



EDISON



Helium – Macro View Update

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Helium – Macro View

Short-term market tightens

Elemental analysis

Oil & gas/Industrials

25 February 2019

2018 has seen a notable tightening in the helium market, driven by lower than expected global output and potential supply deferments. Forecasting remains difficult, but we believe that the balance is weighted towards a tightening market, especially in the short term ahead of new large-scale supply additions from mega projects in Qatar and Russia, which are planned from 2020 onwards. Assumed annual demand growth of 1.5% will continue to put pressure on the supply/demand balance in the longer term. This should support prices, motivating further development and helium exploration. If mega projects are delayed (very possible), the picture could deteriorate further, pushing the market into a substantial deficit.

Supply constrained, short-term deficits likely

Helium is a vital and irreplaceable element in many critical modern components industries. The era of supply being underwritten by the drawdown of US strategic reserves is nearly over, and replacing this supply is not straightforward. New (medium-term) supply is largely as a by-product of planned oil and gas mega projects that are often delayed. While a number of companies have emerged in recent years (mostly in Western US and Canada), almost all are at the pre-drill stage or focused on projects with limited scale. Many have announced ambitious plans, but few have progressed to proving up gas resources, which will take time.

Opaque & oligopolistic supply impedes analysis

Five major fields/facilities (BLM storage, LaBarge, Hugoton, Algeria and Qatar) supply around 80% of global upstream helium. A similar number of large players control the distribution, which is often executed on privately negotiated contracts. Data on current supply/demand/prices are therefore not widely disclosed and create uncertainty around precise estimates. Our analysis of project developments suggests a lack of new supply to satisfy increasing (price-inelastic) demand. BLM's recent crude helium auction, priced at an average \$280/mcf, highlights concerns over an impending supply shortage.

Demand steady, prices should be supported

We see a continued increase in demand underpinned by the lack of substitutes for helium in its main markets of MRIs and high-end science/engineering, including rapid growth in state-funded/private space exploration, pressure/purge applications and semiconductors. A well documented shortage in 2011–13 forced price spikes incentivising new supply (based on LNG plant start-ups), driving prices back to more normal levels. We believe current supply constraints should continue to support pricing and may support marked increases. Our analyses indicate an increasing shortage in 2019–21 and possibly beyond, especially if the mega projects in Qatar and particularly Russia (Amur) are delayed.

Report summary

Helium is a vital element in the manufacture of MRIs, semiconductors as well as being critical for space exploration, rocketry and high-level science. We examine the supply/demand picture for helium, examining key supply sources in the US and globally. We also summarise the reserve situation for helium and look for pricing guidance.

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Summary

In this report, we detail our views on **supply and demand** for helium over the next 10 years, examining major sources in the US and globally. Few projects will come online in the next three to four years, putting increased stress on the market as the sale of stocks held in the US strategic reserve finally ends (held in the Cliffside field, operated by the Bureau of Land Management, BLM). We review the key sources of current and future supply to examine critical components.

Helium supply is structurally fragile, as an outage of one (of the limited number of) supplier could have outsized effects. Major sources (such as Hugoton or the BLM storage) are now at/towards the end of their lives and it is not clear how the reservoirs will react to increasingly low pressures. It is possible that the fields will decline far faster than we model and that the reserves estimated will not be recovered fully.

While a number of companies have emerged in recent years (mostly in western US and Canada), almost all are at the pre-drill stage or focused on projects with limited scale. Few have progressed to providing gas resources, which will take time. The time, effort and costs to secure the property rights and leases also contribute to the barriers to entry.

While it is estimated that there is plenty of helium in the world, the accessibility and commerciality of these reserves are more complex. Reserve replacement of helium has been very poor and hampered by a number of factors:

- helium is scarce and generally found within conventional natural gas reservoirs in small concentrations (<0.5%), making helium a valuable by-product as long as the gas is profitable to extract. In the past, this has meant that upstream companies had no strong incentive to negotiate high prices for helium, while in recent years depressed gas prices (particularly in the US) have discouraged development of conventional natural gas fields;
- prices of helium have arguably been kept artificially low by the large-scale, well-publicised sell-off of the US strategic reserve to a limited number of buyers that gave mid/downstream companies a reliable supply over the last 10 years;
- helium has traditionally been traded on confidential long-term private contracts, keeping pricing opaque and reducing incentives for helium exploration; and
- due to its properties, helium cannot be stored/produced from shale. Helium therefore has to be sourced from conventional natural gas reservoirs, which currently hinder its economics. Helium associated with CO₂ will also suffer from currently low oil prices.

In our view, helium will likely be subject to steady, price inelastic demand growth. Hampered investment in supply led to a shortage of supply in 2011-13. In the resulting price rise, many industries sought to replace (or recycle) helium, where possible. However, its unique properties (lowest boiling point, small atomic size and weight, unreactive nature, high thermal conductivity) mean that it is irreplaceable in many applications. The demand destruction seen in the industry in the spike of 2011-13 may have left the rump of demand more inelastic to price movements. Indeed, despite the current looser supply/demand dynamics, pricing has not retreated and BLM auction prices rose around 137% in August 2018 (vs previous year).

Appendices include a history of the BLM and some notes on the Helium Extraction Act 2017.

Fragility of supply/demand picture to continue

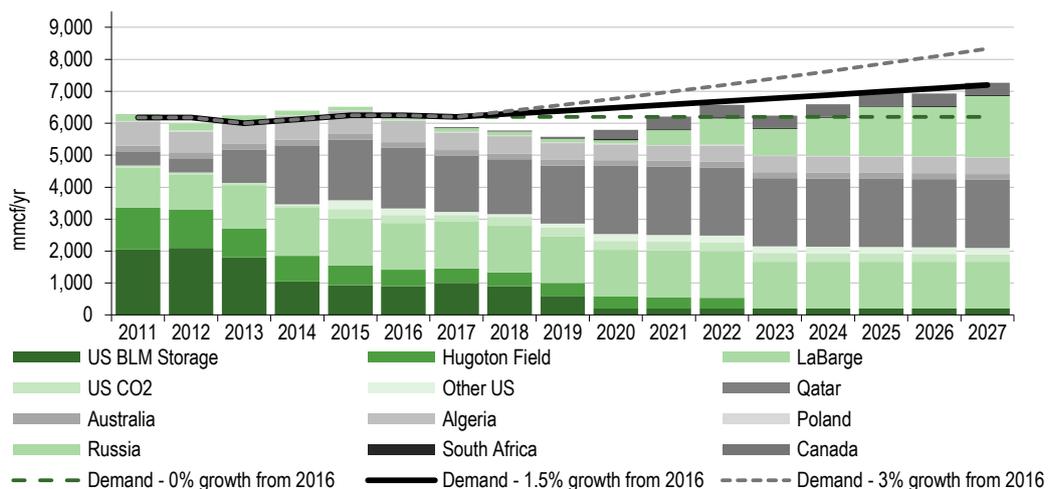
The helium industry is an opaque one, with oligopolies of large companies and nations controlling upstream and downstream supply. There are no independent authorities that accurately trace supply and demand as seen in other industries (eg the IEA, in the case of oil). The vast bulk of production is not disclosed publicly, either because the players are so big that helium production is not relevant to investors (ExxonMobil's LaBarge facility, or Linde/Air Products businesses) or because entities are not listed (for example, the Qatari/Algerian LNG production). As a result, there is no clear picture of supply or demand. Additionally, estimates on key variables such as helium concentration, productive capacity or timelines for expansion often vary between two forecasters for the same facility. Outages in productive capacity are rarely reported widely or on a timely basis, while many future projects will likely be dependent on the level of natural gas prices to be sanctioned or expanded.

