle. It is mainly found in underground gas reservoirs, which may contain a few percent helium alongside other gases. Most of the helium produced from this process makes its way up into the sediments where it seeps into the atmosphere and ultimately escapes into space (not even gravity can keep helium on Earth). In the Earth's heterosphere, the atmospheric zone more than 60 miles above the ground surface, where gases separate by molecular weight, helium and other lighter elements are the most abundant gases.

Helium, named after the Greek god Helios, was first detected in 1868 by the French astronomer Jules Janssen and the British physicist Norman Lockyer in the spectra from a solar eclipse. In 1895, helium was formally discovered on Earth by the Swedish chemists, Per Teodor Cleve and Nils Abraham Langlet. The Swedes observed the gas emanating from the uranium ore cleveite.

For helium to accumulate in commercial quantities, there are typically three main requirements:

- Granitoid (or similar) basement rocks rich in uranium and thorium; these basement rocks should be fractured and faulted to provide escape paths for the helium to migrate into the reservoirs above.
- Porous sedimentary rocks above the basement faults that are capped by impermeable anhydrite or halite.
- The seal is the most important element; it must be impermeable enough, and strong enough, to trap the helium. If a seal is robust enough for holding methane it should be competent at holding helium, although there could be some diffusive helium loss.

Helium is often associated with nitrogen within subsurface reservoirs, as we observe many helium-nitrogen fields globally. The origin of the nitrogen in each case is poorly understood. Nitrogen may be important for helium transport out of the source minerals, though this is a topic of ongoing scientific study.

Geological exploration risk

The geological risks of finding helium are similar in many regards to finding natural gas. The same requirements for success namely having source, migration, reservoir, trap and seal, however the mechanisms are somewhat different.

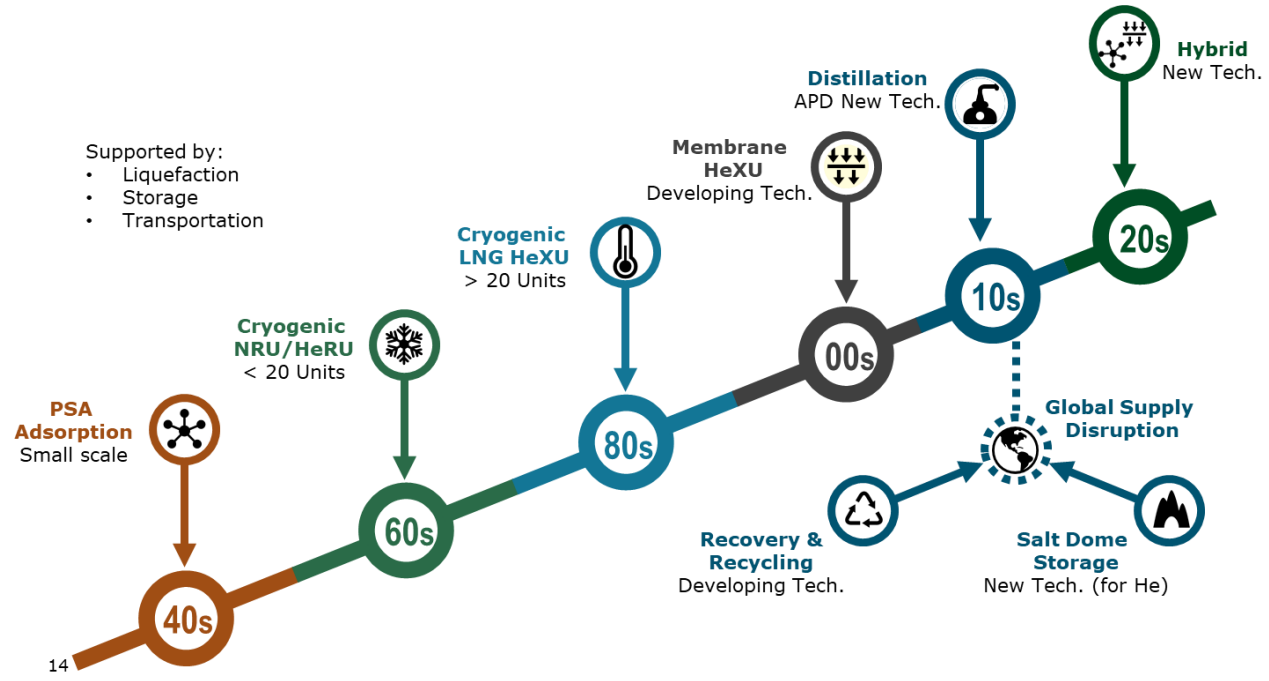
Comparison of Helium and Petroleum Systems

Stage	Petroleum System	Helium System
Source	Organic matter	U^{238}, U^{235} and Th^{232} decay in the crust produce alpha particles
Maturation	Burial and consequential heating	Time to accumulate (stable crust) vs volume of stable crust
Primary migration	Pressure driven (phase change from solid kerogen to fluid petroleum results in volume increase)	Heating to above mineral closure temperatures, fracturing of rocks and minerals, mineral dissolution
Secondary migration	Buoyancy driven	Groundwater/buoyancy driven/stripping
Accumulation in reservoir	Beneath caprock, capillary entry pressure seal	Exsolution in presence of existing gas phase beneath caprock/degassing of oversaturated groundwater/ direct input into trap of a free gas phase
Trap integrity & longevity	Microseepage, capillary failure, fracture failure, tectonic destruction of trap	Microseepage, capillary failure, fracture failure, tectonic destruction of trap

Source: Danabalan (2017)

Helium Processing

Evolution of helium technologies



Source: Air Products

The first functional helium plant was designed by L'Air Liquide as an experimental plant in Ontario, Canada; it produced 87% pure helium in 1918. Helium is normally produced in several steps, each increasing its concentration. Gas separation processes are divided into three categories: cryogenic processes, pressure swing adsorption (PSA) and membrane separation. There have been significant improvements in non-cryogenic purification techniques like pressure swing adsorption with membrane separation, allowing smaller and more cost-effective helium production. It has been widely concluded that extraction of helium from air as a primary product is prohibitively expensive and likely to remain so for the foreseeable future.

The process to get from low concentration helium in a gas stream to high purity helium is as follows. The raw gas is first pre-treated, then either distillation of gas takes place or membrane separation, to produce crude helium and finally purification using a method called pressure swing adsorption. This produces pure helium (99.99%) which can be compressed and sold as a gas or put through a bed of activated charcoal to remove trace impurities before being liquefied.

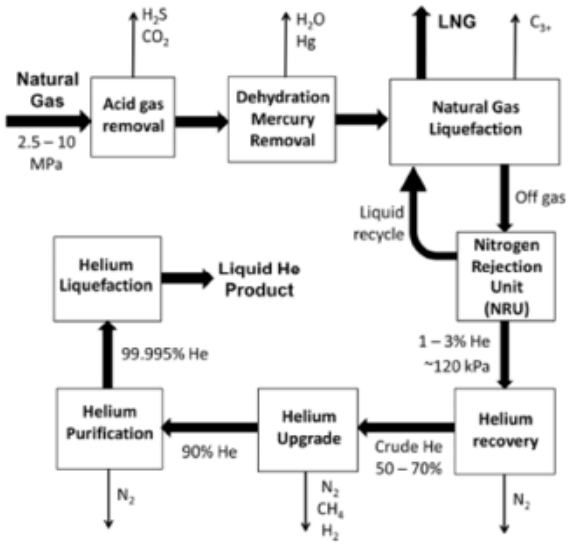
Historically there have been delays commissioning helium processing facilities around the world. A recent example is the DBK field's processing plant which suffered various issues during commissioning and start-up. These included improper installation of the PSA internal bed material, insufficient capacity of the PSA system, inadequate regeneration capability of the temperature swing adsorption system and a faulty slide valve. Therefore, it is necessary in our view to risk new capacity coming onto the market given the potential for delays through the commissioning phase. Generally, plant uptime would be expected to be around 90% after successful commissioning and approaching 95% following experience in operations and maintenance.

Advantages and limitations of helium recovery technologies

Technology	Advantages	Disadvantages
Cryogenic fractionation	High helium recovery purity (>95% up to 99.999%)	High capital requirements
	Advanced technology widely used for direct recovery of helium from natural gas	Intensive energy requirements - high operational expenditure
	Easy scale-up for increased capacities	
	Small- to micro-scale facilities have been economically commercialised	
Adsorption-based	No fluid phase changes resulting in lower energy requirements	Recommended for helium purification, not for direct from natural gas
	Low direct helium recovery from feed natural gas (<65% reported for plants in operation)	Requires high purity feed gas i.e. crude helium (impurities cause adsorption bed saturation leading to reduced efficiencies)
	Helium-nitrogen mix is inert and easier to process. It is possible to get a high (>99.99% He) purity helium, with a 8 – 10% He and ~90% nitrogen feed gas.	Lower helium recovery purity from direct separation
Membrane-based processes	No fluid phase changes resulting in lower energy requirements	Requires "cleaned" high purity feed gas to prevent membrane fouling and damage
	Small footprint (lower impact on environment)	Membranes have not been widely commercialised, requires more research and development - limited data available
	Lower capital costs	Requires high pressure ratios resulting in high operational costs

Source: H&P, EPCM Holdings

Schematic representation of a typical helium recovery process from natural gas in an LNG facility



Source: Soleimany et al, 2017

Fractional distillation

Helium is commercially extracted from natural gas by a low temperature separation process called fractional distillation. Since helium has a lower boiling point than any other element, low temperature and high pressure are used to liquefy and draw off nearly all the other gases (mostly nitrogen and methane). In cryogenic technologies, separation is achieved at temperatures below -65 °C. Cryogenic separations can accomplish up to 90% helium recovery.

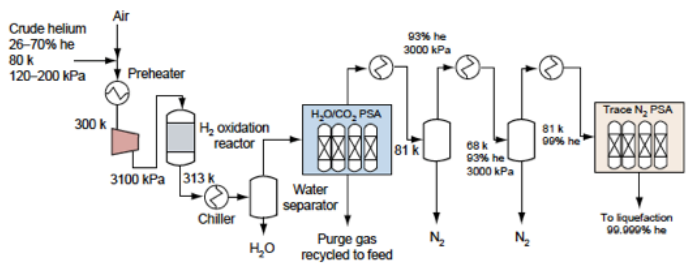
Membrane separation

Generally raw feed gas will pass through liquids and particulate removal equipment before reaching the helium plant. Membrane technology can be used to separate helium to achieve high quality helium directly at the well site. Membranes require little intervention given there are no moving parts. To get a higher purity it is possible to use a high specificity membrane. Generally, membranes can upgrade the helium content in the gas to around 50%.

Pressure swing adsorption (PSA)

The PSA process involves the pressurised gas mixture passing through a solid bed. Helium remains almost totally unadsorbed on this solid while the other gas components are deposited on or in it. As soon as the adsorption capacity of the solid is exhausted, it is regenerated by reducing the pressure. Two solid beds are operated concurrently so that PSA continuously provides helium; while one of these is in the adsorption mode, the other is being regenerated. The PSA process only functions well with a helium content of at least 25%, and its effectiveness increases with the helium content.

Schematic of the upgraded helium purification process



Source: Agrawal et al, 2003

The advantages of PSA systems are that they are flexible, low capital cost, mobile and durable. There is a short lead time for installation and to start operations. PSA units can be scaled up or down easily and even one well can be enough to justify installing a unit.

Liquefaction

In a final production step, most of the helium that is produced is liquefied via a cryogenic process that uses nitrogen refrigerant. Nitrogen is then removed from the gas. Finally, heavy hydrocarbons are removed using Temperature Swing Adsorption (TSA). Activated charcoal is used as a final purification step, usually resulting in 99.995% pure Grade-A helium.

The principal impurity in Grade-A helium is neon. The purified helium can then be compressed and put into transportation trailers. This is necessary for applications requiring liquid helium and allows helium suppliers to reduce the cost of long-distance transportation, as the largest liquid helium containers have more than five times the capacity of the largest gaseous helium tube trailers.

Other helium extraction

Air Products' Doe Canyon plant in Colorado is the only one in the world extracting helium from a gas stream composed primarily of carbon dioxide. Air Products extracts the helium from the gas stream and returns the CO_2 to Kinder Morgan, which supplies it to the Permian Basin in West Texas, where it is used for enhanced oil recovery (EOR).

Recycling

Helium can also be recycled. Higher prices have encouraged users to look at recycling of this valuable commodity. In most applications, helium is used in such a way that it cannot be recycled. However, there are some areas where the recycling of helium can take place and make economic sense, but the issues are often the high upfront cost that needs to be financed and logistical issues. Overall, we do not expect recycling of helium to have a large impact on the market. A more tangible impact is more likely to come from the reduction or elimination of the use of helium where substitution is possible (e.g. MRI scanners).

A recycling system usually involves capturing some or all of the helium gas and reliquefying on-site. For academic institutions with annual liquid helium usage over 30,000 litres per annum it may be economically feasible to invest in small-scale liquefiers, which are typically capable of producing 25-50 litres of liquid helium per hour. A barebones liquefaction system with adequate storage for 3,000 litres of liquid, and a corresponding amount for high-pressure gas storage, is an investment of approximately US$1.5-4mm. For example, University of California, Los Angeles has installed a liquefier than has cut by 90% the 100 litres of helium per week that it used to cool three magnets cutting the annual helium bill to $10,000 per annum. In a supply shortage, the on-site inventory can weather a short-term supply issue. However, there is high maintenance cost and the requirement for personnel for monitoring. Also, one concern might be that the helium can become slightly contaminated during recycling and may need to be re-purified.

Gas capture without reliquefication can also be accomplished, but it requires much of the infrastructure needed for reliquefication and agreements with the supplier on helium gas buy-back. Because helium is not purified and reliquefied, most gas vendors will purchase it at “balloon-grade” pricing. Typically, this will not be enough to give a good return on investment. For example, Nextrom offers a system in which the used helium is collected, cleaned, and re-used for cooling. As much as 90% of the helium can be recovered in this way.

Helium Companies

There are numerous players involved in the helium market but just a handful of companies control the majority of supply and distribution. For example, on the supply side Qatargas, the US Government (through its strategic storage), Sonatrach in Algeria and Exxon produce the majority of supply and will be joined by Gazprom as it ramps up production in the next few years. There are a handful of mainly US focused midstream companies operating helium purification plants. There are now around 20 independent E&P companies globally that either have helium production or are looking to develop helium. These are generally relatively new companies that have emerged over the last few years to capitalise on rising helium prices. Finally, there are the industrial gas companies that buy the helium, the main players are Linde, Air Liquide and Air Products.

There is room for smaller players: for example, the CEO of Weil Group, which is the only small player to export helium from North America to Asia, said that his company is able to operate outside the oligopoly, establishing relationships with unique customers who are "tired of the unpredictability and unreliability of supply".

Large existing producers and plant owners

Gazprom – Gazprom currently produces minor volumes but its East Siberian Amur project is expected to commence production in 2021 with the potential to increase production to 2bcf/y by 2025.

Exxon – Exxon one of the is the biggest producers of helium in North America through its ownership in the La Barge field. It also indirectly produces helium through its stakes in LNG plants in Qatar.

US Government – The US BLM has the largest crude helium storage facilities globally. It is in the process of selling off its storage and associated facilities.

Qatargas – Qatar is one of the largest suppliers of helium through its helium recovery plants associated with its mega LNG facilities. Its gross production capacity will reach 2.6bcf/y in 2021 with its 3rd plant coming online and it has plans to grow this to >4bcf/y by the end of the decade.

Sonatrach – The Algerian state oil and gas company operates helium recovery plants associated with its LNG export facilities in Skikda and Arzew.

PGNIG – PGNiG owns and operates a helium production facility located in Poland that extracts and refines helium from gas produced by its domestic natural gas fields. The company has been consistently producing helium from this plant for supply to the global market since the late 1970's. The Polish state-owned utility company is the only producer of helium in central Europe.

Saudi Aramco – The state-owned Saudi company is planning a 230mmcf/y plant that is expected to start-up in 2023.

North American midstream players

DCP Midstream – DCP is an infrastructure company in the US whose National Helium Plant in the Midcontinent is the largest helium producer in the country.

Tenawa – The company brought online a 100mmcf/y plant in Kansas in 2019 as part of the largest gas processing facility in the Midcontinent.

IACX – The company is based in Dallas and is privately owned. It is an owner and operator of plant facilities for extracting helium from gas production. It operates 8 plants in the US Rockies/Four Corners region, producing balloon grade helium. It uses proprietary technology for extraction and purification of helium from gas; PSA and TSA in combination with membrane technology. It has production from the Harley Dome and has been looking at developing the Woodside Dome, both of which are in Utah.

Rocky Mountain Helium – Independent helium development company with exclusive BLM federal helium extraction contract (Badger Wash Gas Plant) and partnership with Linde, developing high concentration helium reserves in eastern Utah and western Colorado.

Tumbleweed Midstream – The company was established in 2019 to acquire and operate the Ladder Creek Helium Plant and Gathering System located close to the Colorado-Kansas border. Tumbleweed acquired Ladder Creek from DCP Midstream in December 2019.

Quantum Helium Management Corporation – Quantum Technology is a global leader in specialized industrial gas applications, particularly Helium and Hydrogen. Quantum Helium Management Corp opened its first low-grade helium processing facility in Saskatchewan back in 2013. It was the first helium refinery in Canada in 40 years.

Paradox Resources – The Houston based company is privately held and focused on oil and gas production within the Paradox Basin of Utah and Colorado. It brought on stream helium production from its Lisbon plant in early 2020 with a capacity of 180mmcf/y.

North American focused helium E&P companies

Tacitus Corporation – Tacitus is a private Alberta-based helium exploration firm that began helium production in 2018 from the Tocito Dome Field in New Mexico. The plant is currently designed to process 2mmcf/d of gas implying around 50mmcf/y of helium production with an ambition to get to 500mmcf/y of helium production from its assets in the region.

Royal Helium – The company is Canadian listed (TSXV:RHC) with assets in southern Saskatchewan and is one of the largest helium leaseholders in Canada. There have been high helium concentrations in historical wells in the region. Royal plans to prove up 30 structures that could contain 1-2tcf of raw gas with a helium concentration of at least 1%. It is currently planning its maiden drilling programme over its Climax helium permit lands, where 7 targets have been identified, with potential for first production as early as in 2021.

Desert Mountain Energy – This is a Canadian listed (TSXV:DME) helium exploration company focused on assets in Arizona and Oklahoma in the US. In Arizona it is focused on the Holbrook Basin, where it holds 66k acres, with the potential for 8-10% helium based on historic production. Two of the world's richest historic producing helium gas fields, the Pinta Dome and Navajo Springs, are situated in this region. It has drilled and tested 2 wells with helium content of 7.1% and 4.1% and plans to commence commercial production in October 2021 with an estimated capex of US$45mm over 6 years. There is the potential to produce >1mmcf/d of helium from the assets.

Blue Star Helium – The company (formerly known as Big Star Energy) is headquartered and listed in Australia (ASX:BNL) with assets in North America. It

has 3bcf of prospective recoverable helium resource over two prospects in Colorado on its 73k net acres. Colorado is central to the helium supply chain in the US and is on a proven helium play fairway (nearby Model Dome had 8% helium concentration). Blue Star has a drilling campaign planned for Q4'20 at a cost of US$300k per well (plus $100k completion if successful). It is planning to use modular surface facilities that could produce 50mmcf/y of helium based on 2mmcf/d raw gas with a 6-month mobilisation period.

North American Helium – This is a private Calgary based company founded in 2013 which has 3.8mm acres of acreage in Saskatchewan and in the State of Utah. The company has drilled 19 wells and found substantial reserves of helium (four discoveries) and is producing 10mmcf/y from its Cypress field and commercialising its 50mmcf/y Battle Creek field. The company has invested >C$50mm and raised C$123mm over the last year. It commenced helium production in July 2020 with plans to grow production 5-fold by July 2021 with a new plant that has a capacity of 60mmcf/y of helium.

Weil Group – This is a private US based company with active helium projects in the US and Canada. It has four projects including the producing Mankota field in Saskatchewan using Linde's technology for a Membrane-Pressure Swing Adsorption plant producing "Grade A" helium. In Alberta it is targeting a large anticline with high helium-bearing gas on the Sapphire Field. It also has assets in Montana, Utah and the Mid-Continent in the US. It also divested from the Knappen project in 2018.

NASCO Energie & Rohstoff – Private company NASCO is one of the few German suppliers on the world market for helium. It has a long-term offtake agreement with Praxair (part of Linde). Its main asset is the Dineh-Bi-Keyah field in Arizona, which has >5% helium content. Its separation plant allows processing of 0.4mmcf/d of 98.8% purity helium. It plans to grow its position in the US. In early 2020 the company completed an investment grade US$83mm asset-based financing deal based on a 13-year long term supply contract. It also has a JV with a subsidiary of Linde on the Hogback field which has 2.5bcf of helium 2P reserves with 3-6% helium content in the gas.

Thor Resources – This is a private Canadian company based in Alberta. Thor has over 50,000 net acres in the prime area of the helium region of Alberta, Saskatchewan and Montana. It is participating in 5 projects, the most significant of which appears to be Knappen (1bcf of recoverable helium that has tested at raw gas rates of 15mmcf/d).

First Helium – This is a Canadian-based helium exploration company, which has acquired a producing well and a large highly-prospective land position in Alberta. It will further appraise and develop this opportunity, with the goal of producing liquid helium soon.

Imperial Helium – This is a private Canadian company focused on identifying and acquiring helium assets in Alberta. It is targeting existing helium bearing well bores with existing infrastructure and production cash flow potential within 24 months.

Petrosun – This US listed (OTCPK:PSUD) company is a diversified energy company with helium leases in the Holbrook Basin, Arizona. PetroSun has accumulated a major leasehold presence in the Holbrook Basin over the past two decades; and has acquired rights in the Golden Eagle Gas. An internationally respected institutional investor plans to finance in excess of US$60mm for

additional investment in the processing plants and field development of the two projects. Its planned Oso Draw Helium Plant has a capacity of 240mmcf/y. The processing plants will have a nameplate throughput capacity of 10mmcf/d. In 2018, the company signed a 36mmcf/y helium offtake contract with Uniper from Arizona and also has offtake contracts with Linde.

Summit Source Funding LLC – The company develops, manages and funds business ventures specific to the exploration and production of helium and hydrocarbons. Summit Source Funding offers private investors the opportunity to participate in the exploration and production of helium by investing in specific projects. Summit Source Funding, along with teams of geologist and engineers analyse areas that have a high potential for helium production and forms a limited partnership that will drill multiple helium wells or re-enter existing oil/natural gas wells to extract helium from the helium zones.

Pollard Helium – Pollard helium was targeting licences in Arizona. The company has filed for bankruptcy in 2020.

Rest-of-the-world-focused helium E&P companies

Helium One - Helium One Global (ticker "HE1") is a UK AIM-listed pure-play helium exploration company, with a first-mover advantage in developing helium assets in Tanzania, where it has >6,000sqkm of exploration acreage. Founded in September 2015, its goal is to become a significant primary supplier of high-grade helium to industry. It owns exploration licences in three locations in Tanzania, a country with anomalously high helium concentrations and volumes that are amongst the highest worldwide. HE1 is the only listed company in the UK that enables investors to participate in the helium market. HE1 intends to drill three exploration wells (on the Kasuku, Itumbula and Mbuni prospects) within the Rukwa licence in Q2'21. To put it in context each of the wells is targeting the equivalent of around a year's global helium demand. The total Rukwa Project prospect inventory is 138bcf unrisked (P50) helium resource .

Renergen – The Australian and South African listed (JSE:REN) company is an emerging South African helium and natural gas producer with the rights to natural gas fields with high helium concentrations. It is currently developing its Virginia project where first production is expected in 2021 and a plant capacity of 350kg/d with the potential to grow to 10,000kg/d (2mmcf/d). It has prospective helium resources of >100bcf with average helium concentration of 3.4% and the newest discovery (a sandstone trap in the eastern portion of its field) containing up to 12% helium. The helium will be sold to Linde in an offtake agreement up to 24mmcf/y.

Noble Helium – This is an Australian based private company founded in 2017 with >5,000sqkm of exploration acreage in Tanzania containing an estimated resource of 98bcf. Most of their acreage is in the north, in the Eyasi and Lake Manyara regions bordering Ngorongoro, Manyara and Tarangire national parks. All of these seem to be at the PL application status, according to the Tanzanian Govt Mining Cadastre system. It aims to deliver first helium in 2025 and achieve 2.7mmcf/d of sustainable capacity.

Georgina Energy – This is a private company looking to list on the London market, that has acquired a licence in the Southern Georgina Basin, Northern Territory, Australia, which has significant helium potential as well as oil potential. Its EP127 licence has all the essential ingredients for the development of helium within structural reservoirs. It sees significant unrisked helium resource of between 8-138bcf (P90-P10).

Helium Resources – This is a private UK company that is looking to drill three to five test wells to 180-200 meters in Oxfordshire but does not currently have a licence to explore. Soil and waste methane vent gas geochemistry (~100 sites) conducted by HRL with assistance from Oxford and Durham Universities and MIT has confirmed widespread helium presence.

Irkutsk Oil – The Russian company is building a 233mmcf/y plant that is expected to start up in 2022. The plant is located 200km north of Ust-Kut to produce from the Yaraktin oil and gas condensate field. It has an offtake agreement with Uniper.

Helium distributors: industrial gas companies

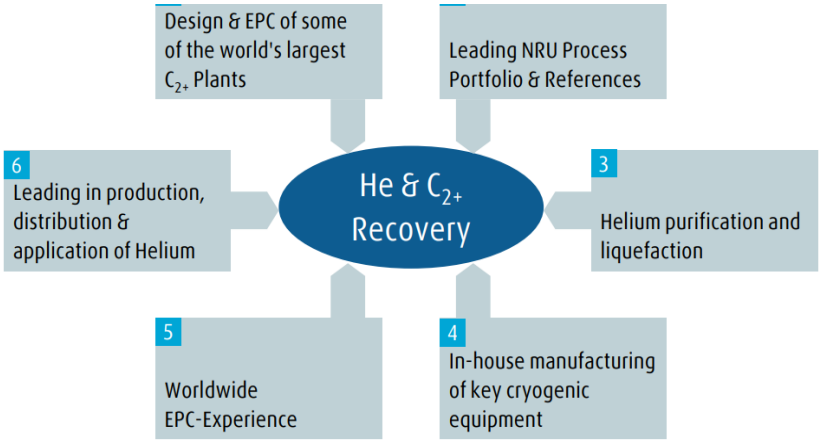
The wholesale helium market is an oligopoly. There is no spot market for helium. The top 3 purchasers (Linde, Air Liquide and Air Products) account for the majority of the global market. Two of the largest companies Linde and Praxair merged in 2018. As part of this deal the companies divested part of their helium businesses to Messer/CVC. The other significant smaller players are Matheson, Iwatani and Uniper. The helium distributors appear keen to diversify their supply options, which is encouraging for the smaller producers. Also, the wholesale buyers of helium, from the helium distributors are also looking to diversify supply.

Air Liquide – The company is a leader in industrial gases and a key player in helium. It has diversified sourcing worldwide and is the largest off-taker in Qatar. It has technical hubs, a large fleet of containers, transfills across all geographies and full secondary logistics (tube trailers, dewars, cylinders). It has a pure helium cavern in Germany for storage, which is the first of its kind.

Air Products – The company claims to have the most diverse supply mix and also makes more liquid helium than it buys off the market. Air Products designed and built the first cryogenic system for extracting helium from natural gas in the 1950s. It has built the majority of helium plants in use today around the world. No other industrial gas company has access to as much helium as Air Products, and no other supplier has as many owned and operated helium facilities. Gardner Cryogenics, a division of Air Products, is the recognised market leader in the manufacture of helium distribution and storage equipment. Approximately $7.9bn of its unconditional purchase obligations relate to helium and rare gases (around $450mm per annum from 2022 to 2025).

Iwatani – The Singapore based company is involved in industrial gases and its biggest source of supply is from Qatar from where it supplies the Asian market. It established a Helium Centre in Malaysia as a hub for supply to SE Asia.

Linde provides all capabilities for helium recovery projects worldwide



Source: Linde

Linde – Linde has a helium market share of around 40%. Linde operates one of the world's largest helium plants in Otis, Kansas, and several other facilities around the world including Algeria, Qatar and Australia. It has 50 helium transfill facilities located in all major helium markets. Linde Kryotechnik has decades of experience in the construction of helium liquefiers. Most of the helium that is captured in natural gas fields is liquefied in a Linde Kryotechnik system. In early 2020 Linde divested its China helium business to Guanggang Gases & Energy. The volume divested was 90mmcf/y with sourcing contracts from Qatar, Darwin and Amur.

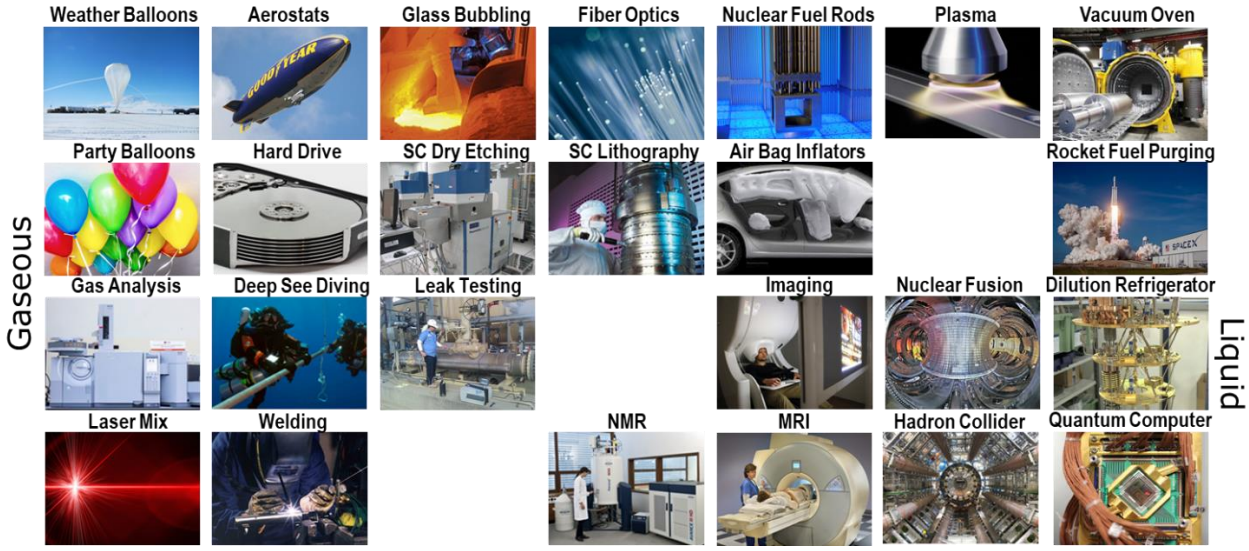
Matheson/Taiyo Nippon Sanso – Following the Linde/BOC merger a package of 500mmcf/y of assets were sold to TNSC. TNSC is a manufacturer of industrial gases, air separation and other gas production plants and gas handling equipment of which Matheson is a wholly owned subsidiary. TNSC is a major helium distributor throughout Asia. It purchases helium from Exxon, BLM, Qatar and will offtake from Gazprom's Amur project from 2021. It has >10% market share in China.

Messer - Messer is the largest privately held industrial gas business in the world. Messer Group has a fleet of its own helium containers. Messer operates helium filling plants in Europe, China and the US. In Europe, these are located in Mitry-Mory (France), Lenzburg (Switzerland), Gumpoldskirchen (Austria) and Pancevo (Serbia).

Uniper – Uniper is a leading international energy company including a diversified gas portfolio that makes Uniper one of Europe's leading gas companies. Uniper also manages an emerging portfolio of liquid and gaseous helium. Uniper started its helium activities in 2017 when it purchased volumes from the US federal helium reserve in an auction organized by the US Bureau of Land Management (BLM). Since then, Uniper has begun building up its fleet of cryogenic ISO helium containers and has been active globally by sourcing directly from helium producers and selling to industrial clients, resellers and research institutes in Europe, Asia-Pacific and the US. As one of the largest gas storage operators in Europe, Uniper also analyses opportunities to store helium in underground facilities. In mid-2020 Uniper signed an offtake agreement with Irkutsk Oil in Russia.

Uses

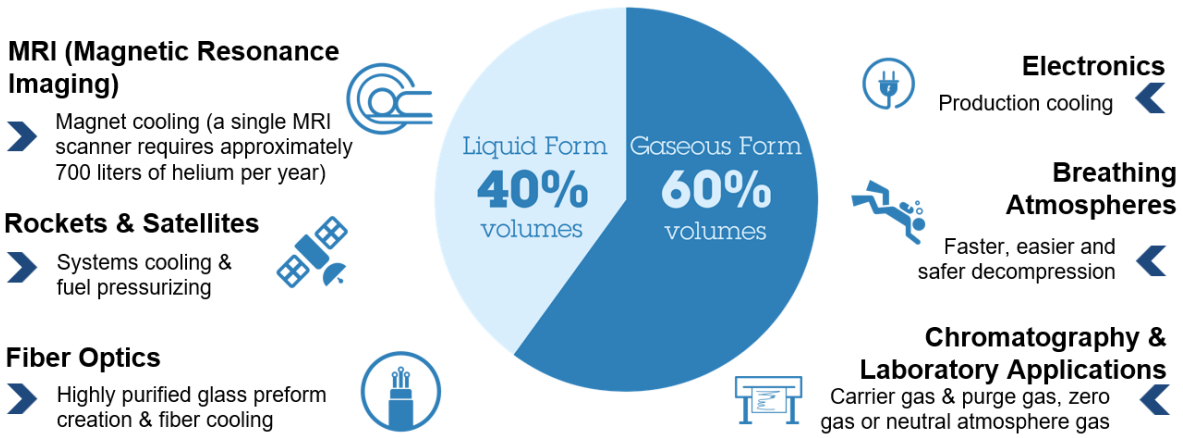
Uses of gaseous versus liquid helium



Source: Air Products

Helium is a vital resource, essential in modern technologies with major critical and irreplaceable use throughout the science, medicine and manufacturing industries. There is growing demand for various high-tech applications such as cryogenics, welding and pressure & purging, in addition to more recent developments which include hybrid air vehicles, helium filled hard drives and Google X Project Loon. It is an inert gas for cryogenic, heat transfer, shielding, leak detection, analytical and lifting applications. It is the most important element in studying super-cold conditions in low-temperature physics studies. It is a critical component in the manufacturing process, specifically ones which serve unique high-tech applications in MRIs and semiconductor chip manufacturing. Major factors driving the market are the increasing consumption of helium in the electronics and semiconductor industry as well as the growing usage in the healthcare industry. Space is another key growth area as well as quantum computing.

Uses of gaseous versus liquid helium



NB: there are several other sectors for which Helium is a key molecule: leisure (balloons), airbags, welding…

Source: Air Liquide

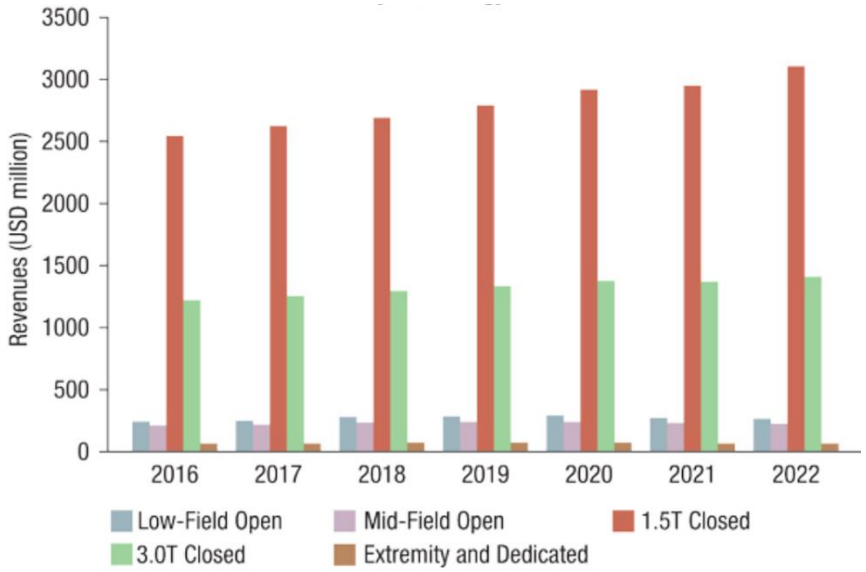
MRI and other cryogenics

Helium is used as a super coolant for cryogenic applications such as Magnetic Resonance Imaging (MRI), Nuclear Magnetic Resonance (NMR), in the Large Hadron Collider, superconducting magnets and other cryogenic research. The Large Hadron Collider required 27mmcf of helium and around 25% of this is expected to be required to be topped up each year due to leaks. So this alone accounts for >1% of global helium demand.

Helium as super coolant cannot be substituted in cryogenic applications, if temperatures below 17 Kelvin are required. Helium cools low-temperature superconducting materials and low-temperature superconducting magnets to a temperature close to absolute zero, so that the electrical resistance of superconductors drops abruptly to zero. The extremely low electrical resistance of superconductors enables the creation of more powerful magnetic fields.

A 2016 report from the American Physical Society (APS), the American Chemical Society (ACS), and the Materials Research Society estimated that 400 U.S. research groups, mostly in the physical sciences, rely on liquid helium for experiments. In the case of MRI equipment in hospitals the more powerful magnetic field yields greater detail in the radiological image scans.

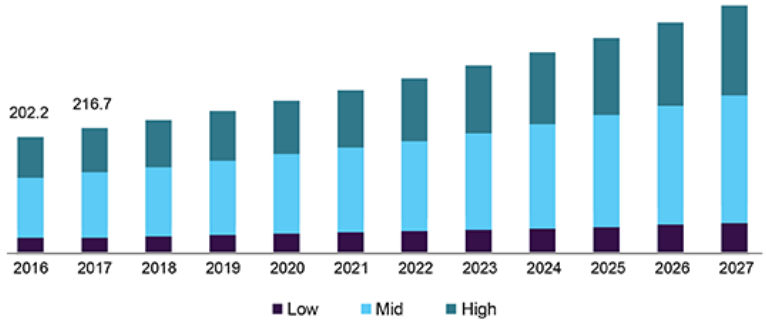
World market for MRI equipment by technology



Source: Medical Buyer

The use in MRI machines represents the largest single use for helium globally. There are differing estimates on the amount of helium used in MRIs ranging from 20-30%. There are estimated to be around 50,000 MRI machines globally of which around a quarter are in the US. Industry forecasts expect annual growth of over 5% per annum driven by expanding clinical applications for MRI and growth from developing markets, which have a very low number of machines per capita. Usually, after an average of seven years, many machines are being replaced or refitted. Overall, around 5,000 new units are sold every year. A typical scanner will cost around US$500,000. The global MRI market size is estimated to be around US$5bn.

China MRI market size ($mm) by field strength, 2016-2027



Source: Grand View Research

A new MRI scanner requires up to 2,000 litres (0.05mmcf) of helium and will lose anywhere between 0-5% per month, which will need to be topped up. Older MRI's can see helium boil-off at the higher end of this range. The new units being produced every year require filling with helium and if we assume around 1,500l per unit (some units are zero helium), this is around 0.2bcf/y of demand. In terms of the existing units, if 25% of the helium needs to be replaced each year (2% loss per month) implies around 0.5bcf/y of demand. So, in total we see around 0.7bcf/y of demand from the MRI market.

Offsetting some of the helium growth from the MRI market is the introduction of low or no helium MRI machines. Over the last decade zero boil off (ZBO) refrigeration systems have become more common, allowing essentially unlimited normal operation without need for helium refill. However, the price difference between the ZBO MRI and non-ZBO is typically more than $100,000 as well as there being higher refrigeration costs and higher power consumption. Also, the cold head and refrigeration compressors still need regular filter changes and other servicing, so some cryogen replacement at these times is unavoidable.

MR Solutions introduced the world's first commercial helium-free MRI scanners in August 2015. Its new magnet design uses superconducting wire to replace the traditional liquid helium cooling jacket. Similarly, in February 2017, GE Healthcare unveiled its Freelium magnet technology. This technology uses 1% of liquid helium when compared with conventional MRI magnets. However, this technology was not FDA approved.

MRI helium usage and estimated costs

Magnet Type	MRI Model	Avg. Helium Consumption	Avg. Helium Refill Cost/Year at Current Rates
GE CXK4 LCC	All GE 1.5T until 2009	Zero boil-off	$0
OR105	Siemens Avanto	Zero boil-off	$0
OR122	Siemens Espree	Zero boil-off	$0
Philips (IGC) F2000	Philips Intera & Achieva 1.5T	.02 - .04% per day	$26,000
OR70	Siemens Symphony	.1 - .2% per day	$36,000
OR76	Toshiba Vantage & Titan	.1 - .14% per day	$36,000

Source: Block Imaging

Scientific Research

Global scientific enterprise depends on a steady, reliable and affordable supply of helium. For tens of thousands of scientists and engineers across the US for example, with research projects ranging from quantum information science to next generation energy materials to space exploration, helium is essential to performing their work.

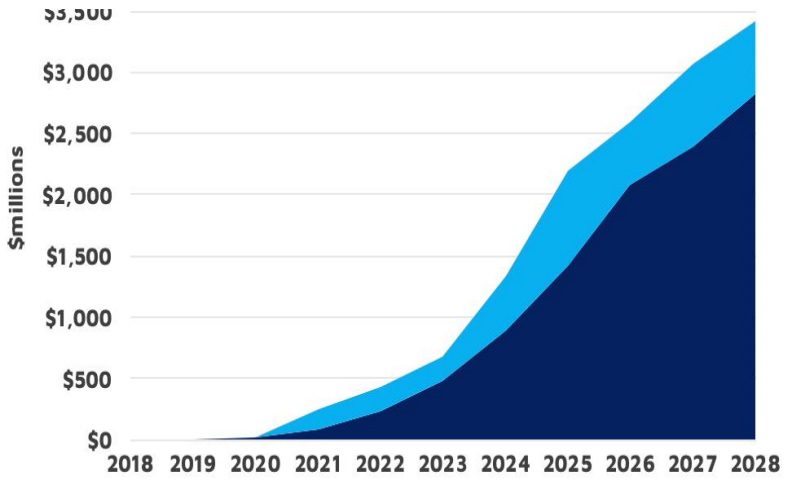
A key use for helium is in universities in NMR machines. It is ubiquitous in the fields of medicine, chemistry, pharmacology, and physics. A typical NMR lab could use around 20l per day or 8,000l per year. Smaller NMR machines may require around 100-200l per year. It is also used in high-tech microscopes to produce higher resolution images. Laboratories also require liquid helium for super-conducting quantum interference devices (SQUIDs). SQUIDs measure extremely small magnetic fields and are used in biological research.

Many experiments and equipment must be continuously supplied with liquid helium to remain cold for extended periods of time. Equipment can become useless or permanently damaged if the liquid helium supply is suddenly cut off, and it warms above a threshold temperature.

Rockets and Satellites

Helium is critical to the space industry. Helium's low temperature and inert properties make it the only gas that can pressurise and purge liquid rocket engines. In 2015, NASA said that it uses up to 100mmcf of helium a year. Helium is used throughout NASA as a cryogenic agent for cooling various materials and in precision welding applications, as well as lab use. Large, unmanned helium balloons provide NASA with an inexpensive means to place payloads into a space environment. Helium also is used as an inert purge gas for hydrogen systems and as a pressurizing agent for ground and flight fluid systems of space vehicles. 1mmcf is used for every launch. China's main space contractor is aiming to carry out more than 40 launches in 2020, including lunar, interplanetary and space infrastructure missions. There are also many other nations that are looking to expand their space programmes such as India and the EU.

Space tourism market revenues



Source: NSR

An expected growth area of the market is space tourism with the potential for 3,000 flights by the end of the decade. Three potential technologies to consider are balloons, rockets, and rocket-planes, such as from Zero2Infinity, Blue Origin,

and Virgin Galactic. All of these technologies will require significant amounts of helium.

The US Defence agencies need helium to operate high altitude balloons, heat-guided missiles and rockets. It remains the only gas that can purge and pressurise the propulsion systems and tanks of rockets that rely on liquid hydrogen and oxygen as fuel.

Helium is critical to keeping satellite instruments cool, which is required to reduce the inherent noise that would drown out the tiny signals that are being measured. This is achieved using a cryogenic helium system.

Semiconductors and electronics

A key area of future growth in helium demand is expected to be from electronics manufacturers in Asia. Semiconductor manufacturing, flat-panel display manufacturing, and optical fibre manufacturing are all significant consumers of helium in Asian markets.