We do know that supplies from major sources (Hugoton and the BLM storage facility) are definitely declining. New sources of supply are limited and will not offset these falls, meaning near-term supply will certainly decrease, and the only projects that could reverse this picture are mega projects (Qatar III and Amur in Russia), which are liable to delays. Our study of other large oil and gas developments worldwide shows material delays are commonplace, so the 2021 start-up of Amur may be at risk, we think. If this is delayed it will have a significant effect on the helium market.

The demand side is equally difficult to pin down accurately, but there have been no reports of sharply increasing prices of the type seen in 2012 (despite the Qatari blockade in mid-2017), suggesting the market was broadly in balance in 2017.

In the longer term, major additions such as Helium III (Qatar, 2020) and Amur (Russia, 2021) will create material new helium sources, but the next few years are likely to bring little new incremental supply to cover reducing supply from existing sources and any demand increases (which we assume will be 1.5% pa, in line with historical increases). There is, therefore, potential for a deficit before then, which would be exacerbated by any downtime (such as further issues with Qatar or unexpected downtime in other major producers).

Exhibit 1: Estimated global supply/demand forecast, mmcf/year

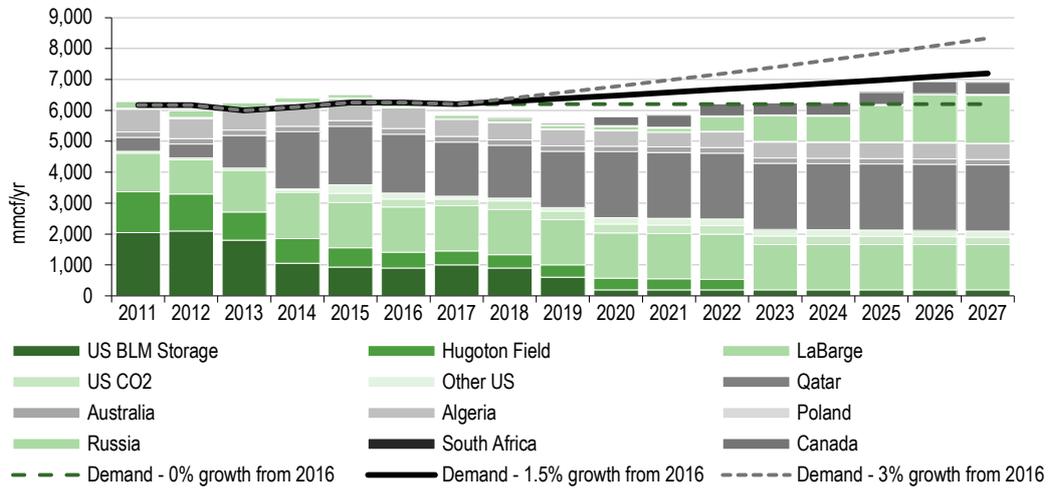


Source: JR Campbell & Associates report for BLM Office of Minerals Evaluation, public and private company data, Edison Investment Research, various

Our base case sees a deficit building from 2017 onwards, only (partially) offset by increased production from Qatar's Helium III in 2020, but more importantly the volumes coming from Amur Gas development in 2021/2022 onwards. While we currently model Amur's volumes coming online in mid-2021 (as currently forecast by GazProm), the effect of possible delays would be very

material on the supply demand balance. For example, if we were to delay the Amur volumes by 12 months (industry studies show an average delay on projects of 20months), the picture become one of severe deficit out to 2026, as seen below. Indeed, under this scenario, the market would only be in balance with virtually no demand growth whatsoever, which we see as very unlikely.

Exhibit 2: Estimated global supply/demand forecast under a delayed Amur scenario (24 months), mmcf/year



Source: Source: JR Campbell & Associates report for BLM Office of Minerals Evaluation, public and private company data and Edison Investment Research, various

If readers were to assume a 3% demand growth, deficits would grow even if Amur and Qatar came online as currently expected, while any delays would leave the deficit at around 1bcf/yr by 2027.

We have seen some action from some market participants that may indicate their preparation for shortages to cover possible market gaps (for example, Air Products bought 100% of the recent BLM auction for 2019 volumes). The market remains very susceptible to supply disruption.

Key supply sources/projects

Our analysis of major production facilities globally indicates little new (guaranteed) supply will come online in coming years (DBK, Tenawa), with incremental supply primarily going towards offsetting declines elsewhere (BLM, Hugoton). We review the major sources below.

United States

The US has been the key source for helium for decades. However, the depletion of the strategic reserve (and other major fields), together with the new supply from Qatar has lessened its role.

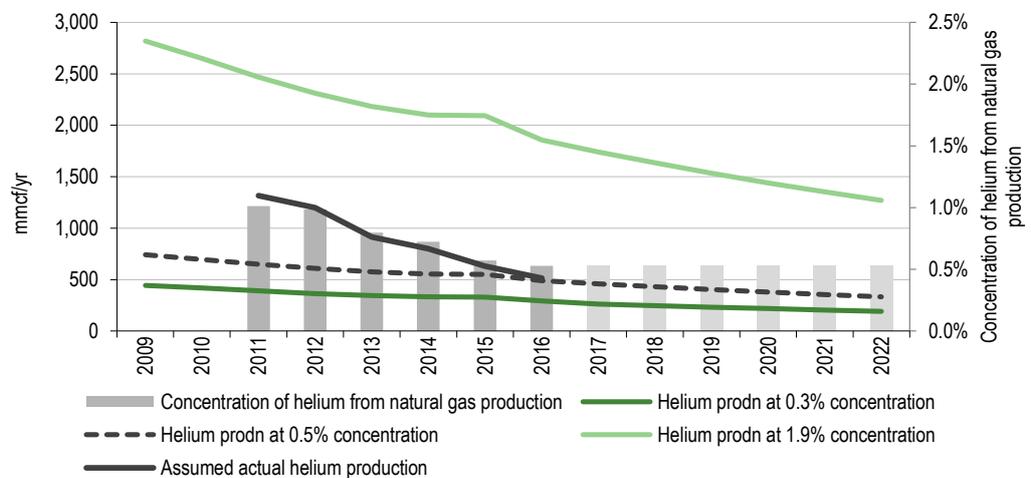
BLM – the strategic reserve will be fully depleted by 2021 (except for 3bcf of strategic reserve, which is to be used only when critical, and some privately held reserves). August 2018’s BLM auction is to be the last, as reserves are anticipated to reach the federally mandated 3bcf limit of strategic reserves. As of October 2017, reserves of helium in the system were 3.475bcf (government) and 3.642bcf (private). After this limit is reached, only the private storage will be released. As a result, we assume 200mmcf/yr will be released each year from private sources.