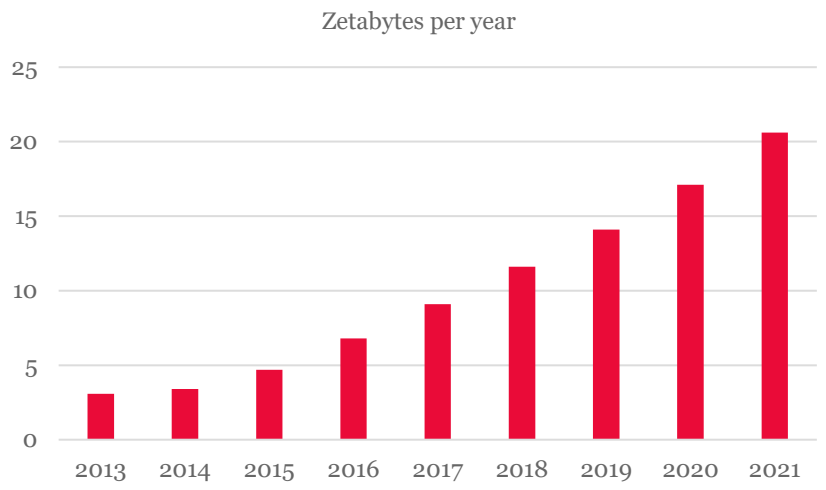
As a noble gas, helium is completely inert and will not react with any other element. This property makes it useful in critical applications such as semiconductor and fibre optic manufacturing. It is used as a cooling gas due to its extremely high specific heat and thermal conductivity in semiconductor manufacturing. For example, helium is used as the sleeve in rods that create LCD screens; during the processing of semiconductor chips it is used as protective gas for flushing vessels, and it is used as a protective and cooling gas when growing silicon and germanium crystals.

Demand for helium in semiconductors is around 1bcf/y and is expected to grow by 7-8% per annum, driven by both higher growth in volume of semiconductor manufacturing but also higher demand intensity as semiconductor process complexity increases. Demand growth has been driven mainly by the emergence of larger-diameter silicon wafers. The growth is aligned with the increased use of vacuum systems for etch and deposition. Semiconductor chips are manufactured on base silicon wafers largely using deposition (additive) and etch (subtractive) chemical reactions in the gas phase to create thin layers of different materials on the wafer surface. There is limited ability to substitute for helium. Helium demand intensity increases as semiconductor process complexity goes up: 15 years ago, helium demand for electronics was less than 1% of total demand and now it is 15-20%.

Helium is used as a coolant during fibre optical cable manufacturing due to its very high specific heat and thermal conductivity. The liquid helium's low temperature and inertness makes it ideal to rapidly cool silica strands in a cooling tube as glass fibres are drawn from a glass billet or preform. These cables are used to enable high speed internet. This increases production speed: a single plant can produce more than two kilometres of fibre per minute. Many glass fibre production facilities spend hundreds of thousands of euros on helium annually.

Another use for helium is replacing the air in a hard drive with helium (seven times less dense than air) the discs inside create less turbulence as they spin, meaning more discs can be packed into less space and use less power. Six terabyte hard drives are 23% more power efficient and offer 50% more capacity than regular drives and we have now seen the introduction of 10TB drives. Helium-filled high-capacity hard drives are now used to power industry's largest data centres, including Netflix video streaming.

Global data centre IP traffic, 2013-2021E



Source: Statista

A further potential use is in quantum computing which may ultimately replace conventional computers over the coming years with plenty of money pouring into research for quantum computing. IBM is already preparing a jumbo liquid-helium refrigerator, or cryostat, to hold a quantum computer with 1 million qubits.

Separation

Helium is used for chromatographic separation (physical method of separation), mainly as a carrier gas. This is required in several sectors such as the pharmaceutical industry for drugs, in the food and beverage industry, medical diagnostics, explosives and environmental assessments. It is an ideal gas because it is chemically inert and diffuses rapidly and there are no obvious substitutes.

Leak detection

Helium is used for leak detection, because helium has the smallest molecular size and it is likewise a monatomic molecule. Therefore, helium passes easily through the smallest leaks. During leak detection an object is filled with helium and in case of a leak a helium mass spectrometer will detect where the leak is located. Helium provides for detecting leaks in rockets, fuel tanks, heat exchanges, gas lines, various electronic devices, television tubes and other manufactured components. Helium for leak detection was first applied during the Manhattan Project to find leaks in the uranium enrichment plants.

Welding

One of the largest uses for gaseous helium is in welding, where it provides an inert gas shield to protect the weld zone from the atmosphere (to prevent contamination with the oxygen in air). The two major welding processes that use helium are gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW). The high ionisation potential of helium enables the plasma arc welding of exotic metals such as titanium, zirconium, magnesium and aluminium alloys used in construction, shipbuilding and aerospace.

Diving

Helium is used as deep-sea diving gas at water depths below 30m due to its extremely low solubility in water and blood. Helium/oxygen breathing mixtures such as heliair, trimix and heliox are used instead of nitrogen /oxygen breathing

mixtures to avoid nitrogen narcosis or the build-up of nitrogen in blood thereby preventing "the bends." In addition, helium does not cause corrosion to the equipment and it is non-toxic.

Lifting

Helium is the second lightest element after hydrogen and it is less dense than air. Therefore, helium is used as lift gas for balloons, meteorological balloons, airships and has been used for blimps since WWI. The use of helium as lifting gas was the first application of helium since its discovery on Earth. As lift gas helium can be substituted by hydrogen or a mixture of hydrogen and nitrogen. Despite being less buoyant than hydrogen, helium is the preferred lift gas, because it is not flammable.

Party balloons remain a big market for helium at just under 10% of global demand. Balloon gas is lower purity (~95%) than what is used in scientific research. As cylinders of pure helium are filled, the escaped gas mixes with air and is captured and compressed into cylinders as balloon gas. Some manufacturers capture this helium when filling MRI scanners. Manufacturers have stated that this wasted helium is considered a 'recycled product' as it would have been lost to the environment had it not been captured and re-purposed.

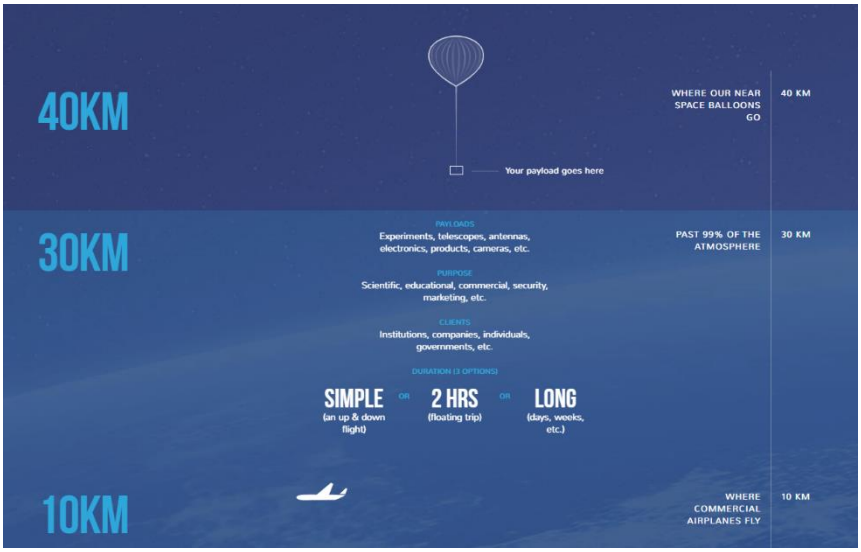
One potential growth area that has been on the cards for years but not materialised is the use of airships. This may return to the forefront as the carbon footprint of air travel becomes a much bigger issue. Hybrid or variable lift airships have been worked on by various companies.

Balloon flight

Source: YouTube

Google is launching a network of helium-balloon carried nodes to bring internet to every corner of the world. More than half the world is still without internet access. Google's Project Loon aims to fix this through a network of Helium gas filled balloons traveling on the edge of space. With a new balloon launched every 30 minutes, it is designed to extend internet connectivity to people in rural and remote areas worldwide. Google has now flown over 25 million km of test flights with one balloon staying aloft for 190 days. We estimate that each balloon uses around 0.02mmcf of helium with a maximum life of 100 days.

Balloons for payload



Source: Zero2Infinity

Helium balloons can also be used for satellite delivery, according to B2Bspace, saving fuel and money by using the balloon to lift a rocket to high altitude before launching it. A giant helium balloon can be used to lift an unmanned rocket up over the sea to a height of around 22-25 miles. The rocket, carrying a satellite, will then blast into space to deliver its cargo. Zero 2 Infinity is a Spanish start-up working on helium balloon-borne spacecraft. The current highest altitude achieved by a NASA balloon is about 160,000 feet.

Airbags

High pressure helium is used to safely inflate airbags in cars during an accident, helping to prevent serious injuries.

Nuclear Fusion

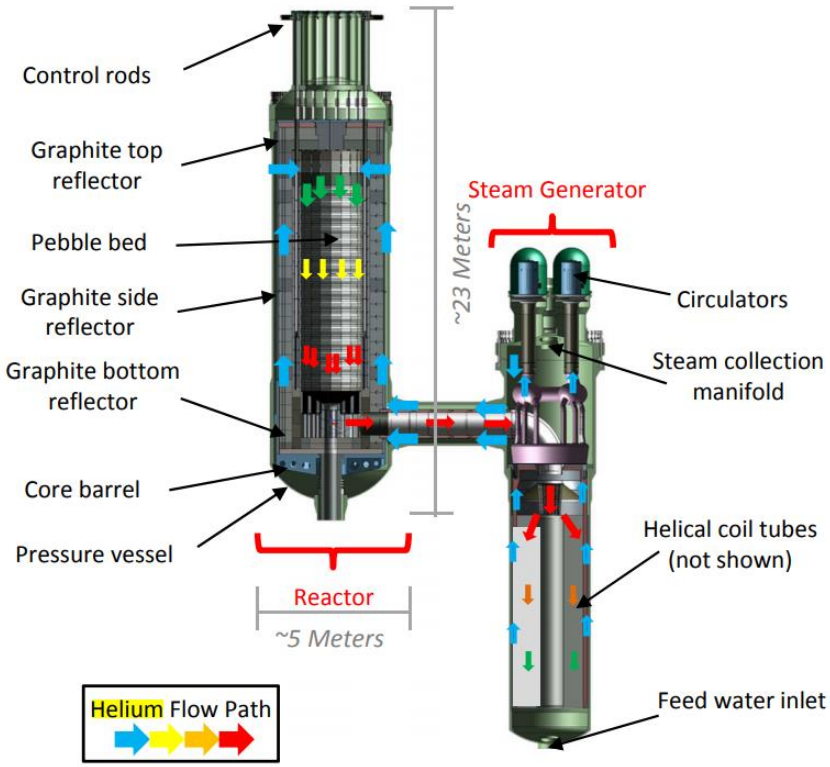
Nuclear fusion has seen some encouraging progress recently and increased investment (large integrated oil companies such as Equinor, Chevron and Eni getting involved) with the expectation that commercial fusion power could become proven within the next decade or so. The largest plant globally is currently the International Thermal Experimental Reactor (ITER) at a cost of over US$50bn to reach commercial production. The ITER plant will use 25 tonnes or 5mmcf of helium. First Plasma at ITER is expected in 2025. If proven, a global roll out from 2035 could replace fossil fuel burning power plants over the balance of the century. This will require a huge increase in helium supply if it takes off. Only helium can cool the reactor as the ITER plasma temperatures will soar to between 150-300 million °C. - at least 10 times hotter than the core of the sun. Within the ITER machine, physicists and engineers are preparing to reproduce

the physical reaction that, by fuelling the energy of the Sun, has maintained life on our planet for billions of years.

Modular helium nuclear reactors

There has been a big push to develop small modular nuclear reactors as a zero carbon power solution that is ultra-safe and affordable. There are a variety of competing technologies but many of these require helium as a coolant in the process. We see this a potentially significant area of growth on a 5-year plus time horizon. The US Department of Energy (DOE) announced recently it will help build two radically new nuclear reactors within 7 years. The Xe-100 design from X-Energy would use pressurized helium gas to cool its uranium-based fuel.

Xe-100 Reactor



Source: X-energy

The use of helium coolant greatly reduces corrosion, boiling, and contamination risks associated with more traditional water coolant. Helium has a very high specific heat and a high thermal conductivity, so that it is one of the most efficient heat transfer gases. In addition, helium does not cause corrosion and it is radiologically inert (no radioactive isotopes). Helium does not change aggregate state and it does not influence neutron multiplication factor. Nuclear plants with helium as heat transfer medium have higher efficiency and higher operating temperatures.

China National Nuclear Corporation has built a demonstration high-temperature gas-cooled helium pebble-bed module reactor plant (HTR-PM) . The plant will initially comprise twin HTR-PM reactor modules driving a single 210MWe steam turbine. A further 18 units are planned for the site.

Pricing and market balance

Market pricing for helium is difficult to determine as it is not a traded commodity, so there is no helium exchange on the commodities markets. This means there is no benchmark spot or futures pricing as is found with other major commodities. Helium is generally priced on long term contracts between producers and industrial gas buyers, which are largely confidential. Ten-year plus contracts are customary, which are generally take-or-pay with price reopeners. The helium is normally sold at the plant gate into buyers' tube trailers. There is the potential to retain some spot market component in contracts, and newer producers have entered discussions over development funding from potential offtakers.

As a result, helium pricing is very opaque as there is no liquid traded market, with only a few key suppliers and a handful of industrial gas buyers. The one consistent source of pricing was from the auction of helium from the large US BLM reserves, but these were only infrequent price points and the last auction held was in 2018. Helium pricing has been on an upward trend as a result of declining volumes from the US BLM storage facility and growing demand for helium globally.

Overall "spot" or current pricing for helium is not so important for the upstream producers in our view because most companies will have signed or look to sign long-term contracts, which means that short-term price fluctuations have little immediate impact, although over time it could lead to price reopener clauses being triggered (either to the upside or downside). This is somewhat similar to the LNG market, however a major difference is that in LNG, generally the price is benchmarked to oil prices, whereas we expect helium prices to be fixed and importantly if there are contracts with investment grade offtakers, it should make them more bankable, especially if there are floor prices. An example of this is the asset-based lending that NASCO was able to secure against its US helium assets.

Major consumers of helium tend to be price insensitive given that the cost of helium in the context of the wider cost of a project is small, so even a large percentage increase in the cost of helium will not alter the economics. Furthermore, given there are no replacements for helium, the buyers are price takers. As seen in the LNG business, we believe that certain buyers are willing to pay a large premium to guarantee security of supply or have a diversified supply given that for some consumers, there is no alternative to helium for their processes. For example, scientific researchers account for only a small percentage of the world's annual helium usage, and individually they have no purchasing power in the helium market.

It has been estimated that around 10% of global helium demand was lost in 2011-13 due to shortages and pricing doubling. If pricing of helium does fall sharply, we believe that this suggests there is some price-sensitive demand that will come back into the market and soften the blow to prices as a result. The market is very susceptible to supply disruption, which has led to price spikes in the past.

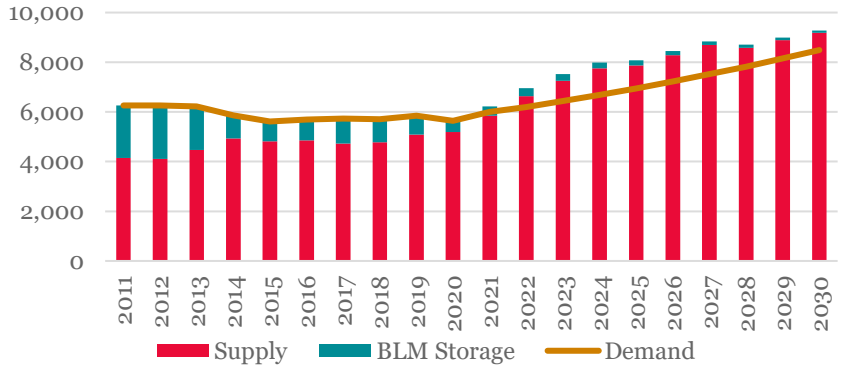
There are various types of helium sold also, which impacts the price. In the US "crude helium" is what is sold by some producers and from the Government storage: this contains at least 50% helium (generally around 70-80%). This is then purified and can be sold as a gas generally as "balloon grade" (~99% helium), also known as "Grade A", or it is further purified to 99.9999% helium and liquefied for storage and transport for many technological applications.

In 2020 the helium market is thought to be oversupplied as demand has taken a hit from the party balloon sector as well as from logistical delays in manufacturing

sectors. Supply has also been impacted by lower LNG production, which will have had a knock-on impact on helium supply in places such as Qatar and Algeria. Also there has been lower supply availability from the US BLM storage facility given the stoppage of sales into the market. Q3'20 results commentary from the gas distributors suggested that although demand was weak, especially in the most profitable balloons segment, pricing was up on a y/y basis. The companies were not optimistic that much of the planned new supply (Qatar/Russia) will materialise until late next year.

Despite the lack of easily available market pricing, we have conducted our own research to ascertain pricing data points. Information can be gleaned from various sources, for example comments from helium users, other market participants, official customs data and industry conferences.

Estimated supply demand balance for helium (mmcf/y)



Source: H&P estimates

In our base case forecasts, we see the helium market as potentially over-supplied in the coming years, suggesting that pricing will come under pressure. However, we think that the risk to supply is to the downside vs our forecasts and demand is to the upside, especially if there is more supply available at lower prices.

Our concerns on supply are that there could be delays to the mega helium projects due online in Russia and Qatar; historically, projects have encountered issues ramping up. Also, in the US, we see a risk of steeper declines if associated natural gas production declines, and if there is less requirement for CO2 (which is produced alongside helium in some fields) for improved oil recovery.

On the demand side, we believe that there is latent, unfulfilled demand for helium as there has been limited supply for several years. A wave of new supply could bring back some of the demand that has been lost over the period of shortages and stimulate new demand from growth technology industries that previously were not able to source helium.

Therefore, we believe our price forecast of US$250/mcf balances the risk of oversupply dampening the market with the upside risk to prices from the potential supply and bullish demand factors mentioned above. Our forecast appears to be substantially lower than current market pricing and in-line with some longer-term contract pricing.

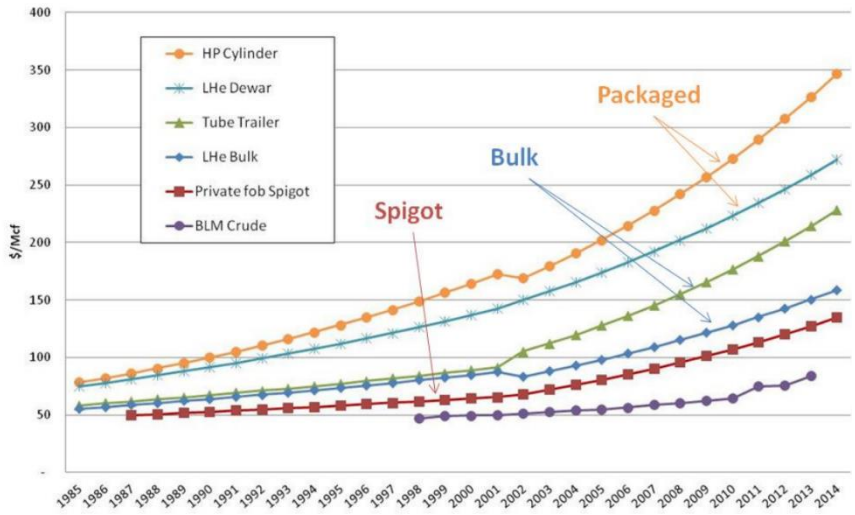
Also, we think that certain suppliers will be able to garner a premium for their product related to security of supply and producing "cleaner" helium. For example, suppliers outside of Qatar and Russia may attract a premium as they provide a diversification of supply and eliminate some of the geopolitical risk for

buyers. Furthermore, suppliers that are producing helium that is not associated with natural gas production can sell this helium as "low-carbon" helium that has not been associated or be viewed as a by-product of hydrocarbon production.

We see recent pricing at around US$250-300/mcf for producers. For example, the majority of imports into Europe have recently been around US$250/mcf and imports into China at US$300/mcf based on the data we have available. The latest US auction pricing (back in 2018) was at US$280/mcf. Gazprom has apparently been selling individual cargoes of helium for ~US$700/mcf. From the data we have seen, when cargoes are being sold in single ISO sized containers (1mmcf) they appear to be selling for well over US$500/mcf. To put these prices in context, end users such as universities have been paying >$1,000/mcf.

US crude helium pricing

BLM crude helium prices versus other delivery modes (US$/mcf)



Source: BLM

The main historical source of pricing data generally referred to in the market is US pricing, released by the US BLM's Federal Helium Program. The BLM sells crude helium at around 80% purity (which still requires refining to achieve high purity helium) out of the Federal Helium Reserve. There have been three categories of sales. It reserves volumes for Government users, sold at low prices, that increase each year based on inflation (there were bigger ~10% increases in the 2016 and 2019 fiscal years). The current pricing for these users is just under US$100/mcf for fiscal year 2021, which is the last year of the programme.

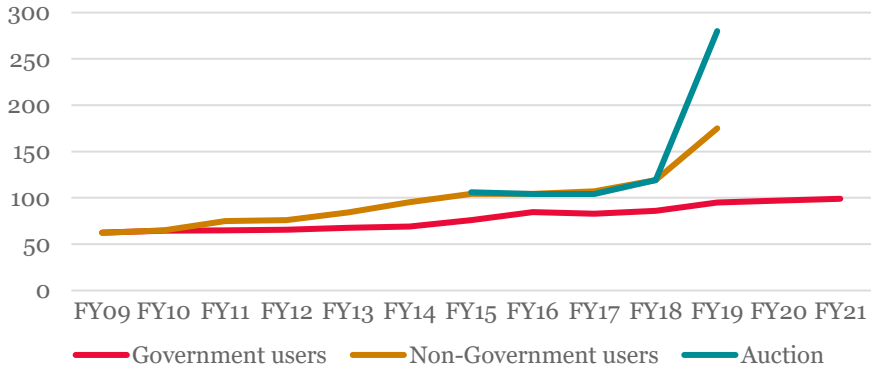
The sell down of the US BLM at artificially low prices has created downward pressure on pricing for the entire market over the last decade. The BLM's crude helium inventory is now being reserved exclusively for government helium users until such time as the BLM's helium assets, including its remaining crude helium inventory, are privatised. This is due to take place by October 2021.

Helium was also sold to non-Government users through "conservation sales", which historically since FY'11 had been priced at a premium to the Government sales (averaged US$99/mcf FY'13-17, which was a 30% premium on average to what Government users paid). The non-Government price increased to US$119/mcf in FY'18 (+11% y/y) and had a steep increase of 47% in FY'19 to US$175/mcf. There were also sales conducted by auction in addition to these

sales; for FY'15-FY'18 the prices mirrored each other but in FY'19 much higher prices were seen in the auction.

The BLM held its last public auction of crude helium in August 2018 (FY'19), when Air Products bought all the helium on offer for an average price of US$280/mcf and the highest price it paid for a single lot was US$337/mcf. The total amount sold was 210mmcf, which generated US$59mm in revenue. The US$280/mcf price was 135% higher y/y.

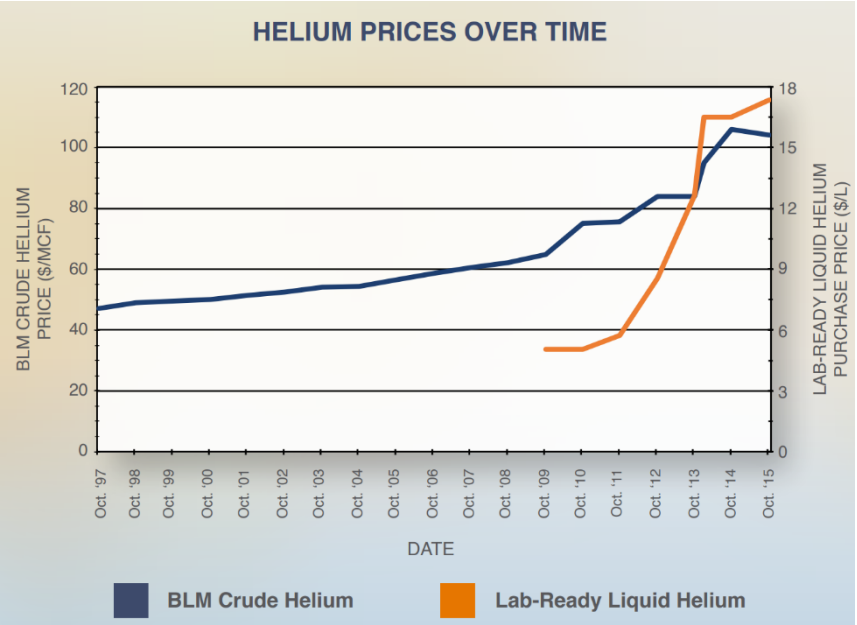
Annual (fiscal year) US BLM prices (US$/mcf)



Source: BLM, H&P estimates

The US BLM also releases its estimates of Grade A helium prices for private industry, which have remained in a very narrow range of US$200-210/mcf since the last increase in 2013. Therefore, we would not put too much credibility on this range, especially as the BLM states that some users post surcharges to this price.

Helium prices over time: BLM crude helium and Lab ready liquid helium



Source: American Physical Society

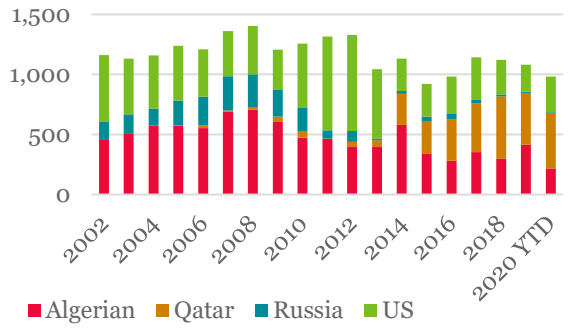
BLM's open market/conservation price for crude helium increased by more than 60% between October 2009 and 2015. During the same time period the purchase price for liquid helium for a professor at a Midwestern tier-one research university went up by nearly 250%.

Import and export data

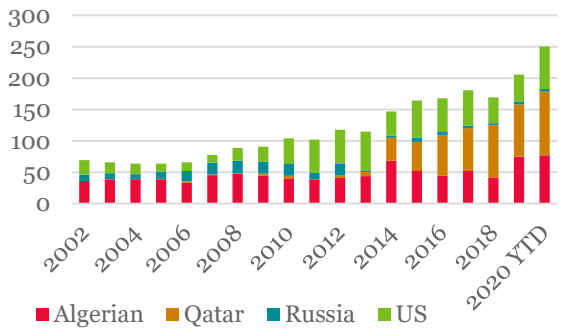
We have conducted a detailed analysis of import and export data relating to helium. Generally, helium is transported globally in standard ISO size containers. There are limitations to the data as in some cases helium is included with other rare gases, so it is difficult to ascertain its contribution. Also although there is pricing data, in some cases there are question marks over the accuracy of the data and also pricing will vary depending on quantity and who is buying (e.g. is it an end-consumer who will pay more than an industrial gas buyer). Nevertheless, we believe that the data we have gathered provides valuable information in a market with little pricing data available.

European import data

EU27 helium imports from major suppliers, mmcf/y



EU27 helium cost from major suppliers, €mm

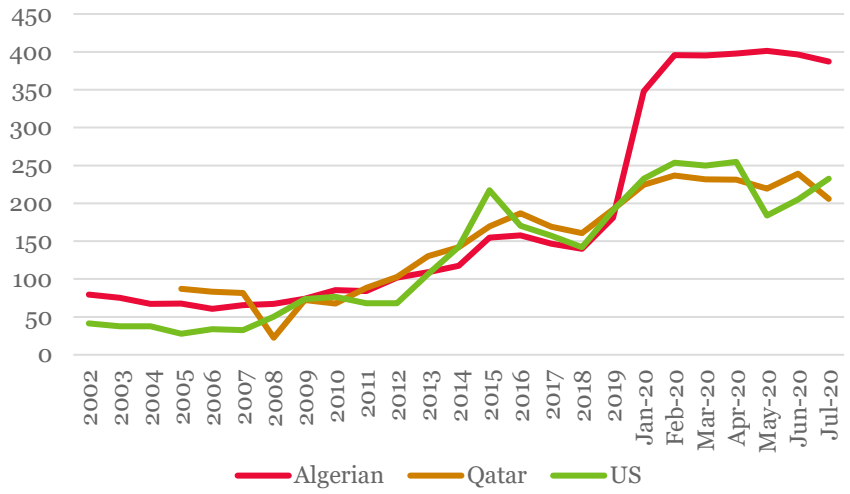


Source: Eurostat, H&P estimates (2020 data above is annualised)

In Europe (EU27 data), we can see detailed data on imports and exports for helium specifically. The data quality appears reasonable. Imports of helium into Europe have been falling over the last decade. However, the value of exports has continued to rise as prices have increased. The data shows that there has been a change in mix of suppliers into Europe over time, with a large fall in US supplies over the last 7 years, largely replaced by Qatar since 2014, which has been the largest supplier for the last 5 years. Algerian supplies have also fallen versus the 2000-2010 levels.

It suggests that the EU27 imported 1.1bcf/y from Algeria, Qatar and the US combined in 2019 at an average price of €190/mcf or $220/mcf. For 2020 data to August annualised we see imports of 981mmcf, which is down 9% y/y, likely due to COVID impacts. We would assume the vast majority of imports were done by the large industrial gas companies, so the pricing implied is what the upstream suppliers would have been paid, not the price that the industrial gases companies are selling for in Europe.

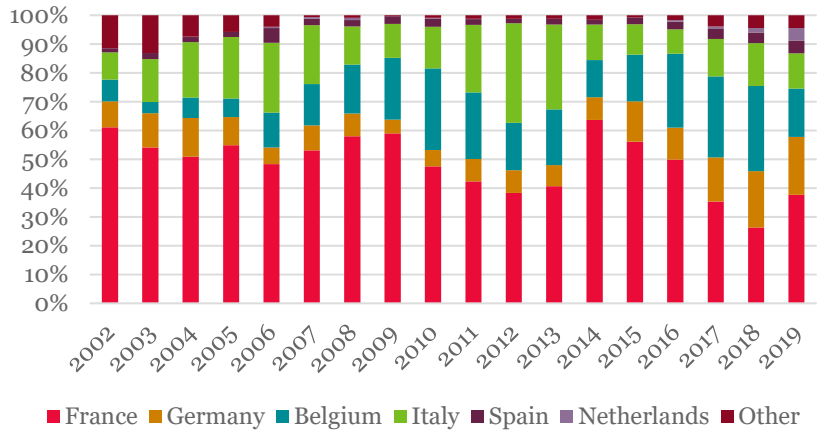
Estimated European import pricing, €/mcf



Source: Eurostat, H&P estimates

Helium import pricing, as we would expect, has been rising over time from all regions. There had been a close correlation in prices over time. For 2020 it is interesting that pricing has increased substantially up around 15% from Qatar to €220/mcf and up 18% from the US to €225/mcf. However, the most surprising rise has been from Algeria, where prices have doubled to €369/mcf and imports have fallen by almost half. It is hard to find further details to explain the data but it could be because of either some low-price contracts expiring or a renegotiation of prices. Some of the shortfall from Algeria in 2020 has been made up by the US increasing volumes.

European helium imports by country as a % of total from Qatar, US and Algeria

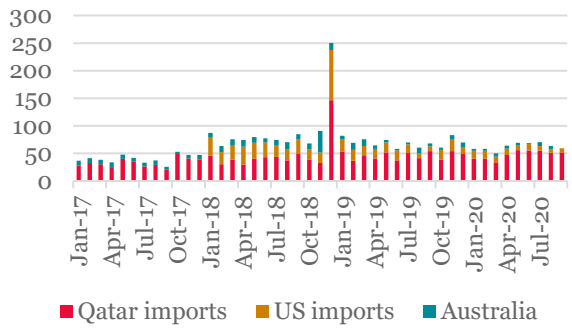


Source: Eurostat, H&P estimates

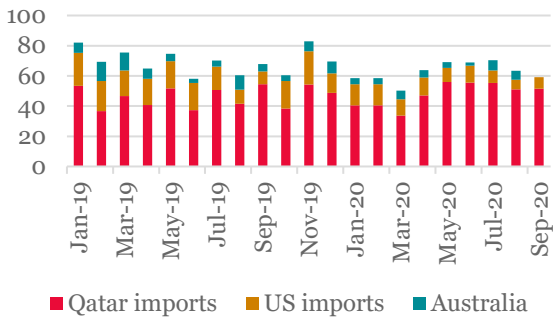
The biggest importers of helium in Europe are France, Germany and Belgium. Given this is only EU data it does not include UK and Swiss imports, which we would expect to be substantial also.

Chinese import data

Chinese rare gases imports 2017-2020, mmcf/m



Chinese rare gases imports 2019-2020, mmcf

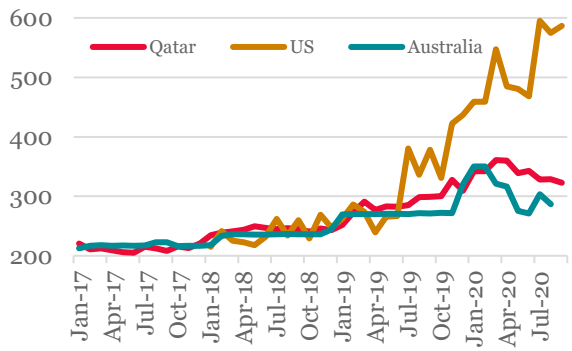


Source: Chinese Customs Data, H&P estimates (2020 for January and February is averaged as only aggregate data reported)

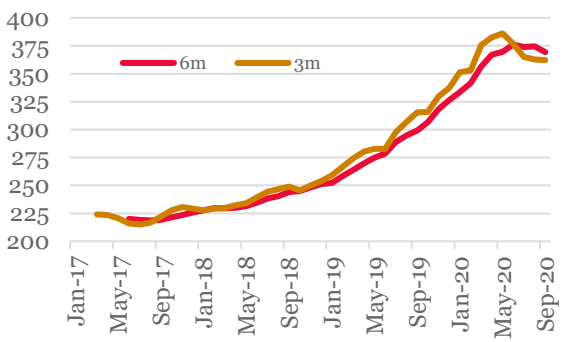
China releases import data for "rare gases", which we believe comprises mainly helium, so it can give a good idea on trends on volume of imports and pricing. There does not appear to have been much growth in Chinese helium imports over the last couple of years. Volumes were down sharply in Q1'20 but have since recovered. Pricing, however, has shown a consistent upward trend since 2017 only starting to moderate recently.

The data shows China importing on average 925mmcf of helium (assuming all of the imports were helium) per annum since the beginning of 2018. Over the last year 71% of imports came from Qatar, 18% from the US and 7% from Australia.

Estimated Chinese helium import prices by region, $/mcf



Chinese rolling average helium import price $/mcf



Source: Chinese Customs Data, H&P estimates (2020 for January and February is averaged as only aggregate data reported)

It is interesting to see that pricing data suggests that import prices for helium had been consistently increasing from January until early 2020, when they started to moderate. Prices from Australia appeared to be constant through the year and then step up into the next year, implying a price reset at the beginning of each year between 2017-2019. Over that period the price increased 8% in 2018 to $237/mcf and 16% in 2019 to $275/mcf. In 2020 however there has been more fluctuation in price and on average the price is up 13% y/y to $309/mcf.

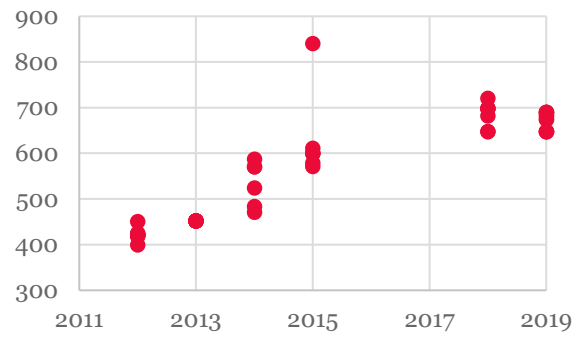
Qatari pricing steadily increased until it peaked in March 2020 at $361/mcf and has since retreated to $323/mcf in the latest month's data but this is still up 7%

y/y. Imports from the US have seen a sharp increase in pricing since H2'19. Prices averaged ~$238/mcf in 2018, $266/mcf in H1'19 and rose to US$381/mcf in H2'19, which was up >50% y/y. Year to date prices have averaged $517/mcf. The reasons for this could be because there are end users buying the gas so this is more akin to a wholesale price, or there may be some other elements in the data.

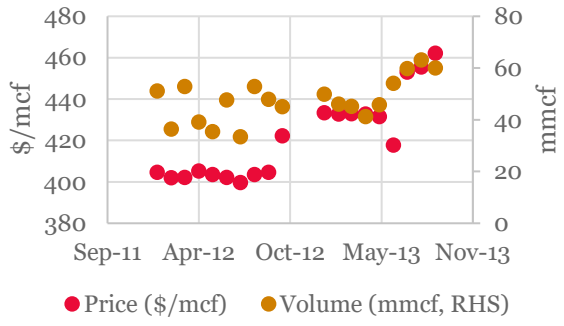
Qatar export data

Data from Qatar on helium exports is like China, in that it includes other rare gases. However, unlike the Chinese data, it appears that there are things other than helium in the data and the volumes and pricing do not match up with what we would expect. We have pulled out some data that we think is related to helium. First on the left-hand chart below we have pulled out the cargo sizes that relate to a single ISO container on our calculations. This shows pricing steadily increasing to levels around $600-700/mcf. As these are single containers, the higher pricing could be valid if based on the price being paid by the end consumers. On the right-hand chart we show gas sales to the UAE, via which Qatar was exporting helium earlier this decade. It shows a steady increase in pricing at attractive levels, but we would cautious about the quality of this data.

Estimated single ISO rare gases export prices, $/mcf



2011-13 Qatari estimated rare gases exports via UAE

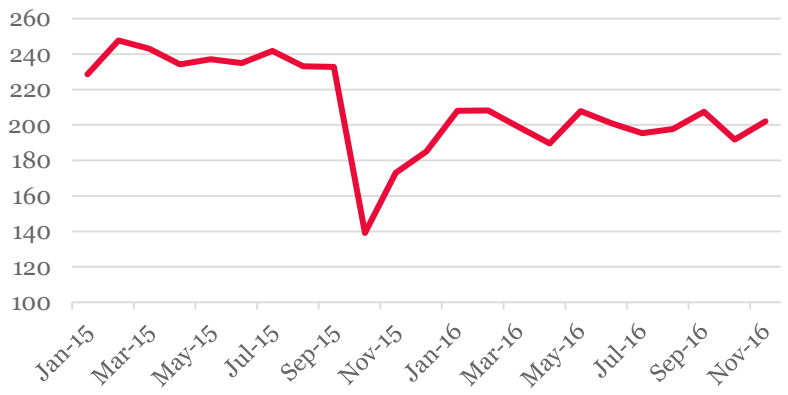


Source: Qatar Customs Data, H&P estimates

Indian imports

Indian import data on helium is available from a few years ago but we do not have more recent data. This shows that between 2015 and 2016 prices averaged around $210/mcf.

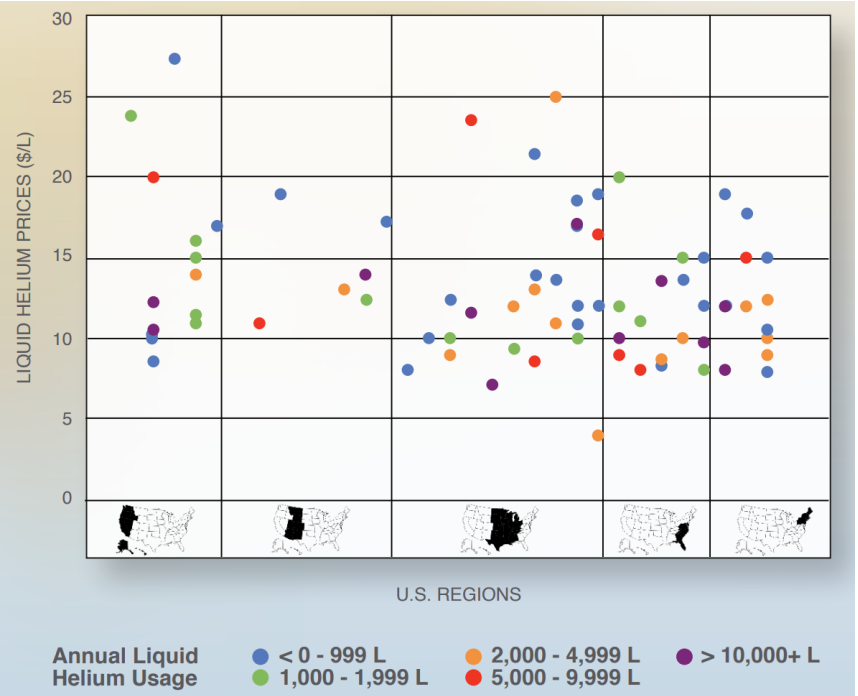
European helium imports by country as a % of total from Qatar, US and Algeria



Source: Indian customs data, H&P estimates

Pricing data points and anecdotes

US regional liquid helium pricing 2014-15 from >70 institutions



Source: American Physical Society

Given the lack of official information on the helium market one must rely on commentary from companies and datapoints where available (e.g. customs data). It is not always clear whether these are producer prices or wholesale prices to large end users. The chart above, for example, shows the wide range of end user prices across the US with little correlation to size of purchase or location (note US$20/l is approximately US$750/mcf). Below we show some data points that we have found:

Gazprom, Nov '20 – Since 2013, Gazprom Gazenergoset has been putting gaseous helium up for sale on the eOil.ru electronic trading platform on a monthly basis. On 24th November, the price quoted on the platform for 5.5mcm was 1,498 Roubles, this is the equivalent of **$700/mcf.** Liquid helium has been selling for a similar price.

Helium One presentation, Nov '20: Anecdotal reports of end users paying upwards of $40/l **($1,500/mcf**).

Party City, Nov '20: Party City is one of the largest retailers of balloon grade helium and with its Q3'20 results it said that prices were up y/y but have reached a point of stabilisation. Originally it expected a 14% increase in helium pricing y/y in 2020. In 2019 its helium balloon sales were down 11% y/y due to a shortage of helium.

Desert Mountain, Oct '20: Prices for the finished product have varying price points that range from **$490/mcf** for shield gas to **$3,200/mcf** for extreme high purity gas.

University cost, June 2020: For the University of Idaho, recent pricing was $35/litre **($1,300/mcf**), which is double the $15/litre paid a year earlier for 100-

litre supply. Tarleton State University in Texas paid $18/l (**$675/mcf**) to the Pentagon's Defense Logistics Agency (aggregator of helium).

Nordic OIL USA 2, LLLP Nasco Helium Processing Facilities, Jan '20: As part of an asset backed financing part of the pricing agreement with Praxair was released. The price is adjusted twice per year according to an index of the average selling price of helium across North America. **The floor price is $105/mcf** for 2017 through 2031. Praxair pays a transportation fee of $10/mcf of contained helium, in addition to the standard $13/mcf trucking fee. Praxair has a minimum monthly purchase obligation of 85% of the helium produced by Nordic 2. Helium purity should be at least 70% and not to exceed 98%.

US university, Nov' 2019: A midwestern US university chemist said that he is paying $27/l (**$1,000/mcf)**, which is triple what he paid 15 years ago. Also, the unnamed supplier cut back on the amount of helium available for sale.

Sinogases, October 2019: An article from the company stated that the average import price was US$51.5/kg **($240/mcf**), which was the lowest import price since 2018.

Australian exports, 2019: Based on Chinese customs data, we estimate that Australia sent around 85mcf to China in 2019 at a price of **~$270/mcf.**

US researchers, 2019: According to a survey conducted by the American Physical Society, the average price of liquid helium for academic researchers has increased by nearly 25% from 2018 to 2019; some researchers' prices have more than tripled.

April 2019: The US Defense Logistics Agency (DLA) renewed its previous 2-year deal at a reported $21-23/l (~**$800/mcf)**, which was almost double the previous cost of US$12/l. The DLA negotiated on behalf of a consortium of 20 universities to increase purchasing power.

Air Products, 2018: Air Products bid as high as **US$337/mcf** at the final BLM sale of helium in 2018.

CREON Energy, Oct '18: Russian helium prices in September 2018 reached 1355 roubles/l ($20/l or **$750/mcf**) on the Russian electronic trading platform, which was a 188% increase (from 470 roubles/l) in September 2017.

Russian customs data, 2017: Russian export data from 2017 shows Gazprom exporting ISO size cargoes from Orenburg at a price of ~$36/kg **($170/mcf**).

Indian customs data, 2016: In 2016 export data showed India was paying around INR3,000/kg, which is the equivalent of **$215/mcf**.