Hugoton field – the Hugoton field is one of the largest gas fields in the US. It has produced nearly 27tcf of natural gas to date and has a high helium concentration (0.3-1.9%). As such, it has been a substantial contributor of helium supply in the US for many years. We estimate that there is c 3–4tcf of natural gas left to be produced.

Hugoton produced 88bcf of natural gas in 2017 and has declined at a five- to 10-year CAGR of around 6-7% (production through to end July 2018 of 42bcf implies a decline consistent with this). We assume the entire field continues to decline at this rate. Using the field production data (from Kansas) and applying the ranges of helium content suggests helium production consistent with concentrations of around 0.5%. The data certainly suggest that the 1.9% upper end of the range is not a relevant figure to use (although it may have been in parts of the field some time ago).

Actual helium output from Hugoton is not available, but we have used the estimates of historical data from JR Campbell and Associates from 2011-15, which imply helium concentrations of production fell from 1% in 2011 to around 0.5% in 2015. If true, this is a concern and suggests that our base assumption of a 6.1% decline in helium production (in line with field declines) will be too optimistic. If the trend of falling helium concentration continues, it may be uneconomic to continue to produce helium at Hugoton in the medium term.

Exhibit 3: Possible Hugoton helium production, mmcf/yr



Source: Kansas Geological Survey, Edison Investment Research. Note: We use the 0.5% helium concentration as a forecast guide for 2017 onwards.

LaBarge field – LaBarge is a large natural gas field in Wyoming with high concentrations of CO₂ and a relatively high concentration of helium (0.6%). The field economics rely on the efficacy of the CO₂ in enhancing oil production in surrounding oil fields as LaBarge is only 21% methane (the lowest methane content of any gas field globally)¹ and is 65% CO₂ (as well as 5% hydrogen sulphide and 0.6-0.7% helium).

The Shute Creek facility separates out the gases, reinjecting the hydrogen sulphide (and some CO₂) into the reservoir, liquefying the helium and piping the rest of the CO₂ to surrounding fields in Wyoming and Colorado. The facility has a helium production capacity of 4mmcf/d, or 1.46bcf/yr, making it a substantial contributor to global demand (around 23%).

According to Exxon, all the gas was contracted for sale since the start of operations in 1986, but long-term sales averaged only half-capacity for much of this time, as the CO₂ enhanced recovery market did not develop as fast as anticipated, partially as a result of the distance to the fields. Higher oil prices from the 2000s onwards made project economics more attractive. We assume that the facility continues to produce at its capacity over the forecast period (of 4mmcf/yr or 1.46bcf/yr).

Big Piney, US (Matheson & Air Products) – Big Piney was designed to extract helium from sour gas at rates of 200mmcf/yr, expanding to 400mmcf/yr. The helium-rich natural gas and CO₂ feed gas was due to come from the LaBarge field via Denbury's Riley Ridge processing plant, Wyoming.

¹ CO₂ Management at ExxonMobil's LaBarge Field, Wyoming, USA. P E Michael E Parker et al, *Energy Procedia* 4 (2011)

Denbury's interest in gas was 1.2tcf of CO₂ with 0.6% helium. Indeed, Gage and Driskill (1998) estimated helium resources of 47bcf, and peak production from the LaBarge field as a whole was envisaged at 1.4bcf/yr. However, design issues meant there were delays to the start-up (in late 2013) and the plant was shut-in in 2014 after additional issues (caused by sulphur build-up in gas supply wells) hampered production. The plant remains shut in and was fully written off by Denbury in its 2016 annual report. We therefore do not expect any helium from this plant.

Doe Canyon, US (Air Products) – a helium separation plant from CO₂ feed was proposed to start in 2015 with a capacity of 400mmcf/yr, but we understand this was quickly reduced to 230mmcf/yr after start-up and that production has declined to 140mmcf/yr currently, due to lack of demand for the CO₂ feed gas. We model that the plant continues to produce at this rate during the forecast period, although sharp increases in oil prices could motivate greater CO₂ and therefore helium (we do not forecast this).

DBK expansion (IACX) – NASCO, a German-listed player, is planning to expand its DBK facility in Arizona. We model production increases from 70mmcf/yr in 2013 to around 140mmcf/yr in 2019. In August 2018, NASCO announced a farm-in agreement with Vision Energy Group (a subsidiary of Praxair) for the appraisal of the Hogback fields in New Mexico, US. Preliminary estimates based on historic drilling suggest probable reserves of 2.5bcf of helium.

Other – Industry sources indicate that new supply from an existing cryogenic plant in the mid-continent US is possible over the next few years. Very little has been made public at this stage, but we have modelled supply of 100-150mmcf/yr starting in late 2019/early 2020.

Miscellaneous – we do not have access to the production data of the other production facilities in the US, so we assume that together they contribute around 100mmcf/yr in 2017, declining slowly over the forecast period. These include projects by IACX (and partners) targeting helium depleted fields and lower pressure extraction techniques. We do not see a material future contribution from such projects.

Worldwide projects

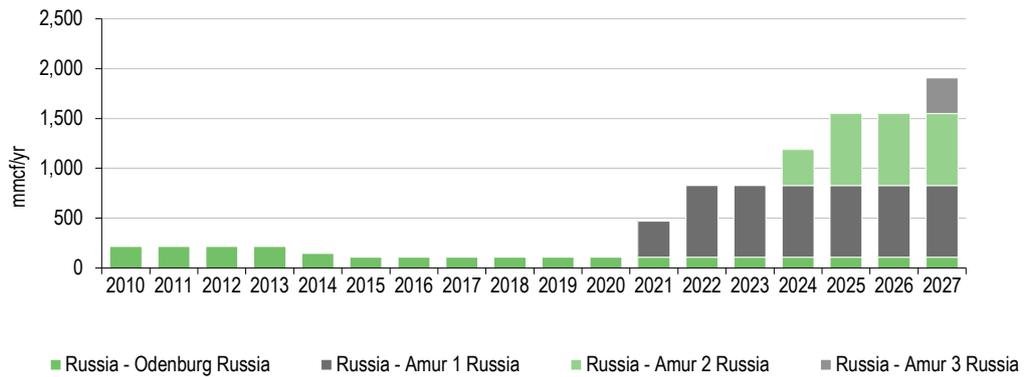
Qatar – the start of the Helium I and II projects had a major impact on helium supply and contributed to a surplus in 2014-16 after the shortage of 2012. The USGS estimates that Qatar produced 1.8bcf of helium in 2016, up from 468mmcf in 2012. In theory, the helium produced should continue at the peak plateau rates (of around 2bcf/yr) as the production is dependent on plateauing LNG production.