United Helium, 2012: In its S1 prospectus ahead of a potential IPO, United Helium said that the 2012 wholesale price for commercial grade helium has been reported as high as **$450/mcf,** with certain the spot market prices to end users in excess of **$800/mcf.**

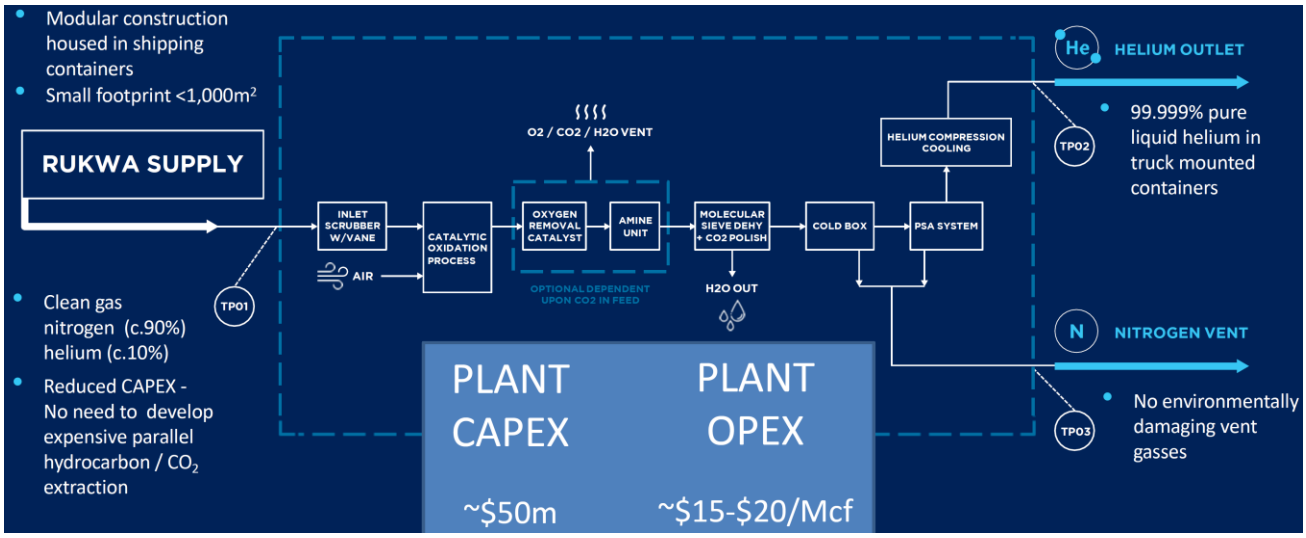
Helium project economics

The economics of a helium project when associated with natural gas will be tied to the plant capex and opex, as the cost of extracting the gas to provide the gas stream can be viewed as a sunk cost that is associated with producing the natural gas, which will generally be the reason the resource is developed. However, for a standalone project, the cost of developing the resource must be considered also. Although, we would expect the operating cost of a standalone project to be lower as it should be processing a much higher concentration of helium gas.

We have modelled out a potential development of standalone helium (rather than associated with natural gas) in Tanzania and on our base case estimates we believe that around US$100/mcf helium price (flat nominal) is required to earn a double-digit IRR. The main assumptions include a plant cost of around US$50mm for what we would consider a mid-scale 365mmcf/y capacity plant. We estimate other costs (e.g. drilling) and contingency at around US$35mm. In total we estimate capex at around US$40/mcf assuming a 2bcf development. We estimate that the operating costs will be around US$20/mcf.

In the Tanzania scenario, development is expected to be straightforward (unlike a traditional oil and gas project). The wells are much cheaper than oil and gas wells to drill and complete (estimated cost of US$3mm per well). The processing plant can be constructed abroad requiring only installation and commissioning – the size of the plant is small at <1,000m².

Simple industry standard gas processing technology

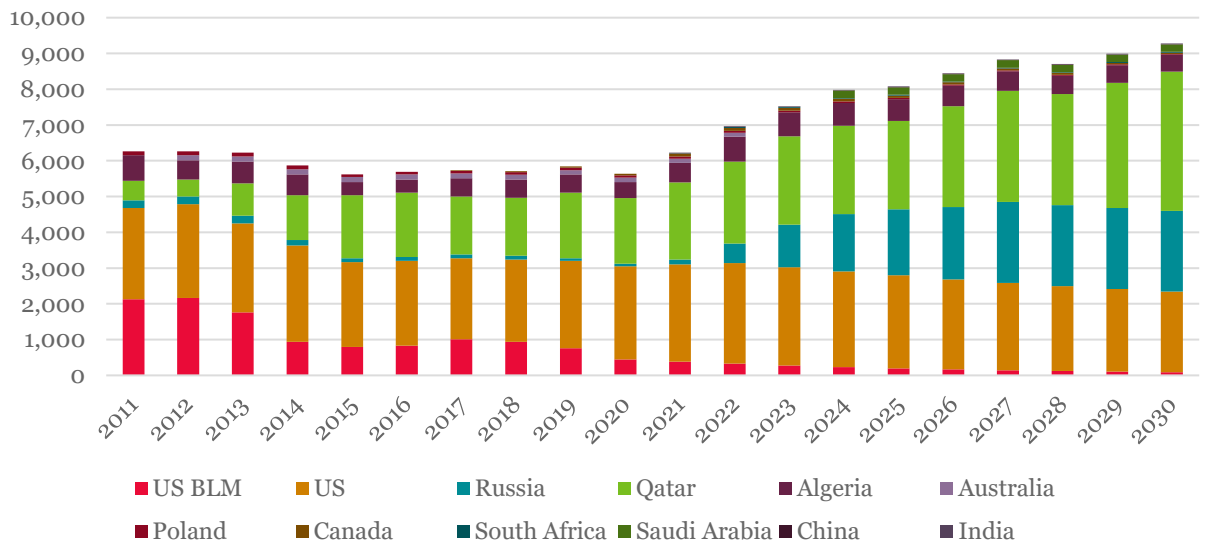


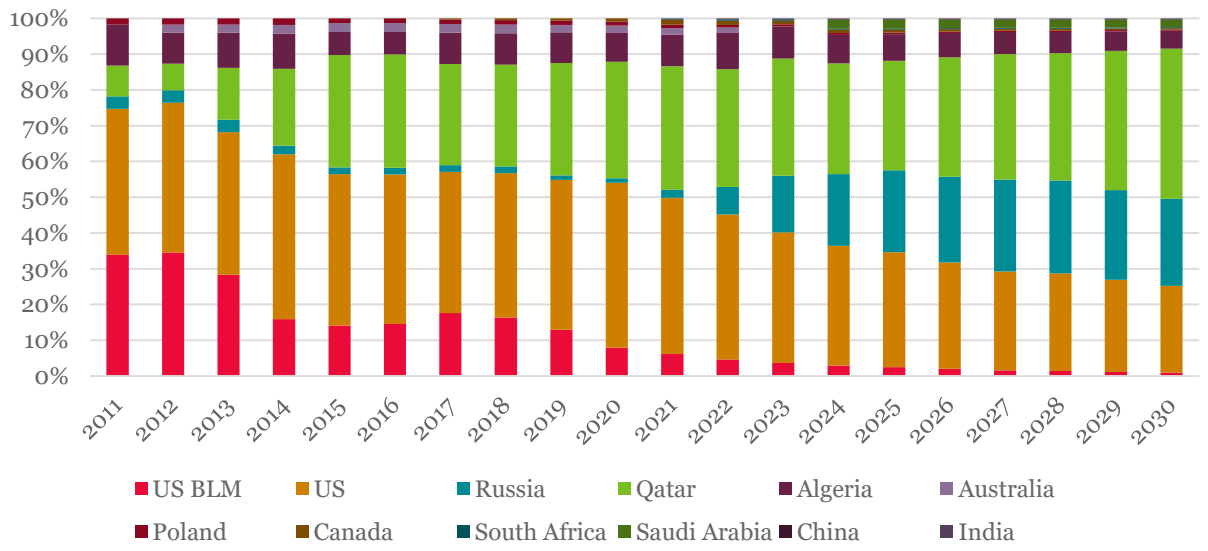
Source: Helium One

Supply

We have created our own proprietary supply model for helium on a bottom up basis. Most companies and countries do not disclose production or sales data, so we have had used multiple sources and made our own assumptions to get to our forecasts. We expect that helium supply will grow at a CAGR of around 5-6% over the next 5 years based on all the current projects planned. However, we see risk skewed to the downside given the history of delays/ramp-up issues for new projects and also the risk of operation/geopolitical disruptions from existing projects. We estimate that 2020 helium supply (including production out of storage) was 5.9bcf/y. In 2020, given the fall in demand for LNG and reduced global production, this would have had a knock-on impact on helium production.

Worldwide helium production by supply source (mmcf/y)



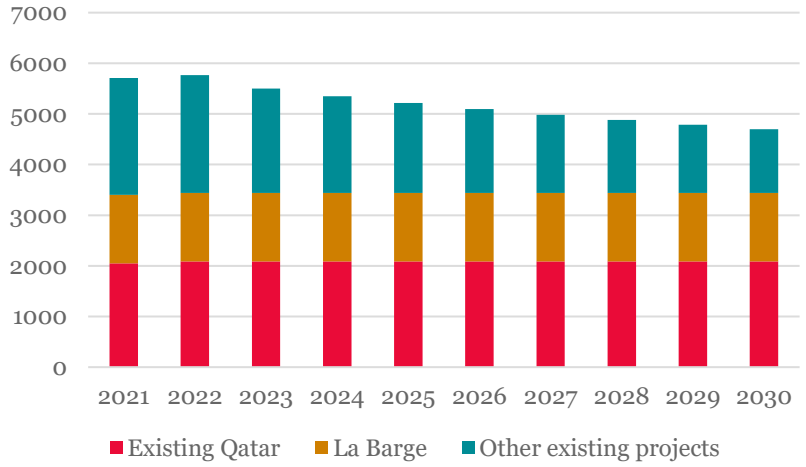


Source: H&P estimates, Company Data, USGS

Global helium supply is currently very concentrated, with the US and Qatar alone currently accounting for ~75% of world supply. There are two notable projects

that supply >50% of world demand: the LaBarge field in the US and the North Field in Qatar. Both are supergiant fields where production can be maintained for decades to come (with further growth in the case of Qatar). Therefore, there is not as much of an issue with replacing underlying decline as there is with hydrocarbon production. In aggregate we see existing production declining at around 2-3% per annum or excluding these fields at around 7% per annum. We estimate that US BLM still accounted for around 8% of supply in 2020 (~450mmcf/y) but this is expected to fall sharply over the coming years as storage is gradually depleted.

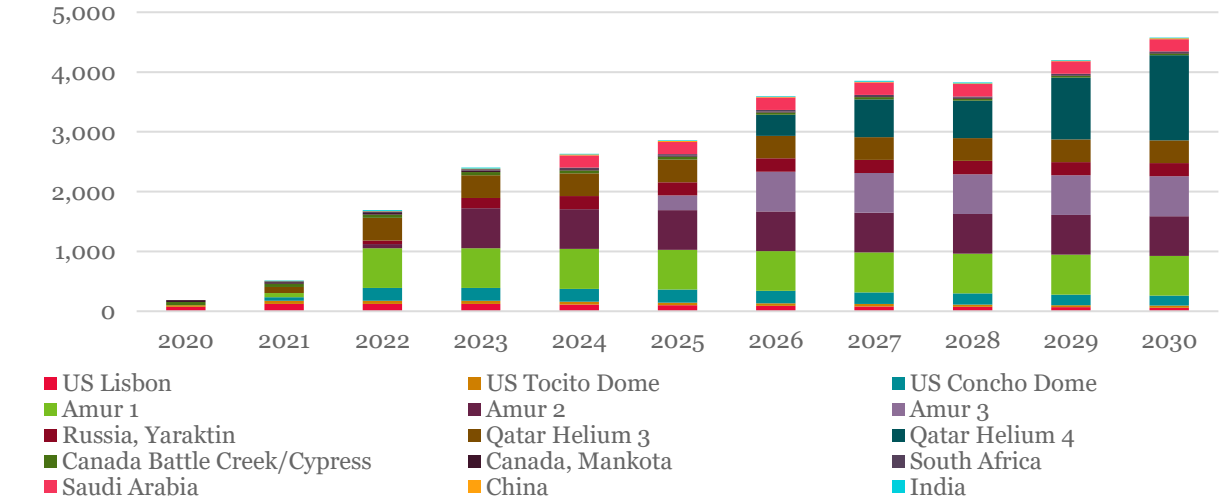
Legacy helium projects supply (mmcf/y)



Source: H&P estimates

There is a significant amount of new capacity under construction globally that could lead to an incremental 3bcf/y of additional capacity by 2025 and >4.5bcf/y by 2030. Of the new capacity being added, around half is coming from Russia and 40% from Qatar. Outside of these regions <500mmcf/y is coming online. There is the potential for further projects in North America and Tanzania to come on line before 2025, depending on exploration results.

New helium projects supply (mmcf/y)



Source: H&P estimates

Geopolitical considerations

Map of helium producing areas

Source: H&P

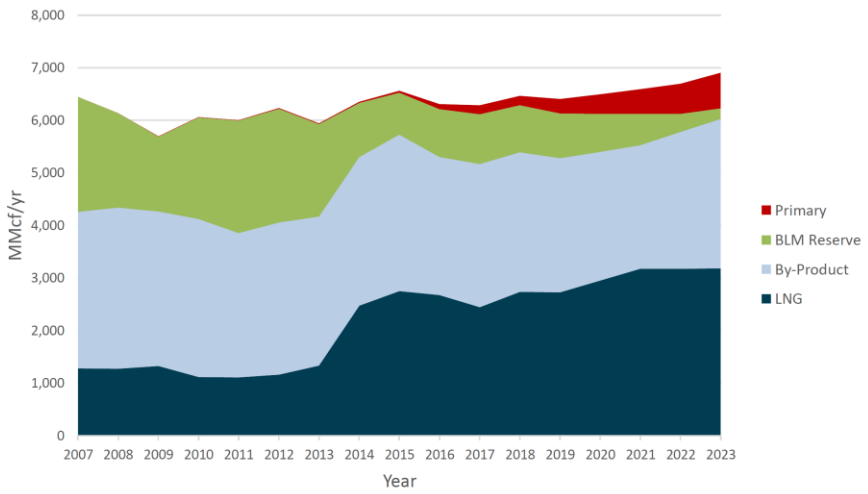
Helium supply has largely been in the hands of state-owned companies in Qatar and the US and these are soon to be joined by a major new state-owned company, Gazprom after it brings online its Amur plant. US production has been declining and will fall from 75% of supply in 2011 to 35% in 2025. More importantly, the US BLM helium storage site will not be able to provide a buffer for any supply outages given falling reserves and constraints on production.

Given that >50% of supply is expected to come from projects in Qatar and Russia by 2025, there is considerable geopolitical risk. These are two nations that are currently subject to significant political sanctions and regions that are historically more prone to political risk. Also worthy of note, given the risks of conflict with Iran, is that an estimated 30% of the world's helium passes through the Straits of Hormuz.

"Given the geopolitical risks, it's not a good idea to depend on Qatar, Algeria, and Russia as a source of helium." Mark Elsesser, associate director of government affairs, American Physical Society.

Helium supply by type

IACX estimated worldwide helium production by supply source



Source: IACX

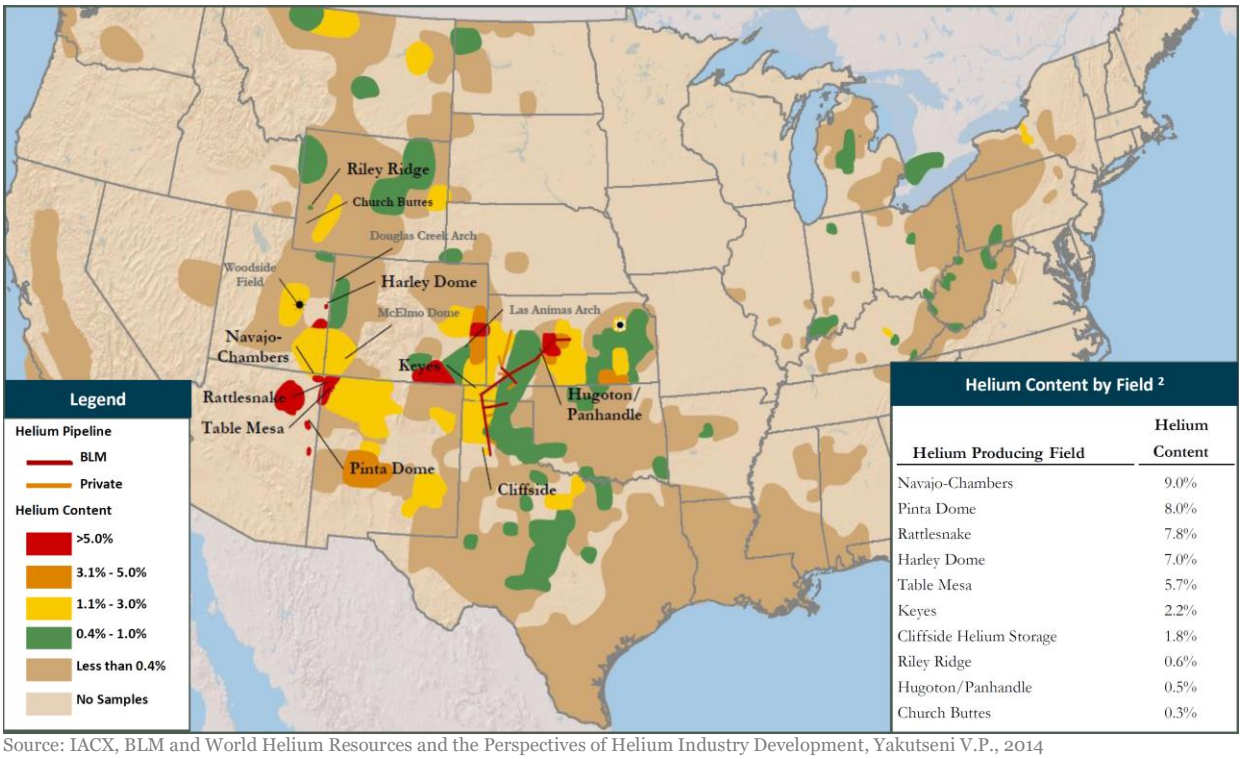
Most of the helium produced around the world is a by-product of natural gas (methane) processing. However, not all natural gas fields contain helium, and very few gas fields have high enough helium concentrations to make it economical for extraction. Historically the helium processing plants were built next to exceptionally large natural gas fields with low concentrations of helium but reasonable quantities in absolute terms. Some plants must process vast quantities of gas to produce helium, for example in Qatar where there is <0.1% helium in the gas stream.

There has been a push for helium production as a primary product following stronger helium prices in the last few years. In the US and Canada, there have been several projects in areas such as Saskatchewan, Alberta, Montana, Arizona and Utah. Globally, Tanzania has emerged as an extremely promising area for primary helium production with some of the highest global concentrations of helium in surface seeps. There are also small projects in India, China and Australia potentially.

According to IACX, when developing gas fields where hydrocarbons are not produced and sold, helium content in the gas must typically be at least 0.6% for development to be economic.

U.S.

U.S. Helium Producing Areas and Helium Shows



Helium Producing Field	Helium Content
Navajo-Chambers	9.0%
Pinta Dome	8.0%
Rattlesnake	7.8%
Harley Dome	7.0%
Table Mesa	5.7%
Keyes	2.2%
Cliffside Helium Storage	1.8%
Riley Ridge	0.6%
Hugoton/Panhandle	0.5%
Church Buttes	0.3%

Source: IACX, BLM and World Helium Resources and the Perspectives of Helium Industry Development, Yakutseni V.P., 2014

Geological conditions in Texas, Oklahoma and Kansas make the natural gas in these areas some of the most helium-rich in the United States. The US currently produces ~55% of the world's helium (45% excluding out of storage). Most helium production in the US occurs in the Hugoton Panhandle. Other producing natural gas fields include Greenwood and Keys Fields, found in Texas, Oklahoma and Kansas. Most of these fields are dedicated primarily to helium production, rather than as a secondary gas. In the Southern Western region, several companies are looking to produce helium from non-hydrocarbon sources.

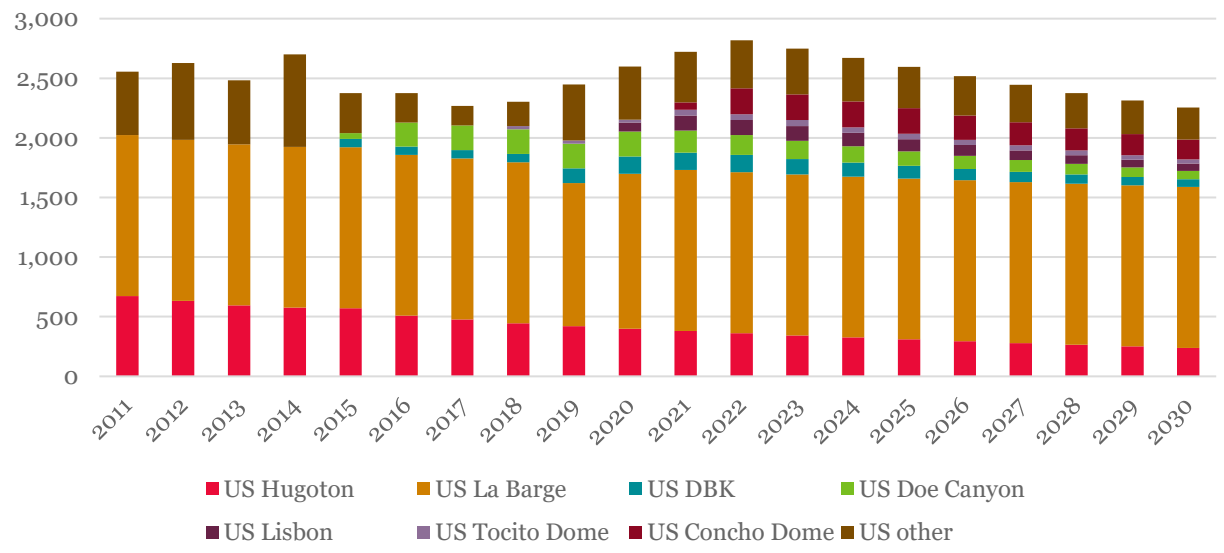
Key U.S. fields and helium plants

Field	State	Companies	Stage	Production mcf/y	Helium %
Hugoton/Panhandle West	Kansas, Oklahoma, and Texas	Various	Production	400	0.3-1.9%
LaBarge	Wyoming	Exxon	Production	1400	0.6%
Dineh Bi Keyah	Arizona	Nasco AG	Production	153	4.9%
Doe Canyon	Colorado	Air Liquide	Production	230	0.4%
Tocito Dome	New Mexico	Tacitus	Production	55	7-8%
Lisbon	Utah	Paradox Resources	Production	183	1%
Otis	Kansas	IACX Energy	Production	8	
Ladder Creek	Colorado	Tumbleweed Midstream	Production	200	
Desert Mountain, Holbrook Basin	Arizona	Desert Mountain Energy	Development	275	6%
Concho Dome, Holbrook Basin	Arizona	Petrosun	Development	240	3.8%
Cliffside	Texas	BLM	Storage		

Harley Dome	Utah	IACX Energy	Shut-in	37	7%
Riley Ridge	Wyoming	Denbury	Shut-in		
Woodside Dome	Utah	N/A	Shut-in		
Golden Eagle Gas Field	Utah	Petrosun	E&A		
Rudyard	Montana	Weil	E&A		
Utah and Mid-Continent	MidCon	Weil	E&A		
Boundary Butte	Utah	Nasco AG	E&A		1%
Hogback	New Mexico	Nasco AG	E&A		

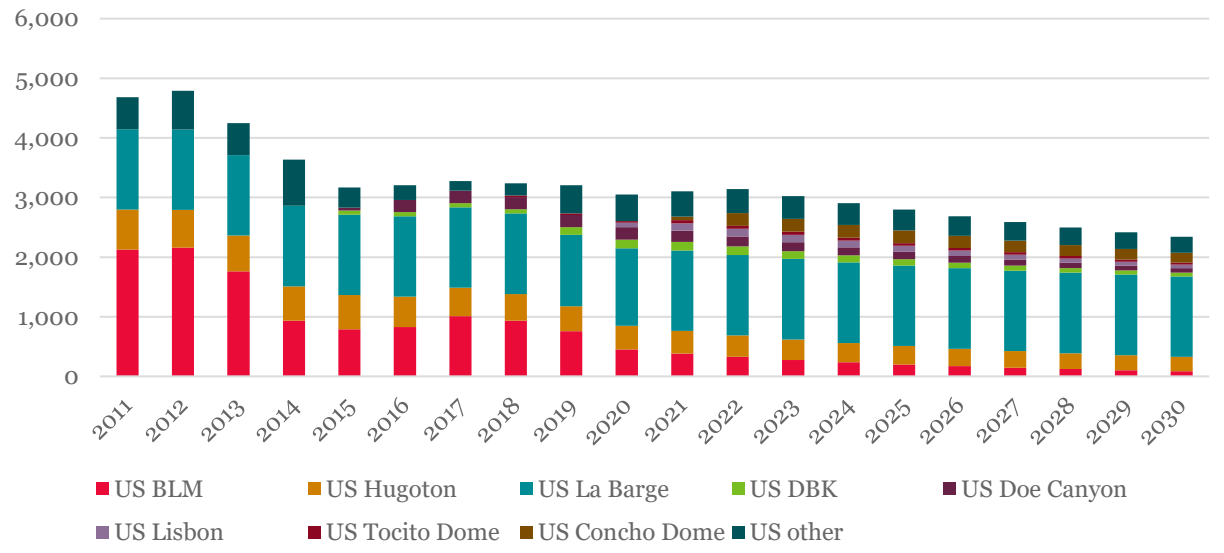
Source: Company Data, H&P estimates

US helium supply 2011-2030E, excluding BLM



Source: Company Data, USGS, H&P estimates

US helium supply 2011-2030E, including BLM



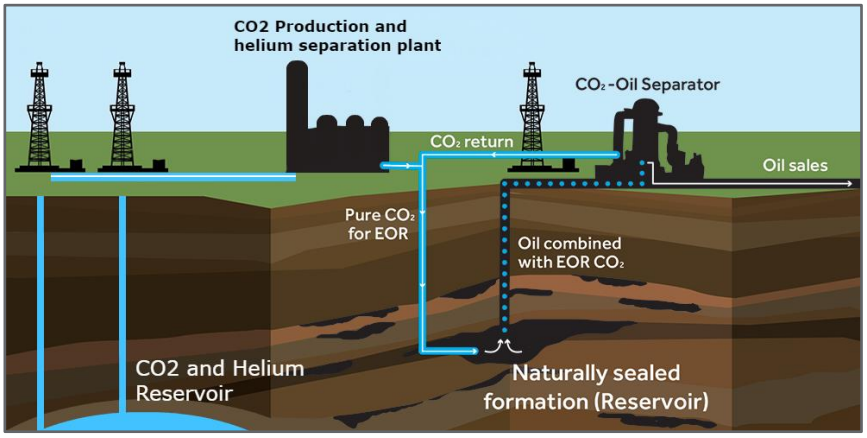
Source: Company Data, USGS, H&P estimates

US helium supply has been in decline since the beginning of the decade falling from around 4.7bcf/y to 3.0bcf/y. This is because existing helium production declining but more importantly because of the sharp fall in production out of storage from the BLM. Several helium plants closed around the middle of the decade due to the lack of available supply. The fall in supply in the US from 75% in 2011 to 55% in 2020 has been the major reason for the increase in global helium prices.

We expect helium production to increase in the next couple of years as a few new plants come online, producing helium as the primary product. However, further declines in production from the BLM will offset this. From 2023 onwards we expect US production to move firmly into long-term decline.

La Barge, Wyoming – The LaBarge field area (comprising the Madison, Tip Top and Hogsback fields) is located in the southwestern corner of Wyoming, contained in Lincoln and Sublette counties. The field, majority controlled by ExxonMobil, contains 170tcf of raw gas of which 20tcf is natural gas. It has 0.6% helium content, 21% natural gas, 66% CO2, 7% nitrogen and 5% hydrogen sulphide (H_2S). CO2 volumes have been historically sold from LaBarge to nearby oil producers, operating EOR oilfield projects. At current rates of production, the remaining field life is >100 years. Total produced natural gas is 720mmcf/d, which implies up to 4.3mmcf/d (1.6bcf/y) of helium production. The Shute Creek helium plant has a nameplate capacity of 1.5bcf/y and we assume that the plant will continue to produce at this level for the foreseeable future.

Stylised diagram of helium production with CO2



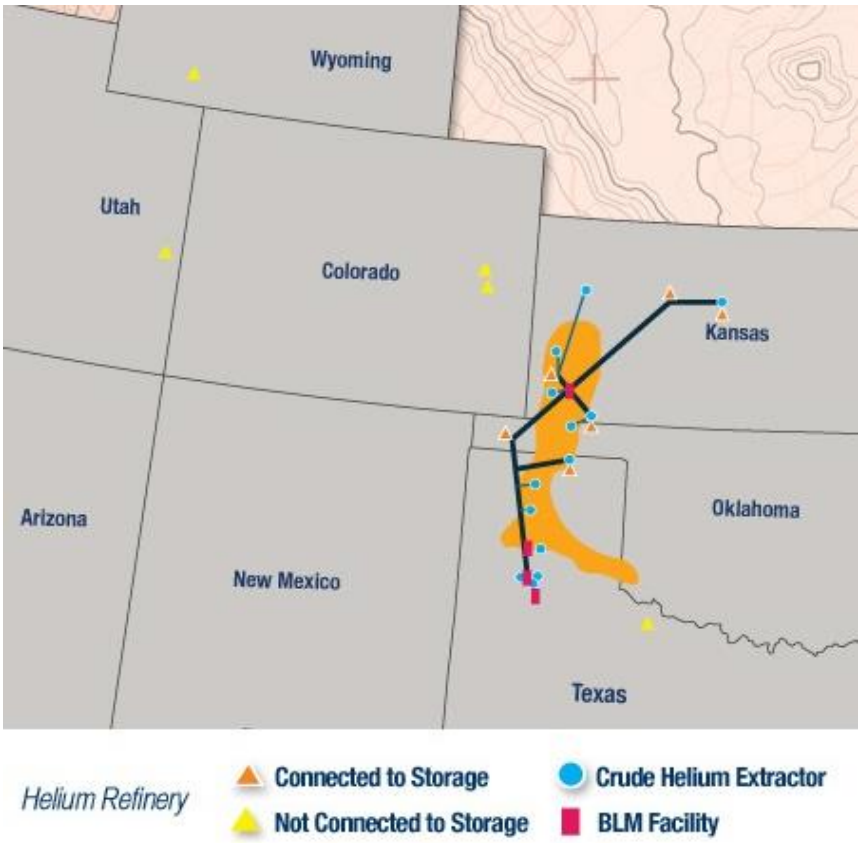
Source: NE Helium

Similarly to helium, the cost of the natural gas extraction and processing operations at LaBarge also heavily depends on the market value of the methane and CO2 present in the extracted gas. A portion of the extracted CO2 is sold for use in nearby enhanced oil recovery (EOR) operations. There is a risk that in a low oil price environment, using CO2 for EOR may be uneconomic and lead to lower sales having a knock-on impact on helium production.

Exxon was expected to start construction in Q3'20 on a US$260mm carbon capture project at Shute Creek plant to be completed by the end of 2022. The purpose of the carbon capture project is to capture the low-pressure, low-quality CO2 that is currently being vented, and compress it to sales quality CO2 that could be sold to customers or injected into a disposal well.

Hugoton/Panhandle West – This is one of the largest natural gas fields in the US having produced almost 30tcf to date. It is a very mature, low decline, highly delineated field. The drilling focus is likely to be on the Chase and Council Grove areas which have higher NGL and helium concentrations. In order to stimulate further drilling, a natural gas price of >US$3/mcf is required according to the previous operator. The Hugoton field has a base decline rate of 4-6% according to the latest data from the previous operator Riviera Resources. It is not currently clear who owns the helium production rights from the field. The field contains helium concentrations ranging from 0.3-1.9%, 73% methane and 15% nitrogen. The company generated on average around US$20mm in revenue from helium in 2018 and 2019. In 2019 Hugoton (including Hugoton NE) produced around 81bcf of natural gas, which implies helium production of around 400mcf/y assuming 0.4% helium. Of note in 2019 Riviera Resources raised US$82mm through a volumetric production payment transaction (VPP) monetising 23% of its helium reserves at a 5% discount rate. The Otis helium plant in Kansas, operated by Linde, is one of the biggest in the world.

Helium activity around the Hugoton field



Source: Rigzone

Dineh Bi Keyah, Arizona – The DBK field in Apache County has >5% helium content and is operated by Nasco AG with the gas sold to Linde. This unique field produces a gas made almost entirely of helium and nitrogen (80%). Its separation plant allows processing of 0.4mmcf/d of 98.8% purity helium. Helium production began in 2014 and production is estimated at 150mmcf/y. A new plant was brought online in 2019 that allowed the doubling of production to this level. We assume a few years of plateau production before moving into decline. Nasco AG completed a US$83mm securitization transaction to refinance the debt secured by its helium assets at DBK Field in 2020.

Doe Canyon, Colorado – The Doe Canyon plant came online in August 2015 and was expected to produce up to 230mmcf/y but has been impacted by a shortage of feedgas. The plant is operated by Air Liquide. The field contains mainly CO2 and 0.4% helium. The plant is the only one in the world extracting helium from a gas stream composed primarily of carbon dioxide (CO2). Air Products extracts the helium from the gas stream and returns the carbon dioxide to Kinder Morgan CO2 for its intended enhanced oil recovery (EOR) use in the Permian Basin.

Ladder Creek, Colorado – The plant is located just west of Cheyenne Wells in Colorado. It separates helium from the natural gas stream and liquefies it for sale to large industrial gas providers, primarily Air Liquide. It has the capacity to liquefy 550mmcf/y. The plant is currently processing 12-13mmcf/d of feed gas and could reach 57mmcf/d by end-2022. The helium concentration is around 3%. In 2021, the plan is process 200mmcf of helium growing to 400mmcf in 2022 with a simple plant expansion involving an additional gas compressor.

Tocito Dome, New Mexico – The Tocito Dome Field began operations in 2018 by re-entering old wells to produce helium. The concentration of helium is high at 7-8%. The plant is currently designed to process 2mmcf/d of gas implying around 50mmcf/y of helium production with an ambition to get to 500mmcf/y of helium production from its assets in the region. It is thought to be currently producing at about 50% of capacity.

Lisbon, Utah – Paradox Resources brought its helium recovery unit online in 2020. The Lisbon gas plant produces pure helium from over 150 wells over ~98,000 net acres in the Paradox Basin. The helium recovery unit (HRU) is capable of 0.5mmcf/d at 90% recovery and purification of "five-nines" (99.999% He). Most of the wells identified within the Lisbon field have a 1.0% or lower helium concentration.

Harley Dome, Utah – In 2013, IACX started helium production at the Harley Dome field in Utah but this stopped in 2018 following a drop in pricing. Over that period 42mcf of helium was produced. The Harley Dome, designated a federal helium reserve in 1934, contains a mixture of nitrogen (86%) and 7% helium (the highest from over 400 wells drilled in Utah). A workaround with the federal government now allows IACX to produce helium from the reserve from a 30mmcf/d gas plant.

Woodside Dome, Utah – IACX is developing a second helium-only site at the Woodside Dome field, also in Utah. Another federal helium reserve, the dome contains largely nitrogen and about 1.4% helium. Though the concentration is lower, the Woodside reserve actually contains more helium overall. IACX drilled a couple of helium wells in 2013 and 2018, the second of which appeared disappointing and no helium production has occurred since.

Holbrook Basin, Arizona – Desert Mountain has recently tested two wells with helium contents of 4.1% and 7.1%. It plans to bring on production in October 2021 and produce 275mmcf/y. Total projected capital expenditure including all drilling and infrastructure over 6 years is US$45mm.

Concho Dome, Holbrook Basin, Arizona – Petrosun's subsidiary Arizona Energy Partners is developing the Concho Dome field. The operator has a 10-year helium offtake agreement with Linde. The plan is to put in place a 240mmcf/y capacity helium plant by Q1'21. The AEP 16-1 well that was recently drilled had seven samples taken with an average helium concentration of 5.8%.

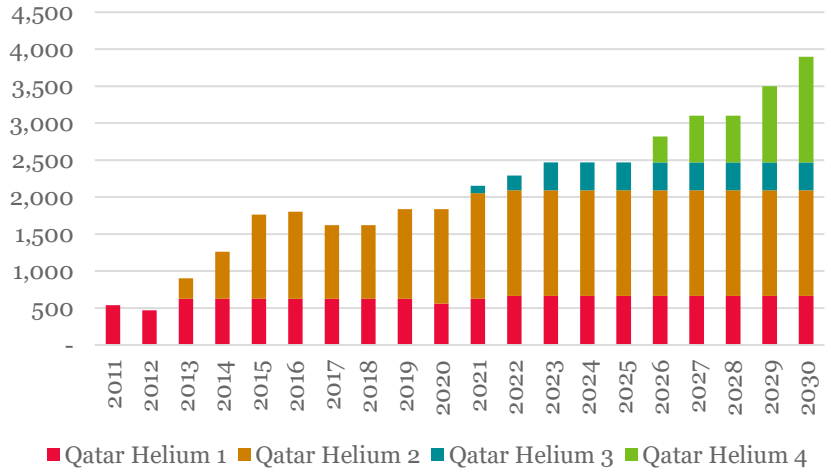
Paden, Oklahoma – IACX has installed a helium recovery unit to process the helium-rich vent stream (containing ~1% helium).

Golden Eagle, Utah – The Golden Eagle gas field is in the Paradox Basin, Grand County. The project has 3 wells already in place with the presence of helium estimated to be 2.25%. The next well to be drilled will be into the Leadville formation and is projected to show 7% helium. Petrosun planned to bring the plant online in Q1'21. Uniper has signed a 36mmcf/y offtake contract from the field.

Riley Ridge, Big Piney – Riley Ridge is not currently producing with it last running in 2014 after coming on in 2013. It suffered from sulphur deposition on the wellbores and at low natural gas prices was not economic. It also has a large amount of CO2 potentially for EOR but is not needed. The field has 0.5% helium and was expected to produced 100mmcf/d of total gas. Kiewit was the general contractor for the grassroots pilot plant for helium and carbon dioxide (CO2) extraction. At low gas prices and with low demand for CO2 we do not expect that the plant will resume helium production.

Ras Laffan, Qatar

Qatar helium supply 2011-2030E, mmcf/y



Source: Company Data, USGS, H&P estimates

Qatar is the leading exporter of helium globally. Its giant North Field (shared with Iran) only contains 0.04% helium but the huge natural gas production rate means that there is still substantial helium available to be produced. The Ras Laffan helium plant, located on the northeast coast of the Qatari peninsula, came online in August 2005 costing US$115mm. The project is a joint venture between the various LNG plant consortia RasGas I, RasGas II, and Qatargas.

The first plant, "Helium 1", designed and constructed by Air Liquide, came on stream in 2005 with an original nameplate capacity of 660mmcf/y, which Qataragas now states at 700mmcf/y. Most recent data show the plant having a high availability of 97%. The two offtakers are Air Liquide and Linde.

The "Helium 2" plant with a design capacity of 1.3bcf/y came on stream in 2013 and had an availability of 98.5% (between 2015-2017) and the capacity has been

increased to 1.5bcf/y according to Qatargas. The three offtakers are Air Liquide, Linde and Iwatani.

A third helium plant with a capacity of 400mmcf/y was originally planned to come online in 2018 but has been significantly delayed and is now expected in 2021. Qatar 3 is believed to be mechanically complete. However, start-up has been delayed due to the inability of foreign technical experts to travel to Qatar to commission the plant. We forecast that it will produce at 33% of capacity in 2021 before ramping up to capacity in 2022.

Qatar is planning to increase its LNG export facilities further. It originally had plans to grow from 77mpta of LNG production to 100mmtpa and alongside this increase its helium production by 700mmcf/y. However, it upgraded its LNG expansion plans to 110mmpta and alongside this increased the size of the helium additions to 1,500mmcf/y. This would increase its total helium production capacity to >4bcf/y. We expect the new facility to come online in 2025 at the earliest and it will likely take a few years to get to full capacity as we expect the ramp-up to be staggered.

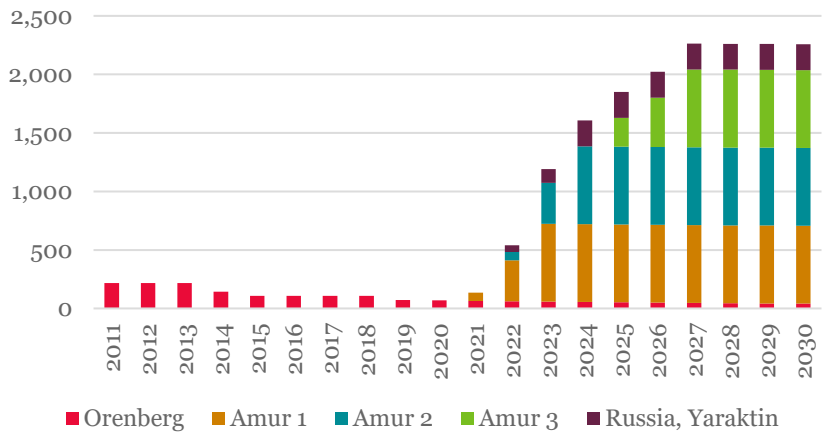
Qatar helium logistics

Source: Air Liquide

In 2017 an air, sea and land blockade was imposed on Qatar by four countries including Saudi Arabia and the United Arab Emirates (UAE), which is still ongoing. This meant helium production stopped for 2 weeks in June 2017. Previously helium was trucked to the UAE for export from the Dubai / Jebel Ali Port. Now helium is shipped directly from the Hamad port in Qatar and it takes around a month to get to either western Europe, the east coast of the US or China/Japan/Korea.

Russia

Russian helium supply 2011-2030E, mmcf/y



Source: Company Data, USGS, H&P estimates

Orenburg, Russia – The Orenburg plant is a relatively small plant that was first brought online in 1978. Orenburggazprom (100% subsidiary of Gazprom) is the operator of this facility just west of the town of Orenburg. The rated capacity of this plant is about 230mmcf/y. Natural gas produced from the Orenburg field and stripped from H2S and CO2 at amine plants of the Orenburg Gas Processing Plant is the feedstock for helium production. In 2014 Linde installed a 100mmcf/y helium liquefier. Today, the commercial helium is produced by the helium plant of Gazprom Dobycha Orenburg in gaseous and liquid forms in total volume of up to 175mmcf/y. Up to 80% of helium produced is consumed in the internal market of Russia and the rest is exported. Customs data suggest that Gazprom was selling at around US$175/mcf in 2017 but data from the electronic exchange this year shows prices of around $700/mcf.

Gazprom's helium hub

Source: Gazprom

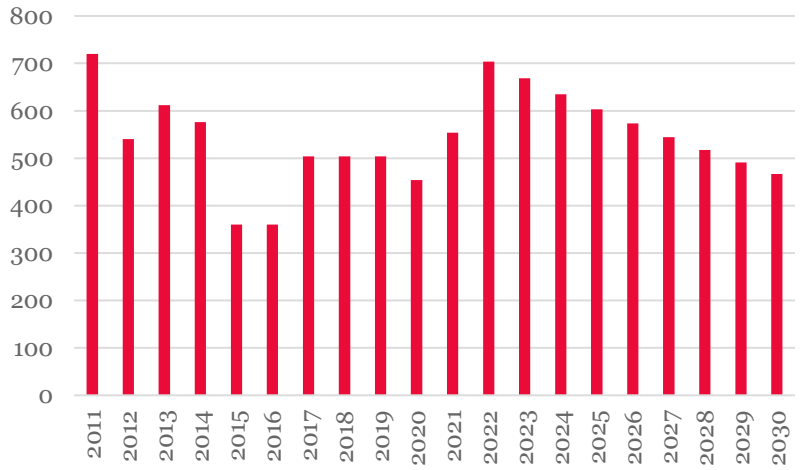
Amur, Russia – This will be one of the world's largest helium producers when fully ramped up with a design capacity of 2.1bcf/y and potential to grow to 4bcf/y. Gazprom's Amur gas processing facility is designed to process gas destined for China as part of the Power of Siberia project and will produce 3.8bcf/d of natural gas. The gas flowing in the Amur plant is expected to have a helium content of just 0.15%. However, the economics are very much driven by natural gas sales. The Amur project will add production of 2.1bcf/y in increments of 700mmcf/y (3 separate trains) starting in 2021, then 2022 and 2025 ramping up through 2026

to full capacity. Gas deliveries started through the line in late 2019 and the originally planned completion date was April 2021 for the helium plant. Given the size of this mega project, there is risk of delays but recent reports have suggested that the project is running to schedule. The helium has been contracted to Gazprom Export and will be sold in ISO containers for export from 3 distinct Vladivostok ports. The helium will probably displace some of the Qatari production that is sold into the Asian market and is also well positioned for the US West Coast market. At peak, there will be 45 ISO tanks per week being trucked to the port. A helium hub is being created outside of Vladivostok, which is expected to be operational in early 2021 and will contain two 1,000 l/h liquefiers.

Yaraktin, Russia – Irkutsk Oil is building a 233mmcf/y plant that is expected to start up in 2022. The plant is located 200km north of Ust-Kut to produce from the Yaraktin oil and gas condensate field. a contract was signed with American Cryo Technologies for the supply of equipment for cleaning and liquefaction of helium.