Despite the large volumes produced, estimates are difficult as no public information is available. In 2017, the USGS estimated 2016 production at 50m cubic metres, falling to 45m cubic metres in 2017. The Helium III development, located in the Barzan facility, was planned to come online in 2018, adding a further 425mmcf/yr. However, issues with the pipeline that will transport feedgas to the processing facility meant that this has been delayed. Such issues are often complex to fix and take time (especially given the size of the development). We therefore assume production comes online in October to December 2019.

Qatar supplies c 28% of global demand and helium was exported from the UAE (via Saudi Arabia), but this route was blocked in mid-2017. Helium production was suspended in June 2017, but restarted in July after a new route was organised.

Russia is currently a small contributor to helium production (the USGS estimates production of just under 110mmcf/yr in 2016) and has seen production decline steeply in recent years, as seen below. With no further information, we assume Odenburg continues to produce at this rate, although this could be optimistic.

Exhibit 4: Russian helium production



Source: USGS, Edison Investment Research. Note: 2017 onwards are Edison estimates.

However, the massive Amur gas development has the potential to help Russia rival Qatar as the largest helium producer in the world by 2030. Planned to produce 42bcm of natural gas per year (contributing to a 30bcm pa export of gas to China over 30 years), the staged development could produce as much as 60m cubic metres of helium per year (2.2bcf/yr) – equating to 0.15% helium concentration.

Data on the development is not easily found, but we assume helium plants come online in the middle of 2021, 2024 and 2027, each of 720mmcf/yr. We would caution that as with all mega-projects, it is entirely possible that the development see delays – albeit that intense pressure will be on managers to hit the targets given the strategic importance of the project to Russia and China of such massive volumes of natural gas. Operator reports as of October 2018 suggest that the project is currently running to schedule. The Amur complex will be one of the largest gas/chemicals plants in the world. We also do not know how the construction of the plant will be affected by western sanctions or exactly how it will be funded (we understand China has yet to provide some of the substantial loans required to build the complex). The gas plant alone is currently scheduled to cost €11.5bn.

Studies of projects by industry observers found that (i) 78% of upstream mega projects faced either cost overruns or delays;² (ii) 73% of projects are delayed³ – indeed, of the 20 largest projects examined by an Ernst & Young study, only seven were on budget;⁴ (iii) large oil & gas, mining and infrastructure projects run on average 20 months late and cost 80% more than budgeted; and (iv) the Oil and Gas Authority (in the UK) stated that fewer than 25% of new projects were delivered on time over the last five years.⁵

The impact of any delays would be very material for helium balance, as we described earlier in this report.

Algeria supplies helium when gas from its massive Hassi R'Mel field is exported via LNG. While the helium concentration is low (0.17%), the field accounts for c 60% of Algerian gas exports so economic extraction is possible (no other fields have commercial helium extraction). Historically, estimates have put helium production at around 900mmcf/yr, but we believe recently production has been lower.

² Independent Project Analysis (IPA), 2011

³ Spotlight on Oil and Gas Megaprojects, Ernst & Young

⁴ HIS Global Insight

⁵ Lessons Learned from UKCS oil and gas projects 2011-2016, The Oil and Gas Authority

We believe Algeria prioritises its pipeline gas exports to Europe, with LNG a less critical component. LNG volumes can therefore suffer if demand in Europe increases or gas supply in the country is not as high as hoped.

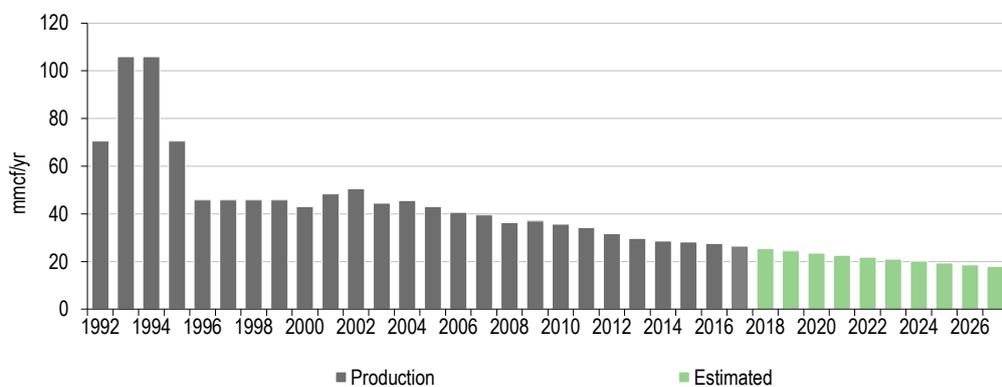
As the crown jewel of the Algerian gas industry, the Hassi R'Mel field has taken the brunt of delays or under-production of other fields (In Amenas, Ohanet and Reganne to take just three examples) meaning that it has been used to fill-in these production gaps. The consequence is a reduction in the recycling of some gas (reinjecting dry gas and stripping the liquids for sale, keeping pressure up for longer-term reservoir management). This is bad for helium markets as it possibly reduces ultimate recoverable helium in the long term but also means that this in-filling of near-term gas production goes through the pipeline to Europe, bypassing the LNG system and helium extraction. This is a major source of uncertainty for our analysis. For modelling purposes, we assume a 5% decline pa in production of helium after the USGS estimated 550mmcf/year in 2017.

As the source of so much revenue, Algeria has made strides to try to better conserve the field (and capture more gas elsewhere). It is possible that the decline in volumes in LNG may flatten out in the near term. More work is required to maintain long-term volumes.

Poland is one of the minor players in global helium, but the only European producer. According to the Polish Geological Institute, there are 16 helium fields in the country (situated in the Zielona Góra-Rawicz-Odolanów area) of which 14 are producing. Reserves and production are dominated by two fields that make up almost 60% of production. The reserve life of the complex is over 30 years. For 2017, the combined resources were estimated⁶ to be 24.37m cubic metres and production was 0.75m cubic metres.

This is notably different from the USGS estimate of 2m cubic metres. We take the Polish Geological Institute figures, which show an average (10-year) yearly decline of 3.8% and assume production continues to decline at this rate for the foreseeable future.

Exhibit 5: Polish helium production



Source: Polish Geological Institute and Edison Investment Research

Other new (possible) sources

Renegen operates a natural gas field in the Virginia field in Free State in **South Africa**, which has high helium concentrations (of between 2-4%) and 9.2mkg of 2P reserves (corresponding to 1.96bcf). A project to extract the natural gas over a phased development has started, but the helium cannot be extracted until a pipeline network and central processing facility have been completed. The latest (May 2017) estimates for this development put the helium start-up in 2019, although delays are very possible. We currently expect the helium capacity to be around 30mmcf/yr at peak.

⁶ <http://geoportal.pgi.gov.pl/suowce/energetyczne/hel/2017>.

We note South Africa is extremely short of energy, so there are strong incentives to develop any gas (and associated helium) over time.