Algeria

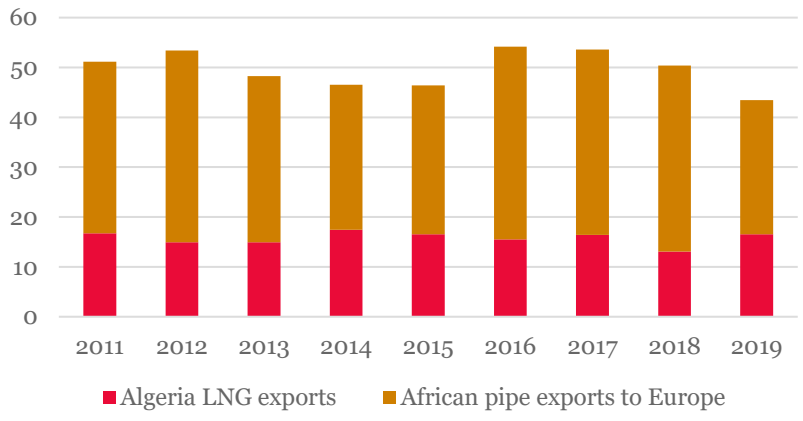
Algerian helium supply 2011-2030E, mmcf/y



Source: Company Data, USGS, H&P estimates

Algerian helium supply is tied to LNG production. LNG production in turn is related to the amount of natural gas Algeria decides to direct towards LNG relative to the amount that is sent by pipeline into Europe. Helium comes from the supergiant Hassi R'Mel field (0.2% helium concentration) which supplies around two-thirds of Algeria's gas exports. Over the last few years, the field has been used to supply increasing amounts of pipeline supply which, in turn, has reduced helium production.

Algerian LNG and pipeline exports (bcm/y)



Source: BP Statistical Review of World Energy, 2020

The country's first helium project at Arzew started in 1992 and the start-up took place in 1995. The Helios plant is situated at the Arzew GL2-Z LNG complex. It is a joint venture between Sonatrach (51%) and HELAPS Sa (49%), which is a fully owned subsidiary of Air Products. It consists of 2 identical trains with a capacity of 600mmcf/y.

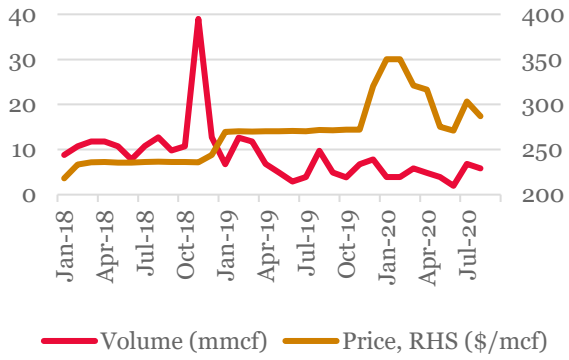
Sonatrach signed a deal in 2018 with Air Products to deliver helium to the existing Helios JV's plant in Arzew that has been recovered from the GL1Z and GL3Z LNG facilities. This is expected to add around 300mmcf/y of helium capacity.

The success of the original Helios Arzew plant quickly led to the construction of another facility in 2002 known as the Helison plant which is a joint venture between Sonatrach (49%) and Linde (51%). This plant is located at the GL1-K LNG facility in Skikda.

Australia

Australian helium supply 2011-2030E, mmcf/y

Australian exports to China



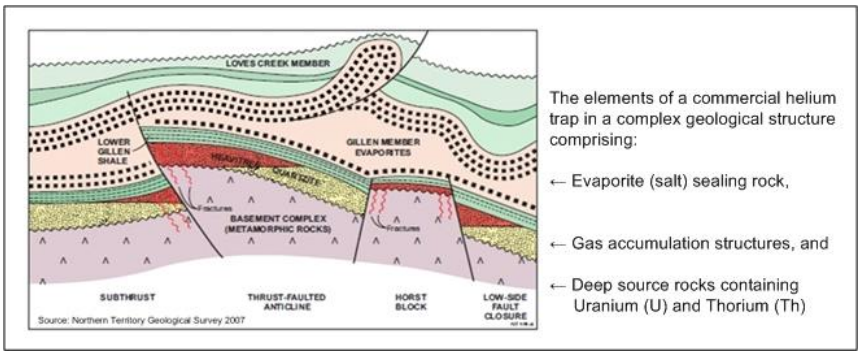
Source: Company Data, USGS, H&P estimates

Darwin, Australia – The Darwin LNG facility is Australia's sole plant that produces helium from the Bayu Undan field, which contains just 0.1% helium. The 150mmcf/y plant was brought online in March 2010 by BOC (now Linde) at an estimated cost of US$50mm. Production in recent years has declined at Bayu Undan and we estimate that production has fallen to ~125mmcf/y as LNG

production was only 80% of capacity in 2019 and 2020 to date. Bayu Undan is expected to cease production around 2022. The LNG facility will be adapted to take gas from the Barossa field, which has a much lower helium content (0.02%). The helium resource in Bayu-Undan has been estimated at 4.3bcf but in Barossa just 0.7bcf. The Bayu-Undan accumulation in the Bonaparte Basin is processed for LNG and the tail gas, enriched in helium (3%), is the feedstock for helium extraction. Therefore, we expect that helium production is likely to cease after 2022. Based on Chinese customs data, we estimate that Australia sent around 85mcf to China in 2019 at a price of ~$270/mcf.

Amadeus, Australia – Companies are also looking at the onshore helium potential from the Southern Georgina Basin/ McArthur Basin in the Northern Territory of Australia. Helium shows have been encountered in wells in the basin suggesting rich accumulations of basement-sourced helium.

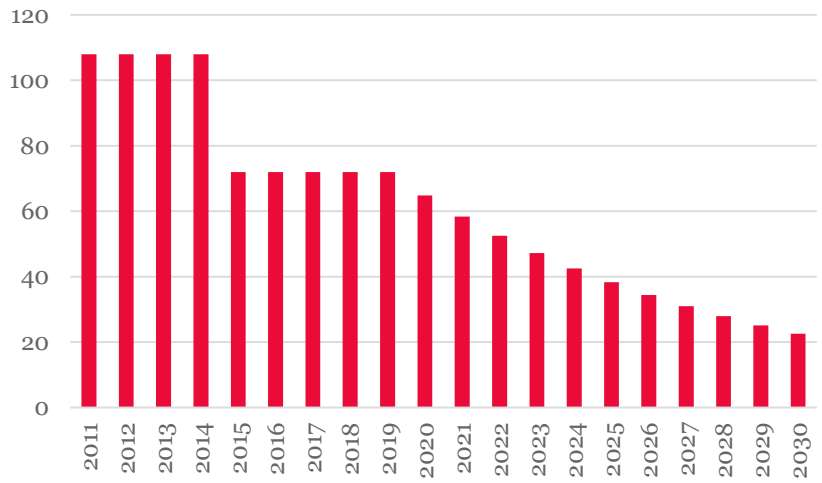
Southern Amadeus Basin helium bearing structures



Source: M.E.T.T.S. Pty. Ltd.

Poland

Polish helium production 2011-2030E, mmcf/y



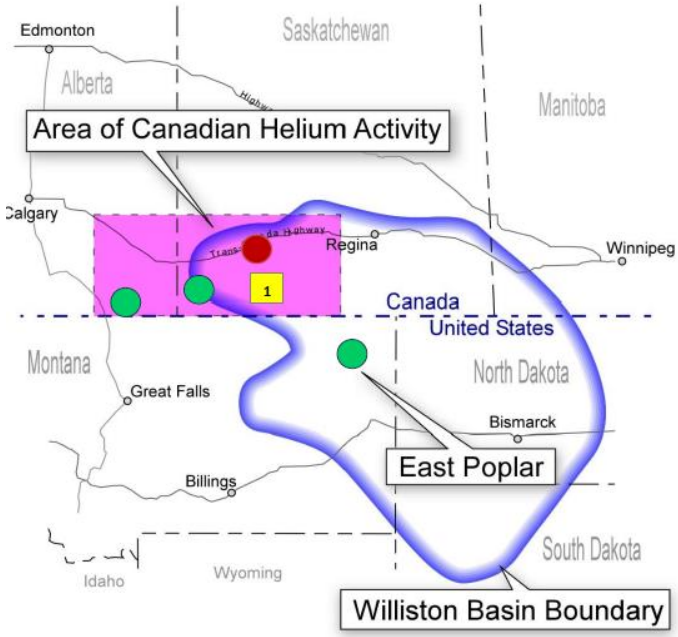
Source: Polish Geological Institute, H&P estimates

Odolanow, Poland - The Odolanow plant in Western Poland first came online in 1977. The owner and operator of the helium plant in Odolanow is Polish Oil and Gas Company (PGNiG). The gas produced at the Odolanów plant contains between 0.08% to 0.45% helium. There are 16 helium fields in the country in the

Polish Lowland area. We estimate current production of around 65mmcf/y and expect production to decline in line with mature field declines.

Canada

Canadian helium plays



Source: IACX

Key Canadian fields and helium plants

Field	Companies	Stage	Production mcf/y	Helium concentration %
Battle Creek	North American Helium	Production	58	1%
Mankota	Weil	Production	40	1.50%
Knappen	Thor	Development		1.50%
Coutts	Thor	E&A		
Aden	Thor	E&A		
Wild Horse	Thor	E&A		
Sweet Grass	Thor	E&A		
Sapphire	Weil	Development		

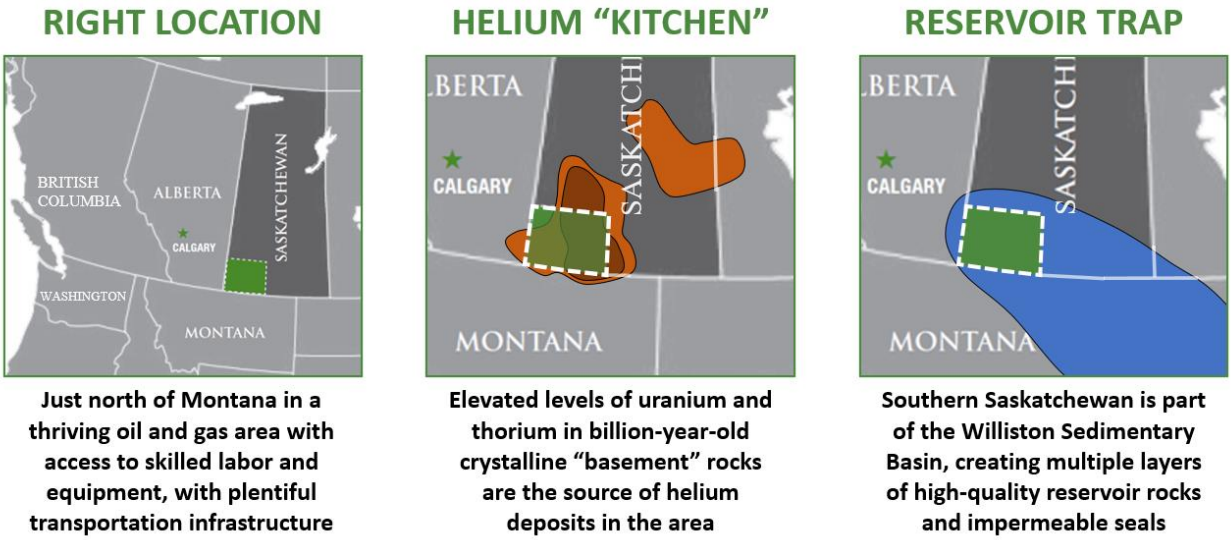
Source: Company Data, H&P estimates

There are two or three substantial, private explorers active in southwest Saskatchewan where the long-established helium sector has seen a resurgence as global prices have risen. In Southern Saskatchewan, there are at least 8 helium fields discovered in the region with production from three areas. The gas contains 0.5-2% helium and the remainder is mainly nitrogen (up to 97%) with low CO2 and methane.

Mankota, Saskatchewan – Weil group started producing from 2 wells in 2016. Using a US$10mm pressure swing adsorption unit designed by Linde, Weil's processing plant separates helium from other gases in the well and can produce

40mmcf/y of helium annually. Helium was trucked to Weil's liquefaction facilities in the U.S. and sold until the wells were suspended due to production problems in mid-2019. Weil has since drilled a new well to try to restore output.

Canadian helium potential



Source: NE Helium

Battle Creek, Saskatchewan – North American Helium has developed the Battle Creek field. The company has invested >C$50mm and raised C$123mm over the last year. It commenced helium production in July 2020 with plans to grow production 5-fold by July 2021 with a new plant that has a capacity of 0.16mmcf/d of helium.

Rest of the World

South Africa – Renergen is currently developing its Virginia project where production is expected in 2021 as South Africa becomes the newest member of the helium producing club. The initial plant capacity is 25mmcf/d with the potential to grow to 775mmcf/y. It has prospective helium resources of >100bcf with average helium concentration of 3.4% and the newest discovery containing up to 12% helium. The helium will be sold to Linde in an offtake agreement up to 24mmcf/y.

Tanzania – Helium One is conducting an exploration campaign in early 2021, which, if successful could lead to production of 1mmcf/d starting as early as end-2022 and the potential to grow significantly after that. The Rukwa Rift Basin possesses unique and ideal characteristics with the potential to host a globally significant helium project. Rukwa is one of very few helium projects that could be produced from non-hydrocarbon sources. To put it in context each of the wells is targeting the equivalent of around a year's global helium demand. The total prospect inventory is 138bcf unrisked (P50).

China – China has opened its first large scale helium plant in Yanchi county, Ningxia that can produce at a commercial scale. However, production is only expected to be 4mmcf/y (less than 0.5% of annual Chinese demand for helium) but the plant cost was only ~US$5mm. There is the potential for hundreds of similar facilities like this in China if the Government wants to instigate this. This is because there is a significant amount of helium (~1%) in the boil-off gas from Chinese gas plants. The costs of production are reportedly competitive versus

imports and China can manufacture all the components required to build the plants.

Fadhili, Saudi Arabia – Saudi Aramco is planning on bringing on stream a 230mmcf/y helium plant at the Fadhili gas field in 2023. The $13bn Fadhili natural gas plant has a processing capacity of 2.5bcf/d of natural gas. Also, The Royal Commission for Jubail and Yanbu and Air Products Qudra signed a Memorandum of Understanding (MoU), which sets out preliminary framework details to establish a helium recovery network.

India – The Indian state Atomic Minerals Directorate with the National Institute of Technology is looking to produce the world's first helium from a hot spring site using a non-cryogenic PSA technique. The site is located at Bakreswar in Birbhum, about 230km from Kolkata. Out of 340 hot springs in India, 50% have a concentration of about 3.5% helium gas. Bakreswar is estimated to produce 60,000 commercial cylinders per annum of helium or around 15mmcf/y.

Demand

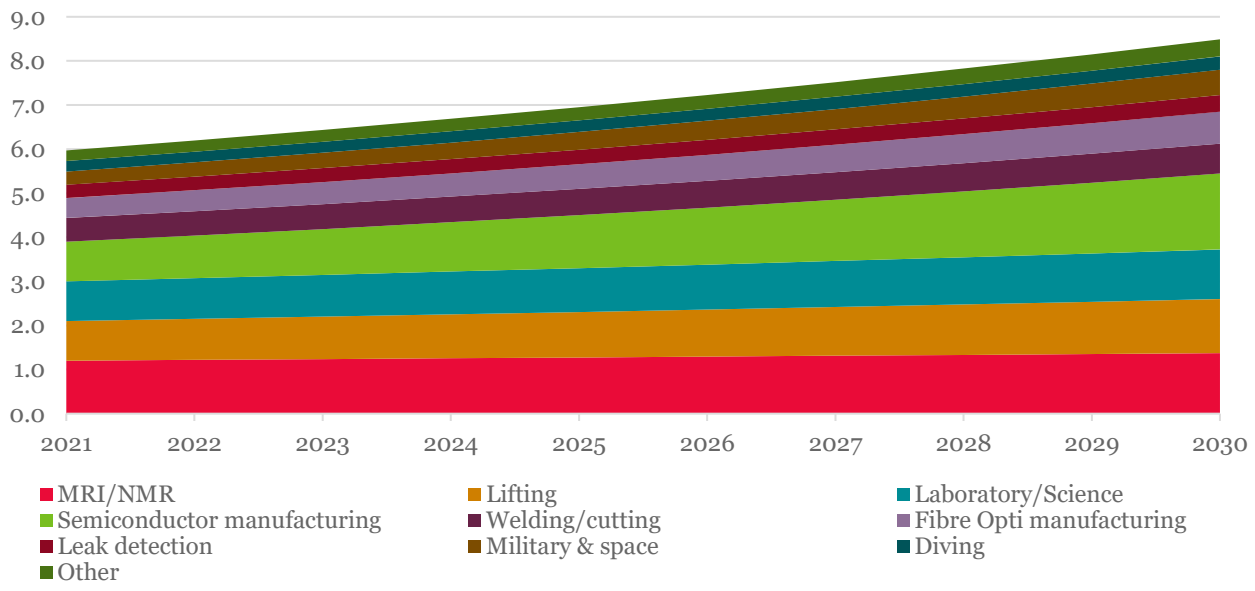
We examine helium demand by usage type and by region. From our research, there are not many sources that provide demand data, we believe that much of the data in the market at present is stale and has relied on extrapolated trends from outdated information and there has been a lack of bottom-up demand analysis. For example, one of the widely quoted sources, the US Government data on helium consumption by sector, has not changed since 2016. We have looked at the various industries using helium and taken a bottom-up approach to forecasting demand. Also, we have looked at helium consumption by geography aided by using import data.

Given the inability to substitute helium in many applications, we see demand as relatively price inelastic. There has been some price elasticity as consumers (where they can) have looked at recycling helium (if cost-effective), conservation and substitution. With prices already significantly higher than at the beginning of the decade, most of the price elastic demand has most likely already been eliminated. In fact, if there are periods of lower pricing there is likely to be latent price-sensitive demand that returns to the market.

Given there has been a supply shortage of helium and there is not any significant commercial storage to draw on, it is hard to quantify what the unmet or latent demand for helium is. If more helium supply was to come onto the market, there will likely be demand coming out of the woodwork. If there was "cheap" helium available on the spot market this would be likely to be snapped up. For example, users of MRI machines that were running close to the minimum limits of helium could take the opportunity to restock and fill their units to capacity.

Another example, according to the USGS, US use declined by c 15% in 2013–14, amid rising prices. As industries switched or became more efficient with supplies (many have built more effective helium recycling facilities for example), we believe there was a certain level of permanent demand destruction.

Forecast helium consumption by industry 2021-2030E, bcf/y



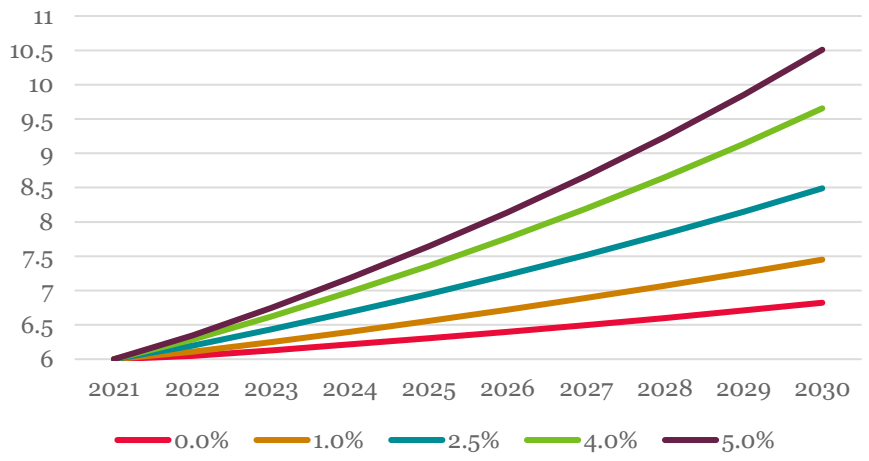
Source: H&P estimates

We see the key uses of helium coming from MRI/NMR machines (20%), around 15% for each of the following categories: lifting, scientific and semiconductors; around 8-9% for both welding and fibre optics and 5% or less for leak detection, space and diving.

Our methodology for forecasting helium demand is to use a base growth rate of 2.5% for all industries. We adjust up and down our growth expectations for various industries from this base line. For example, we assume lifting grows 1% faster, semi-conductor manufacturing usage 5% higher than the base and military and space also 5% higher. This results in an overall CAGR of 4% over the forecast period, with demand growing from 6bcf/y in 2021 to 8.5bcf/y in 2030. Using base growth between 0-5% results in a CAGR of between 1.4% to 6.4%. The chart below shows the different potential scenarios.

We see major growth potential for helium in space travel, near-space travel in balloons, semiconductors and other electronics applications. The future growth of helium is expected to be driven by demand from electronics manufacturers in Asia. Semiconductor, flat-panel display, and optical fibre manufacturing are all significant consumers of helium in Asian markets. We also think there will be new uses for helium emerging that we have not considered as yet or markets that grow quicker than expected such as quantum computing or fusion.

Forecast helium consumption at different base growth rates, bcf/y

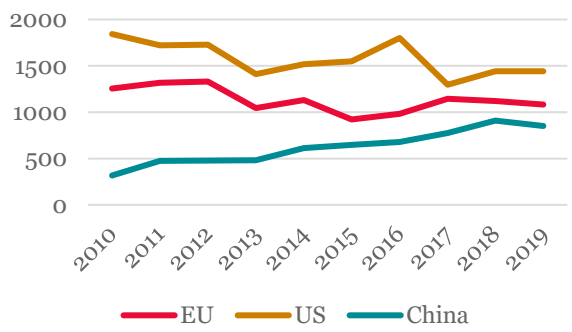


Source: H&P estimates

2020 demand has been impacted by COVID with market signals such as Chinese imports and end users such as Party City (helium balloon seller) suggesting lower helium usage in H1'20. However, there does appear to have been a market recovery. For example, Nasco, one of the biggest helium producers in the US, said in October 2020 that it saw demand for helium being robust through COVID-19 and sales prices in the US continuing to increase.

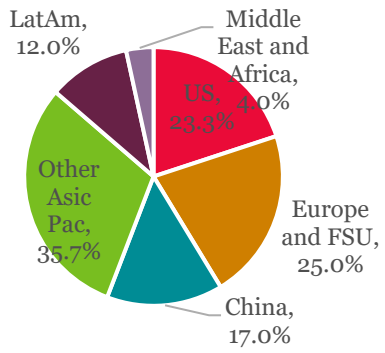
Regional

Estimated historical helium demand, mmcf/y



Source: Eurostat, USGS, Chinese customs data, H&P estimates

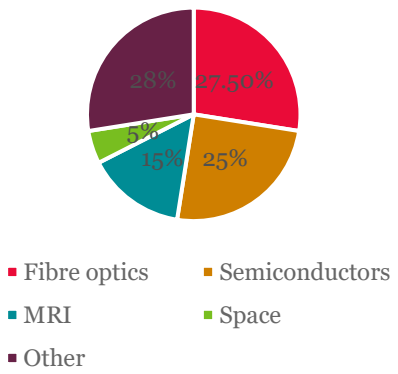
Forecast 2021 helium consumption by region



The general trend in the helium market has been a fall in demand from the US and Europe over the last decade, which has been offset by growth in China and Asia. This is because of the growth of MRI usage in Asia at a faster rate than the west and also due to technology growth industries for helium such semi-conductors and fibre optics being centred in China and the Far East. We expect this trend to continue and China's helium usage to grow rapidly.