Iran – the South Pars field is the same field as Qatar's North Field and therefore could be a massive source of helium as/when it is developed; some estimate it to contain 350bcf of helium. Total's deal with Iran (signed in July 2017) for phase 11 of South Pars envisaged 2bcf/d of natural gas, but as of August 2018 Total had informed the Iranian authorities that it was due to withdraw from the development after failing to obtain a waiver from US sanctions. Initial gas flows were expected to start in 2021 (for domestic market); large-scale export volumes by pipeline/LNG would have been delivered some time after. Without Total's involvement the timeline of development remains uncertain.

The field already has a pipeline network so we would think additional supplies will be exported via this infrastructure, negating the need for LNG facilities (and therefore helium extraction plants). For LNG facilities to be built we would likely need a large increase in LNG pricing, which we think is unlikely in the near term. Given the low concentration of helium (0.05%) it is likely that helium production from South Pars will have to wait many years before sufficiently large LNG facilities are built to allow commercial extraction of helium.

In this vein, on 20 November, the National Iranian Oil Company signed a contract with IFLNG to produce floating liquefied natural gas (FLNG). The press release mentions first LNG could be supplied before the end of 2018. Given the small volumes and the complexity of the FLNG vessel being employed, we think it is extremely unlikely that any helium will come from this LNG supply.

There are a number of projects in **Canada** of differing maturities. Exploration for helium in Canada could be very promising given proven deposits of helium in deeply buried traps, often with little associated CO₂ or other gases (other than nitrogen) making extraction and liquefaction cheaper.

Weil Group is currently producing 35-40mmcf/yr from its Mankota plant, and Medicine Hat has announced plans to commission a facility in 2019 (of unknown helium capacity).

There are a number of players exploring (or planning to explore) for helium in Canada. North American Helium is a private company operating in Southern Canada and has accumulated a large property position (>500,000 acres) within a known helium province. It is seeking to further expand its proven resource base in the Greater Battle Creek. It has so far drilled six wells, finding helium in concentrations of around 1% (within a majority nitrogen reservoir, which makes commercialising cheaper than if it was in a natural gas reservoir). Given the proven helium resources in the location, we include volumes from 2020 onwards at this point.

Royal Helium Corporation is a listed vehicle focused on exploring in Canada. The company holds 399 sections (255,400 acres) of crown helium land; approximately 45% is held as helium leases on 21-year terms with the remainder held as helium exploration permits. Royal's assets are associated with Saskatchewan's highest known helium concentrations. The company believes its targets have concentrations of 1.1-2.8% helium and it was planning on re-entering a well in November 2017 to prove up its G&G analysis.

Thor Resources names five helium projects of varying maturities (from well tested to much earlier stage). The Knappen project is believed to contain over 1bcf of helium (management estimates) and is in development with Weil Group. We have found one source to indicate that this will be commissioned in 2017, so timelines are uncertain at this time.

Tanzania – Helium One is a private company seeking to explore for helium in Tanzania after traces of helium were detected in geothermal springs. According to Helium One's website, Netherland Sewell and Associates has estimated P50 unrisked prospective recoverable helium volume of 98.9bcf, across 28 leads (as seen on 2D seismic).

Until exploration wells are drilled, we remain cautious on the potential for commerciality of the area – many geothermal waters around the world contain helium so this in itself is not a major indicator of commercial traps. Indeed researchers posit that identifying the ratio of isotopes of helium ^3He and ^4He from many such sites could be an indication for good locations for geothermal energy plants.⁷ Historical wells by Amoco detected helium, but reservoir quality still has to be proven. Additionally, the site is remote and the economics of liquefying and exporting the product may be challenging.

Global reserves

There is no clear picture of global helium reserves/resources and relatively little written publicly. Many papers and books reference papers that are decades old and there are no global authorities that publicly release data on helium in the same vein as seen in other industries.

In 2013, this uncertainty led US congress to request the USGS to perform a national and global helium gas assessment. Given the scarcity and niche nature of helium, the USGS expects this to take many years. However, the BLM expects to update its view on helium resources in the US in a shorter timeframe. Discussions with the USGS indicate a report may be published by end 2018, but this is uncertain.

Intermediate results (from January 2016) are shown in Exhibit 7. Assuming 7.0bcf/year demand (foreseen in 2019), this would translate to 23 years of proven reserves for the US, moving out to over 200 years including probable reserves in the US and the rest of the world. While this may superficially seem generous, these resources have to be developed, and this is not a given. Development of the helium is hugely dependent on the development of the gases that it exists alongside.

Transparent reporting of reserves and resources is not helped by the tiny concentrations found in many natural gas fields. It exists in such small quantities in many natural gas reservoirs that it is often overlooked given the small volumes/revenues it may represent vs natural gas. Helium has largely been a profitable by-product but not valuable enough to justify standalone developments (nor in the US of a statute to allow federal land lease).

In most fields, large quantities of natural gas (or CO_2) have to be extracted for commercial volumes of helium to be separated, and as a result, the commerciality of a helium project largely rests entirely away from the helium itself. As natural gas prices have declined in recent years (particularly in the US), projects have become less attractive and fewer projects have been sanctioned.

- The current surfeit of LNG supplies (and low prices) has led to postponement of large LNG projects (such as Browse) from which other helium could have been recovered.
- The low oil prices also mean that CO_2 flooding (from which helium can be extracted) has become less economic, reducing the demand for CO_2 . A number of projects have been put on hold.
- Shales cannot trap helium, which means that supplies have not benefited from the massive shale boom in the US, and the economics of shale gas production have the potential to price out conventional natural gas development (which may contain helium) in the US in the medium term.

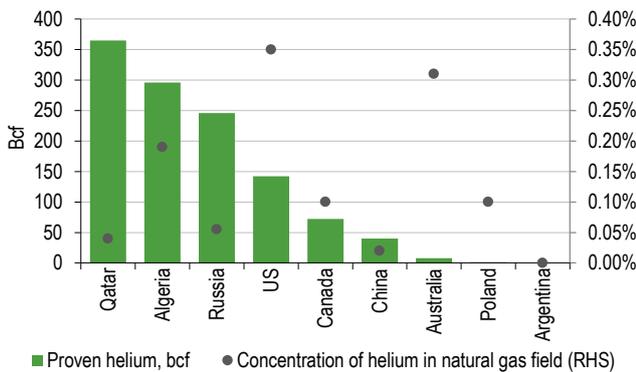
In the US therefore, helium development may have to be driven by helium economics, necessitating higher helium prices to incentivise investment.

⁷ Flow of Mantle Fluids Through the Ductile Lower Crust: Helium Isotope Trends, B Mack Kennedy, Matthijs van Soest, 2007 (Science)

Kinder Morgan has a JV with Air Products (announced in 2013, started in October 2015) at Doe Canyon to extract helium from the CO₂ stream going to EOR projects (the plant is designed to produce 230mmcf/year of helium but is probably producing closer to 140mmcf/yr now), while IACX has a number of plants extracting helium from a number of small natural gas fields. Standalone helium separation (of the type that Canadian companies are contemplating for example) requires high helium content to be commercial (which is around 0.5%, but is highly dependent on gas volumes and other gases in the stream).

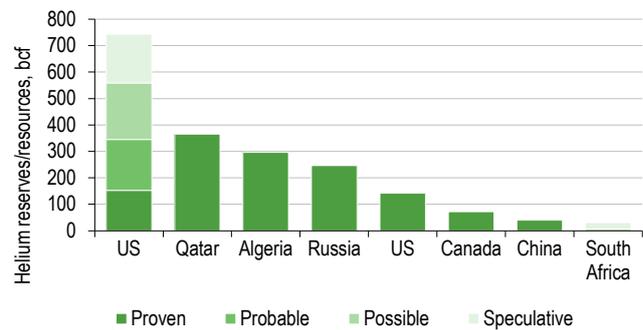
In the rest of the world, helium production comes from large LNG schemes in Qatar and Algeria. A planned development of a massive Russian gas field, Amur (with material associated helium), has a risk of delays, we think.

Exhibit 6: Reserves of helium globally, including from natural gas fields



Source: BLM – ‘Determination of fair market value pricing of crude helium’. Note: Proven helium reserves are given in bcf. Estimates made in 2013.

Exhibit 7: USGS summary of global helium resources (intermediate findings)



Source: USGS Mineral Commodity Summaries, January 2016. Note: Converted using a 36cf/m³ ratio. South Africa (Regergen) 6.2bcf 3P and speculative 24.3bcf.

Pricing context (BLM-era to future)

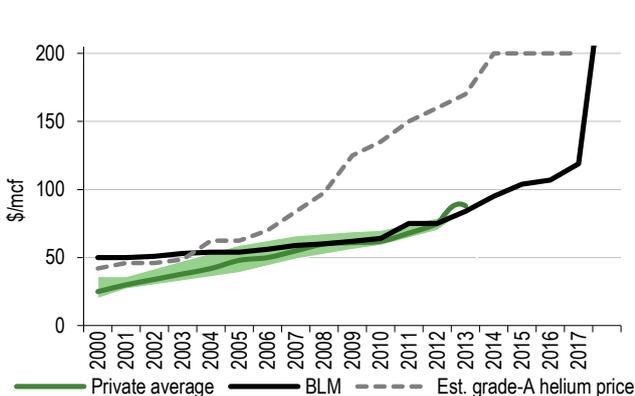
The US government-mandated sell-off of the helium reserve was designed to recoup the investment (plus interest) on the helium reserve and get the government out of the helium market. Initially the price set on the crude from the reserve was purely to cover the costs of the US\$1.33bn debt, and was well above the prevailing crude helium market price at the time, as can be seen in the years 2000-05 (Exhibit 8). Helium was a profitable by-product of natural gas production, and as such prices had little reference point, while its private nature meant price discovery was difficult.

With the advent of the BLM auction process, a partially market-driven price became public and a reference point for private contracts. It is clear that the private spigot prices are materially above the BLM crude pricing, with bulk liquid helium well above this level (not surprisingly given the refining that is required). Unsurprisingly, prices rise the closer you get to the consumer, with HP cylinder prices currently up to 10 times the wholesale price.

Recent price history

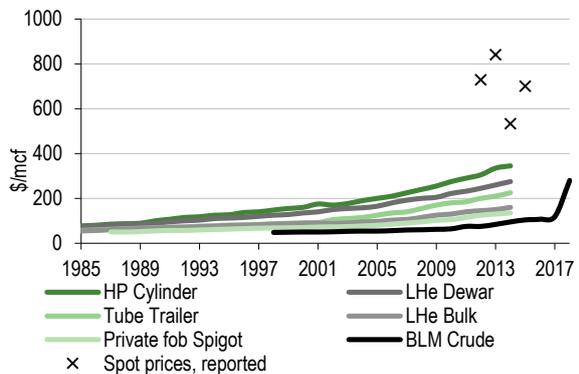
BLM prices are increasingly less informative given that the auctions will shortly end as the reserve is depleted. However, for reference, prices for BLM crude helium have risen substantially over the last three years. Cargoes are usually sold at a 99.999% purity or Grade 5, for which we have little pricing information. The lower Grade-A (or 99.99% purity) helium was priced at \$280/mcf in the BLM August 2018 auction. This was a significant increase over 2017, up 135% or \$160/mcf from a 2017 price of \$119.3/mcf. The auction provided helium refiners and marketers with an opportunity to accumulate inventory for future years and to increase their crude helium allocation for 2019. Due to the price attached to allocation rights, the auction price was materially higher than BLM's posted price for 2019 of 175\$/mcf.

Exhibit 8: Wholesale prices of private crude helium converged towards rising BLM pricing



Source: USGS. Note: All prices are for crude helium. The green range is the low to high estimates of private crude helium, and estimates past 2012 are not available.

Exhibit 9: Prices for different customers, from wholesale (BLM and private spigot at the bottom) to retail



Source: USGS – 'Determination of fair market pricing of crude helium', assorted sources for spot prices.

What is helium?

Helium is a unique industrial gas that exhibits characteristics both of a bulk, commodity gas and of a high-value "specialty" gas. Due to the high cost of extraction, helium use is restricted to relatively few, generally high-technology, applications.

Liquefied helium is distributed in bulk containers each carrying over 25,000 nm³ (cubic meter at normal temperature and pressure, defined as 20°C and 1 atmosphere). It is the only industrial gas

distributed in such large quantities on a global basis. However, only a handful of sources in the world produce helium.

Why is helium important?

Helium is a vital element in the manufacture of MRIs, semiconductors as well as being critical for space exploration, rocketry and high-level science.

How is helium made/extracted?

Helium is made either by the nuclear fusion process of the sun, or by the slow and steady radioactive decay of terrestrial rock, which accounts for the Earth's entire store of the gas.

However, because the cost of removing helium from the air is significantly higher than that of procuring it from alternative sources, it is unlikely that air separation will be an economic source of helium in the foreseeable future. Instead, almost all commercially available helium is extracted from a small number of natural gas reservoirs with relatively high concentrations of helium. In the last several years, as natural gas liquefaction facilities have come on line, the amount of potentially recoverable helium has therefore increased.

There is no way of manufacturing helium artificially, and practically all of the world's reserves have been derived as a by-product from the extraction of natural gas, mostly in the giant oil and gas fields of the American South-west, which historically have had the highest helium concentrations.

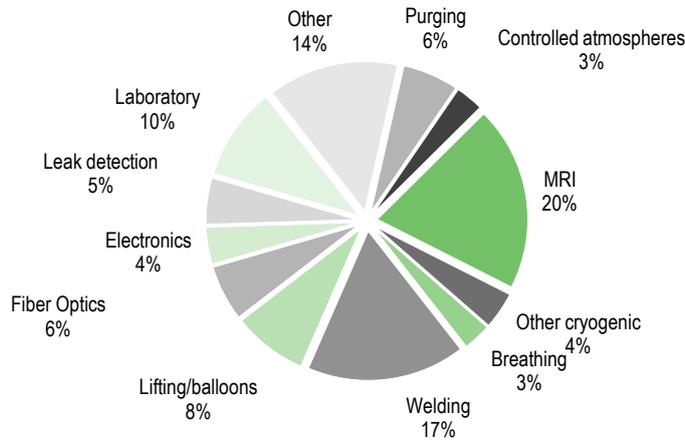
For large-scale use, helium is extracted by fractional distillation from natural gas, which has historically contained as much as 7% helium. Since helium has a lower boiling point than any other element, low temperature and high pressure are used to liquefy nearly all the other gases (mostly nitrogen and methane). The resulting crude helium gas is purified by successive exposures to lowering temperatures, in which almost all of the remaining nitrogen and other gases are precipitated out of the gaseous mixture. 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.