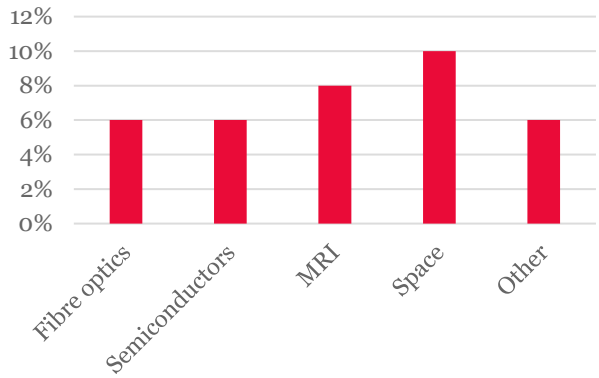
China

Chinese usage of helium by sector



Source: H&P estimates

Forecast annual growth in Chinese helium demand



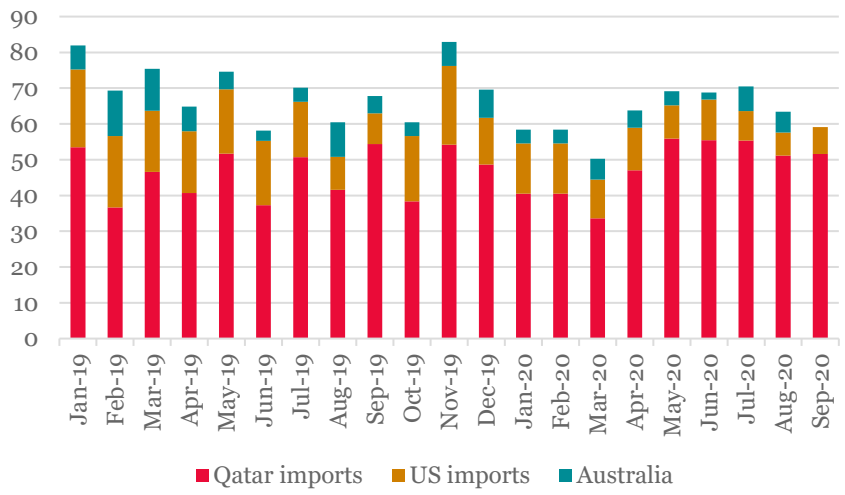
As with so many commodities, China is the most important growth market in our view for helium. It has already doubled its helium consumption over the last decade and is almost completely dependent on imports given a lack of a domestic helium industry. We expect Chinese helium demand to be around 1bcf/y in 2021 or 16% of the total global market. We expect demand to grow at 100mmcf/y.

The growth is also related to the industrialisation of China and GDP growth (e.g. welding, balloons, diving, leak detection), plus the increase in manufacture and deployment of MRI scanners and growth in fibre optic and semiconductors manufacturing as China takes market share in a growing market. There is also expected to be considerable growth in space rocket launches over the next 5-10 years.

We think that China will be an important market to watch over the coming years. There is virtually no domestic helium production in China but demand for helium is estimated at ~1bcf/y and is growing sharply. As with other commodities, we believe that there is a good chance that China will look to stockpile helium (build storage like the BLM) and also look to acquire helium resources globally. Therefore, we would not be surprised to see Chinese state-owned companies looking at buying into some helium projects globally.

The major industrial gases companies all have a presence in the Chinese market. Linde recently divested its China helium business to Guanggang Gases & Energy. The volume divested was 90mmcf/y with sourcing contracts from Qatar, Darwin and Amur. However, Linde may have retained its Praxair subsidiary volumes, which are similar in size. Air Products, Air Liquide, Iwatani and TNSC all have similar shares in the market.

Chinese monthly helium imports by exporter, 2019-2020, mmcf

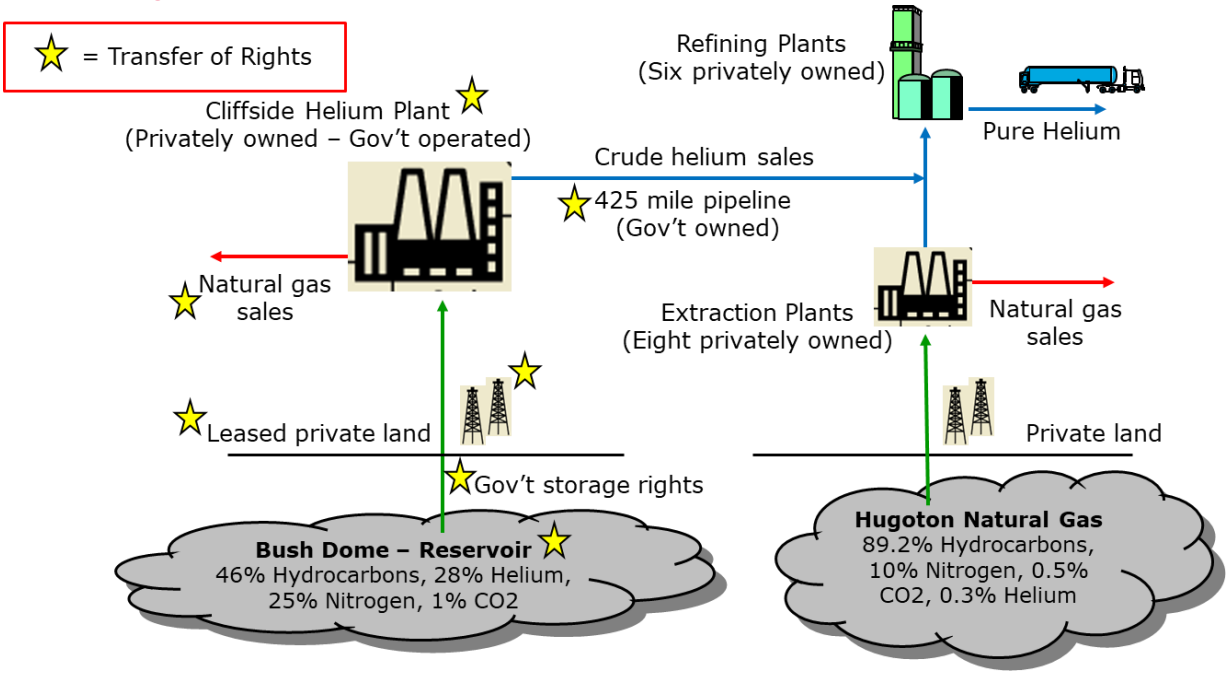


Source: Chinese customs data, H&P estimates

In 2020 helium demand was impacted by COVID and also imports were impacted by port congestion and disruption. March appeared to mark a trough in Chinese imports with a recovery into the summer.

Storage

US BLM storage



Source: BLM

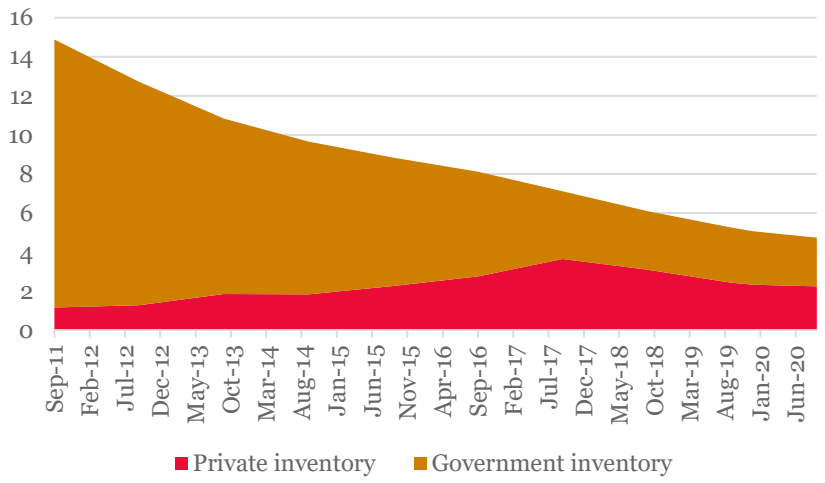
The main site for helium storage and the only real buffer for the helium market is the US Bureau of Land Management's owned and operated storage facilities. It controls a helium storage reservoir, enrichment plant, and pipeline system near Amarillo, Texas. There is minor storage elsewhere (e.g. Air Liquide has a site in Germany) but this is small in the scheme of things. However, we would not be surprised if some of the large producers (e.g. Russia) or large buyers (e.g. China) would look to build their own storage to ensure security of supply. This could be positive for demand and offset the upstream capacity growth over the coming years.

At its peak the facility hosted >30bcf of helium. Even though there is still around 4.7bcf of gas (around 75% of annual global demand), the facility is limited in what it can produce due to field pressure constraints. A new booster compressor was installed in October 2019 to allow an extra 500mmcf of helium to be delivered by October 2021. Including this, production capacity for the fiscal year ending September 2020 was ~750mmcf, down >20% y/y and this is expected to fall to 616mmcf over the next fiscal year. By 2023 this is expected to be just 375mmcf/y. Also the market is dependent on production coming out of the field to meet regular demand (was 750mmcf in 2019 before COVID-19), which shows that there is little in the way of a buffer if there are any global supply outages.

We believe that the dramatic fall in the production capacity and the total reserves in the BLM storage should ensure a structurally higher price for helium in the future. Buyers that cannot do without helium would be willing to sign long term contracts with a diversified set of suppliers, to ensure security of supply, even if this entails higher pricing, as the cost of not having helium could be many times higher (e.g., causing equipment failure and damage).

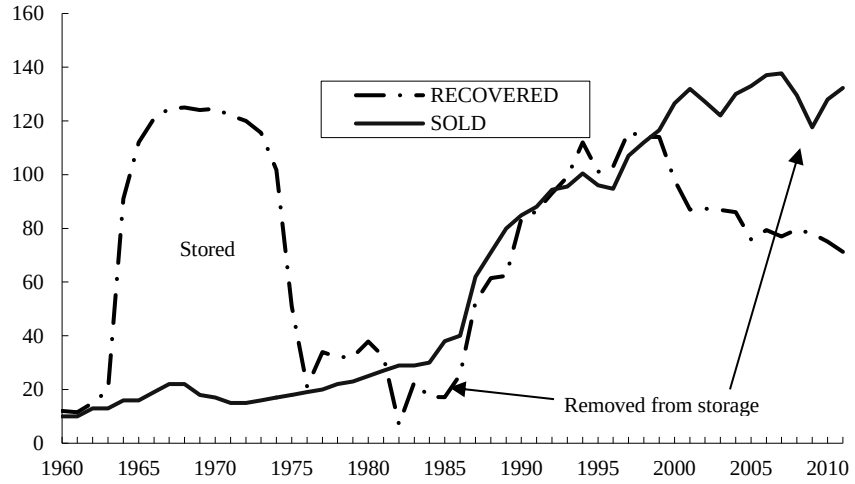
Given the concentration risk in terms of supply and the critical importance of helium, we would expect both private and Government demand for helium for storage in order to create a buffer in the event of disruption to supplies. Also, from a logistics standpoint a key challenge is to meet customer on-time requirements, independently of the reliability of production sources, by ensuring an optimum transport lead-time to customers, while avoiding losses due to helium warm-up which can occur during transport.

BLM inventories 2011-2020, bcf



Source: BLM, H&P estimates

BLM storage and withdrawal pre-2011, mcm



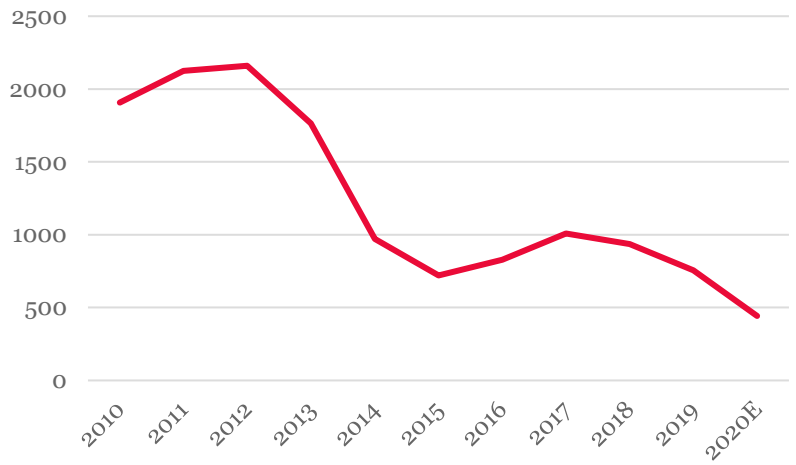
Source: BLM, H&P estimates

The BLM stopped public auctions of helium after 2018 as the strategic reserves fell to 3tcf and the remaining helium was retained for federal users. In October 2018 the reserves were 3bcf government and 3.1bcf private and this has fallen to 2.5bcf and 2.2bcf respectively in October 2020.

Between September 2019 and October 2020, approximately 225mmcf (4% of global supply) was added into the BLM storage by private producers. This suggests weak demand in 2020 and possibly some stockpiling by producers. From

January to September the amount of helium sold out of inventory was 330mmcf and annualised that works out to 445mmcf, which is a dramatic reduction of 40% y/y.

Volumes sold from BLM storage, 2010-2019, mmcf/y



Source: BLM, H&P estimates

The US BLM helium storage facility is due to be sold by 1st October 2021, whereby, Federal helium operations management will pass to the General Services Administration (GSA), which will follow its statutory disposal process. Federal In-Kind users will continue to have access to helium until September 30, 2022, while the GSA completes their disposal process. This will also allow the BLM to continue operations until such time as all privately owned helium is produced from the field (about 2023).

The intention is to transition to a private operator. The sale will include Government injected helium, which stands at 2.5bcf on 1st October 2020, around 55bcf of natural gas, a 425-mile pipeline distribution network (through Texas, Oklahoma and Kansas) amongst other ancillary assets. There is considerable uncertainty around what impact this will have on the market after a sale.

It is thought that the buyer will be free to sell this helium as they choose rather than it being reserved for Federal helium users. The American Physical Society recently urged House and Senate members to continue allowing federally supported researchers to access the remaining helium even after the reserve assets are sold off. It said some researchers were having “difficulty securing helium at any price” and warned that becoming dependent on foreign sources “would not be prudent” for scientists.

In Germany Air Liquide has a pure helium cavern, which stores helium in a salt reservoir (former salt mine) 1,300m underground. It is in Gronau-Epe, Germany, in the centre of the major European market. Air Liquide owns the right to use the cavity, operates the facility and can store in Gronau-Epe more than one year of its helium sourcing. It represents a first-of-its-kind technology thanks to an Air Liquide innovation. It ensures independent reliability of helium production sources, optimum transport lead-time and an all-round secure helium supply from Air Liquide.

History

The element helium was first observed by a French astronomer Pierre-Jules-César Janssen during the solar eclipse of 1868 in India, using a portable spectroscope. The new yellow line belonged to an unknown element. Sir Norman Lockyer found the same thing a few months later and named it helium after helios (meaning sun in Greek).

It was not until 1882 that the presence of helium on Earth was spotted by Luigi Palmieri, an Italian volcanologist and meteorologist, during the spectral analysis of lava from Mt. Vesuvius. In 1895, the gas helium was discovered in uranium ore, cleveite by Sir William Ramsay. In addition, helium was discovered by N.A. Langley and P.T. Cleve at 1895 in London and Uppsala, Sweden.

In 1903, helium gas was found in a natural gas field in Dexter, Kansas. The concentration of helium was 1.84% in the field. Helium was likewise found in several other gas fields in northern Oklahoma, Texas, Ohio and Montana with different concentrations, for extraction as a by-product of natural gas.

Interest in helium picked up in 1914 when the German chemist Géza Austerweil highlighted the utility of helium as a buoyant, non-combustible gas for filling military balloons. Once the military application of helium was recognised, the U.S. Geological Survey was tasked with investigating helium resources.

The first US helium extraction plant was built by the United States Army at Petrolia, Texas in 1915. The helium came from the natural gases of the Petrolia oil field, in Clay County. The Petrolia oil field contained 1% helium.

The United States has maintained international dominance in the helium production business since the first large-scale helium production facility in Texas began in 1921.

Helium was so important to the United States during and after World War I that the Government took ownership of all helium produced on federal lands. In 1927, the Government took even greater control over helium because of its expanded role in military uses essential to national defence. Congress's Helium Act of 1927 stated that US Government helium could not be sold to nongovernment entities.

Ten years later and four months after the Hindenburg disaster, Congress passed the Helium Act of 1937. The provision of this Act opened up the use of helium to scientific and commercial industries. It also allowed for "non-hostile" foreign governments to purchase helium for their own commercial use. Helium played an important role in WWII.

By the 1950s helium demand in military applications, scientific applications, and commercial applications had exploded and the US experienced its first major helium shortage.

President Dwight Eisenhower signed the Helium Act of 1960, essentially allowing the US Government to purchase helium from private sources at a fixed price. This would eventually allow the US Government to stockpile helium in enormous volumes. Legislative changes in the early 1960s paved the way for private industry to enter the helium business. The largest liquid helium plant at the time, Otis, Kansas was brought online in 1965 and is still producing today.

The US Government's supply and access to helium was essential to the Space Race at the time. In the 1970's and 1980's, with the end of the Space Race, US demand for helium dropped and there was an increase in the export of helium to other countries. Likewise, as prices fell, the US Government dropped its purchasing of helium and private companies stopped their exploration and production.

In 1995, President Clinton initiated the withdrawal of the government from a leading role in the helium industry, later supported by the Helium Privatization Act of 1996.

Qatar's first liquid helium was produced in August 2005; the Ras Laffan Helium 1 plant reached its designed production capacity of 700mmcf/y in 2008.

During 2010, some helium suppliers announced price increases of 5% to 10% in response to continued increased raw material, energy, and distribution costs. Helium consumption increased by about 15% compared with that of 2009.

In 2013 the US Congress passed the Helium Stewardship Act, which continued authorisation of the Helium Program through at least 2021.

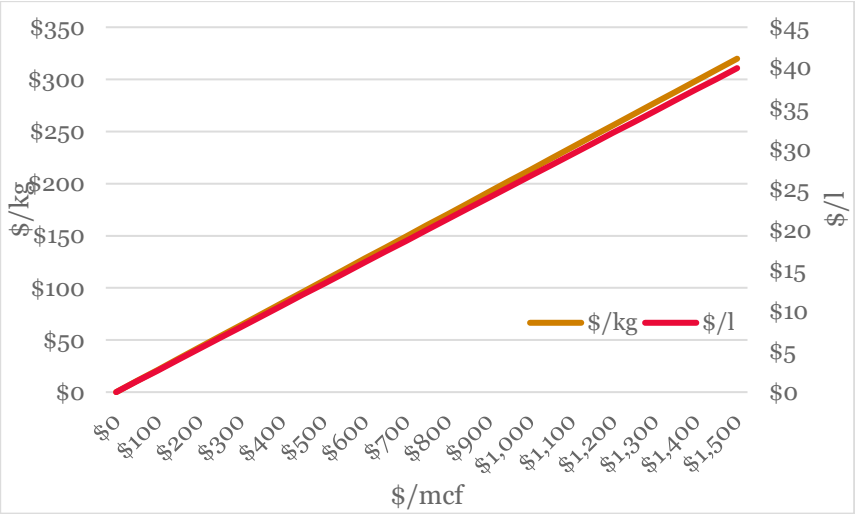
In 2014, as part of the implementation of the Helium Stewardship Act of 2013, the BLM began an auction process to price helium more closely to the open market value. The average price of helium sold to private buyers as a result of this process was $106/mcf. Expansions to facilities were completed as planned in Algeria and Qatar. Additionally, in 2014, new US production began in Wyoming.

In June 2017, the enforcement of an embargo on Qatar saw ~30% of global helium supply taken off the market for several weeks. As a result, production of helium from the US Federal Helium Reserve increased along with exports.

In May 2018, the U.S. Department of the Interior, in coordination with other executive branch agencies, published a list of 35 critical minerals, including helium.

Units of measurement

Helium pricing conversion chart



Source: H&P estimates

Helium production is generally referred to in million cubic feet per year or mmcf/y (unlike natural gas which is referred to on a daily basis) or billion cubic feet per year: bcf/y. Helium pricing is referred to in various units: either per thousand cubic feet (mcf), per litre (l) or per kilogram (kg). The chart above provides a simple way to convert between the three. At our base case price of US$250/mcf is the equivalent of US$7/l or US$53/kg.

Helium Conversion Data

	Weight		Gas		Liquid	
	pounds (lb)	kilograms (kg)	cubic feet (scf)	cubic meter (Nm^3)	gallons (gal)	litres (l)
1 pound	1.0	0.4536	96.69	2.542	0.9593	3.630
1 kilogram	2.205	1.0	213.17	5.603	2.115	8.003
1 scf, gas	0.01034	0.00469	1.0	0.02629	0.009918	0.03754
1 Nm^3, Gas	0.3935	0.1785	38.04	1.0	0.3773	1.4282
1 gallon, liquid	1.043	0.4730	100.82	2.650	1.0	3.785
1 litre, liquid	0.2755	0.12496	26.64	0.7002	0.2642	1.0

Glossary

BLM: US Bureau of Land Management

Crude Helium: Helium with equal to or greater than 50 percent "contained" helium which is recovered from upstream processing of natural gas to produce natural gas liquids (NGLs) or liquefied natural gas (LNG)

ISO Tanks: Cryogenic super insulated tanks designed/built under the UN's International Standards Organization code for intermodal and oceanic container transport and shipping

Liquid Helium (LHe): Helium which has been cryogenically liquefied for liquid bulk transport and/or for use as an ultra-low temperature refrigerant

Pressure swing adsorption (PSA): Pressure swing adsorption processes utilize the fact that under high pressure, gases tend to be attracted to solid surfaces, or "adsorbed". The higher the pressure, the more gas is adsorbed.

Spigot: Referring to Capacity or Production of helium volume free on board (fob) at the plant

Refined Helium: Helium purified to commercial Grade A gaseous helium

USGS: United States Geological Survey

US BLM In-kind sales - The "in-kind" programme means that when a helium supplier sells a significant amount of helium to a Government agency, it must purchase an equivalent amount of crude helium from the BLM.

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