In a final production step, most of the helium that is produced is liquefied via a cryogenic process. This is necessary for applications requiring liquid helium and also 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.

Uses of helium

Key uses of helium include Magnetic Resonance Imaging (MRI), welding, lifting, purging and laboratory use. A recent breakdown of uses from Kornbluth Consulting is shown in Exhibit 10 below.

Exhibit 10: Demand constituents for helium



Source: Kornbluth consulting www.kornbluthheliumconsulting.com

For some applications, other gases can replace helium, but other applications rely critically on helium’s unique properties, and there are no alternatives. Applications in the first category, where substitutes for helium might exist, include the following:⁸

- Lifting. For these uses, where low density is the only requirement, hydrogen is sometimes substituted if safety concerns can be met.
- Welding. Here, chemical inertness is the key property. For processes such as gas tungsten arc welding - a critical process applicable to reactive metals such as stainless steel, titanium, aluminium, and others in high-value, high-reliability applications -Europe mostly uses argon, while the United States uses helium.
- Semiconductor and fiber optics manufacturing. In these applications, high thermal conductivity is the important property. Often, hydrogen may be substituted.

In the above applications, economics, market conditions, availability, safety, and legislation can influence the choice among helium and other gases. In contrast, other applications require the unique properties of helium, typically relying on the extremely low boiling point of liquid helium to achieve a desired result. These applications include the following:

- Purging. Here, entities such as the National Aeronautics and Space Administration (NASA) and the US Department of Defense (DOD) must purge liquid hydrogen (LH2) and liquid oxygen (LOx) fuel tanks or systems that may be at liquid air temperatures or colder. Although gaseous hydrogen might have the right physical properties for use in LOx systems, its reactivity with oxygen precludes its use. Nitrogen is not desirable because nitrogen might contaminate the LOx. In LH2 environments, all gases other than helium and hydrogen would freeze, clogging fuel lines and systems and rendering the rocket engines non-functional.
- Superconductivity. One such use is in the superconducting magnets that all medical magnetic resonance imaging (MRI) machines employ. Current materials and technologies dictate that only helium can act as the crucial refrigerant.
- Basic research. Here, no other substance can be used as a refrigerant to achieve temperatures from 4.2 K above absolute zero down to millikelvins (thousands of a kelvin) above absolute zero.

⁸ Demand for Helium, Selling the Nation’s Helium Reserve, 2010 (nap.edu)

Exhibit 11: Summary of the properties and applications of helium

Property	Application
Lowest boiling point; does not solidify at atmospheric pressure	Liquid cooling of low temperature superconductors Purging liquid hydrogen systems
Second lightest element (after hydrogen)	Lifting medium for balloons, airships
Smallest molecular size	Leak detection
Chemically inert	Carrier gas – analytical, semi conductor
Very high specific heat and thermal conductivities	Gaseous cooling – fiber optics
Radiologically inert (no radioactive isotopes)	Heat transfer medium in fusion reactors
Highest ionisation potential	Metal arc welding – aluminium Plasma arc welding – titanium
Extremely low solubility	Deep sea diving gases
Very high sonic velocity	Metal coating
Superfluid below 2.2k	Cooling of low temperature superconductors

Source: Air Products and Chemicals Inc, Paper on “Challenges to the Worldwide Supply of helium in the next decade

Specific applications

Magnetic resonance imaging

Magnetic resonance imaging (MRI) is a widely used non-x-ray-based technique that provides extremely detailed internal in vivo images of body structure. An MRI apparatus uses a strong magnetic field to align the nuclear magnetic spins of hydrogen atoms in a body, then drives the aligned hydrogen atoms at radio frequencies, and after detecting the properties of the aligned, driven atoms, uses tomography to process the density- and environment-dependent response, producing a non-invasive three-dimensional image. The only commercially viable source of the large (0.5-3.0 tesla) magnetic fields required for this process is a superconducting magnet contained in a cryostat—a container designed to thermally insulate the liquid-helium-cooled superconducting magnet and the liquid helium source.

MRI relies on helium to regulate the powerful magnets needed to create MRI scans, which are cooled to minus 452 degrees Fahrenheit (minus 269 degrees Celsius). Indeed, the fact that helium has the lowest boiling and melting points of all the chemical elements — liquid helium is the only liquid that cannot be solidified by lowering its temperature — is what makes it so irreplaceable in so many industries.

The availability of helium at low prices and the stability of the market over the years has contributed to the rapid growth of MRI as a diagnostic tool.

At the present time there is no substitute for helium in this application⁹, notwithstanding that manufacturers of MRI systems have adapted or developed technologies that significantly decrease the consumption of liquid helium to operate these devices.

⁹ Demand for Helium, Selling the Nation’s Helium Reserve, 2010 (nap.edu)

Fundamental research¹⁰

Large-scale facilities are characterised by signature research tools used by many, often hundreds of, research groups. All such facilities located, for example, in the United States are supported with substantial US government funding and typically are located in national laboratories. The principal use of helium in these laboratories is to cool superconducting equipment for accelerators, particle detectors, and research magnets.

These accelerator facilities rely on superconducting magnets, cavities, and other superconducting components to produce and maintain high-energy particle beams. The superconducting components used in these facilities must be kept at very low temperatures, which in practice can be achieved only with liquid helium because of its low boiling point and high thermal conductivity. Large amounts of helium are often required at start-up in particle accelerators because liquid helium must be distributed along the entire length of the machine, which can be many kilometres.

Helium is also used in large-scale research laboratories because it exhibits unique superfluid properties below 2.17 K (achieved by pumping to low pressure), including extremely high thermal conductivity. This makes it useful for cooling superconducting radio frequency (SRF) cavities. A significant supply of helium is required for the development of such cavities for current and future accelerator projects because the complexity of the systems and the present cost of helium make it most practical to vent used helium gas to the atmosphere.

Small laboratories rely on liquid helium to operate diagnostic and measurement tools. Among the more important of those helium-cooled tools are superconducting quantum interference devices (SQUIDs). SQUIDs measure extremely small magnetic fields and are used in a wide range of studies, from biological research on brain activity to the assessment of materials characteristics. Devices used in astronomy and astrophysics studies also depend critically on liquid helium.

Industrial cryogenics

Liquid helium is used in the manufacture of semiconductor single-crystal boules, where helium-cooled superconducting magnets mechanically stabilize the melt during the pulling process. Helium is critical to this process and, by extension, to the semiconductor industry. In addition, some fabrication facilities require processing in ultraclean environments or under ultrahigh vacuum. Cryopumps (being vacuum pumps that trap gases and vapours by condensing them on a cold surface) cooled to liquid helium temperatures are one of the more widely used means of reaching those high vacuum conditions.

Optical fibre manufacturing

Helium is a critical element in the production of optical fibers, an important component of the telecommunications industry. Helium accounts for a small percentage of the total cost of fiber production.

Semiconductor processing

The high thermal conductivity of helium gas has been incorporated into the manufacturing process for plasma screens.

Chromatography

Helium is used for chromatographic separation, predominantly as a carrier gas. Helium is ideal for gas, gas-liquid, and gas-solid chromatography because it is chemically inert and diffuses rapidly. Chromatographic and gas-chromatographic systems are used in the pharmaceutical industry for drug analysis and purification, derivatization, and separation; in the food and beverage industries

¹⁰ Demand for Helium, Selling the Nation's Helium Reserve, 2010 (nap.edu)

for separation and analysis; in environmental assessments for air, water, and soil toxin analysis; in medical diagnostics for analysing the presence of gases in the bloodstream, as an example; and in explosives forensics and petroleum testing. There are no obvious substitutes, given the current state of technology.

Weather, defence and other lighter-than-air applications

As helium is lighter than air, it can be used to inflate airships, blimps and balloons, providing lift.

Although hydrogen is lighter than helium, helium's chemical inertness makes it safer to use as it is non-flammable, and so it has replaced hydrogen in most lifting applications. The party-balloon industry uses significant amounts of helium, as do weather balloons.

Lighter-than-air vehicles are also used for advertising and transportation purposes, an example of which is the Goodyear blimp.

Divers and others working under pressure use mixtures of helium, oxygen and nitrogen to breathe underwater, avoiding the problems caused by breathing ordinary air under high pressure, which include disorientation.

As well as being used to clean out rocket engines, helium is used to pressurise the interior of liquid fuel rockets, condense hydrogen and oxygen to make rocket fuel, and force fuel into the engines during rocket launches.

Because of its low viscosity and large diffusion coefficient, helium is an excellent leak detector gas and is widely used as such in science and technology. By way of example, helium is used in solar telescopes to prevent the heating of the air, which reduces the distorting effects of temperature variations in the space between lenses.

Praxair Linde merger

Industrial gas giants Linde and Praxair agreed an all-share merger in principle in December 2016 and have since been divesting assets to satisfy the requirements of the US Federal Trade Commission (FTC). An agreement to dispose of businesses with a combined US\$4.3bn in sales, or €1.1bn in EBITDA, was struck with anti-trust regulators and the merger received a final green light from regulators in October 2018.

The merger is expected to complete by 31 March 2019 with 92% of shares tendered to date. The combined group (named Linde plc) is expected to be larger than rival Air Liquide (which recently combined with Airgas) at combined revenues of US\$29bn and a market value of US\$90bn, and will be a dominant force in the global supply of helium.

Appendices

US Helium Extraction Act 2017

The Helium Stewardship Act (2013) set a timetable for the release of the US national helium reserves to be steadily sold off, but did little to incentivise longer-term helium exploration. It arguably had the opposite effect; by selling a large percentage of global demand per year to a small number of players, it may have reduced prices below the market equilibrium. With only a few years to go before the reserve is exhausted, steps are now being taken to motivate helium exploration again (on federal lands).

Currently, the Mineral Leasing Act (1920) only allows companies to retain acreage if they are extracting oil or natural gas. The Helium Extraction Act of 2017 is intended to extend these rights to

companies looking to extract helium, thereby taking a further step towards allowing focused helium exploration. As the sponsor of the bill (Paul Cook: R-CA) stated in the House on 1 November 2017, '[u]nder existing law, the Mineral Leasing Act only permits helium extraction as a by-product of an existing oil or natural gas lease. As a result, if oil and gas production on a Federal site is not economically viable, the lease will expire, regardless of the revenue brought in by helium sales. The Helium Extraction Act of 2017 would correct this error and authorize helium production activities where economically viable.'

The act was passed by the House (Committee) without amendment in January 2017 and subsequently referred to the Senate Energy and Natural Resources Subcommittee on Public Lands, Forests and Mining in August 2018. We do not expect this to have a material effect on helium for a number of years, but it is nevertheless a positive step.

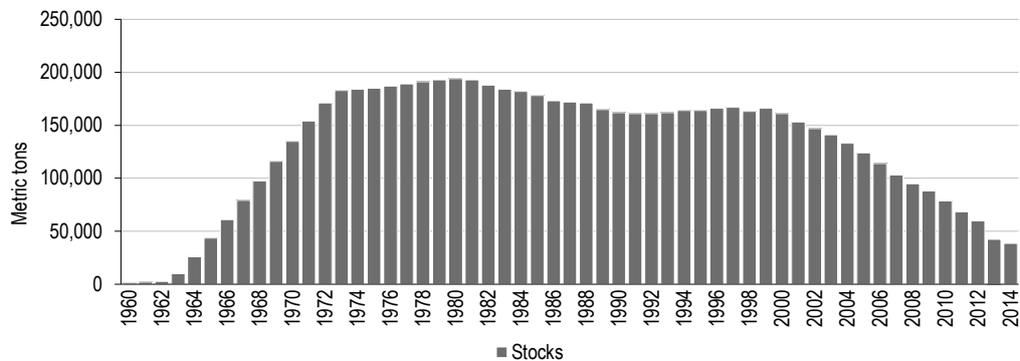
History of the BLM and the Federal Helium Reserve

In 1925, the US government started to store helium in the Bush Dome Reservoir in Texas (also known as the Cliffside field), in order to retain reserve and flexibility on the scarce resource. Initially set up as a strategic supply for airships, the focus moved to space exploration. As more gas was required for the reserve, the 1960 Helium Conservation Act allowed for a 425 mile pipeline to be built connecting a number of natural gas fields in Texas, Kansas and Oklahoma with high helium content to the Cliffside field, where it was injected for storage. The act also funded construction of five large natural gas processing facilities that produced crude helium as a by-product for sale to the US Bureau of Land Management (BLM). Later, the government looked to increase the stockpile further, and this resulted in the huge growth of reserves over the next decade, as seen in Exhibit 12. During this period, the government was the major buyer of helium.

This growth was funded by a debt to the US government, which had grown (with help from high interest rates and inflation) to US\$1.33bn by 1996. With the 1996 Helium Privatization Act, Congress sought to recoup this amount through a controlled sale of the resource to the market, starting a gradual depletion of the resource since then. As can be seen in the supply/demand charts, this is a significant percentage of global supply.

It is clear that this supply will be exhausted soon. In October 2013, Public Law 113-40 (Helium Stewardship Act) was passed, requiring the BLM to auction volumes off (to any qualified bidder), a revision to the previous set sales price approach. In 2019, or once the resources gets to 3bcf, this process will stop (the 3bcf will be reserved for government use). Once privately owned crude helium has been delivered, the world helium market will no longer have the flexibility that was historically provide by the BLM reserve.

Exhibit 12: Stocks of helium in US strategic reserve



Source: USGS

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