# Endangered helium: bursting the myth

Contrary to recent reports, we are not about to run out of helium any time soon, say **Richard Clarke**, **William Nuttall**, and **Bartek Glowacki**

**The Earth just cannot hold on to its helium. If it could, the noble gas might comprise more than 10% of the atmosphere and we would not be writing about a helium supply problem. For nearly a century chemical engineering has enabled helium to underpin our increasingly technological world. A new US helium law may have averted a crisis, but there is still much to be done if helium's vital role is to continue.**

Although helium is being generated underground as uranium and thorium atoms decay, practically all of the Earth's helium – 99.997% to be precise[1] – has escaped into space through a peculiar mechanism called ion outflow. Most of what remains is in the atmosphere[2]. The 3.8bn t of helium in the air would keep helium users going indefinitely. But at a concentration of just 5.2 ppm, meeting the world's helium needs of 30,000 t/y from the air would require a fleet of gas plants as big and as energetic as power stations.

Instead, we must make do with the 8m t the US Geological Survey estimates is buried in the Earth's crust. That substantial resource has supplied the world with abundant helium. It is a story that started in 1903, at a dud natural gas well in Dexter, Kansas. The disappointed townspeople called it "wind gas"; it had a composition of 72% nitrogen, some methane, and 1.84% helium. And that might have been the end of the matter, had it not been for two unrelated events.

The first was that helium was also found to occur in many other natural gas wells in Kansas (though nothing like as much as was later found in the giant, but now declining, Hugoton-Panhandle field). The second event occurred in 1914, early in the First World War, when first the British, and later the Americans, became convinced that Zeppelins were being filled with helium (in fact, German airships were lifted by hydrogen right up until the Hindenburg disaster of 1937).

From the 1920s onwards an all-out US national programme, for a long time led by chemical engineer Clifford Seibel, sought to find helium-bearing gas fields and co-produce the helium for strategic purposes. As a lift gas, helium played a vital role in the Second World War, filling airships that were used to guard the Atlantic convoys.

As new applications emerged in the 1950s, helium purity was much improved through the use of activated carbon; when cooled by liquid nitrogen all gases except helium and neon are adsorbed. From the Helium Conservation Act of 1925 until the Helium Privatisation Act of 1996 (HPA) the US government dominated the helium market, and for half a century the US was the sole source of helium overseas.

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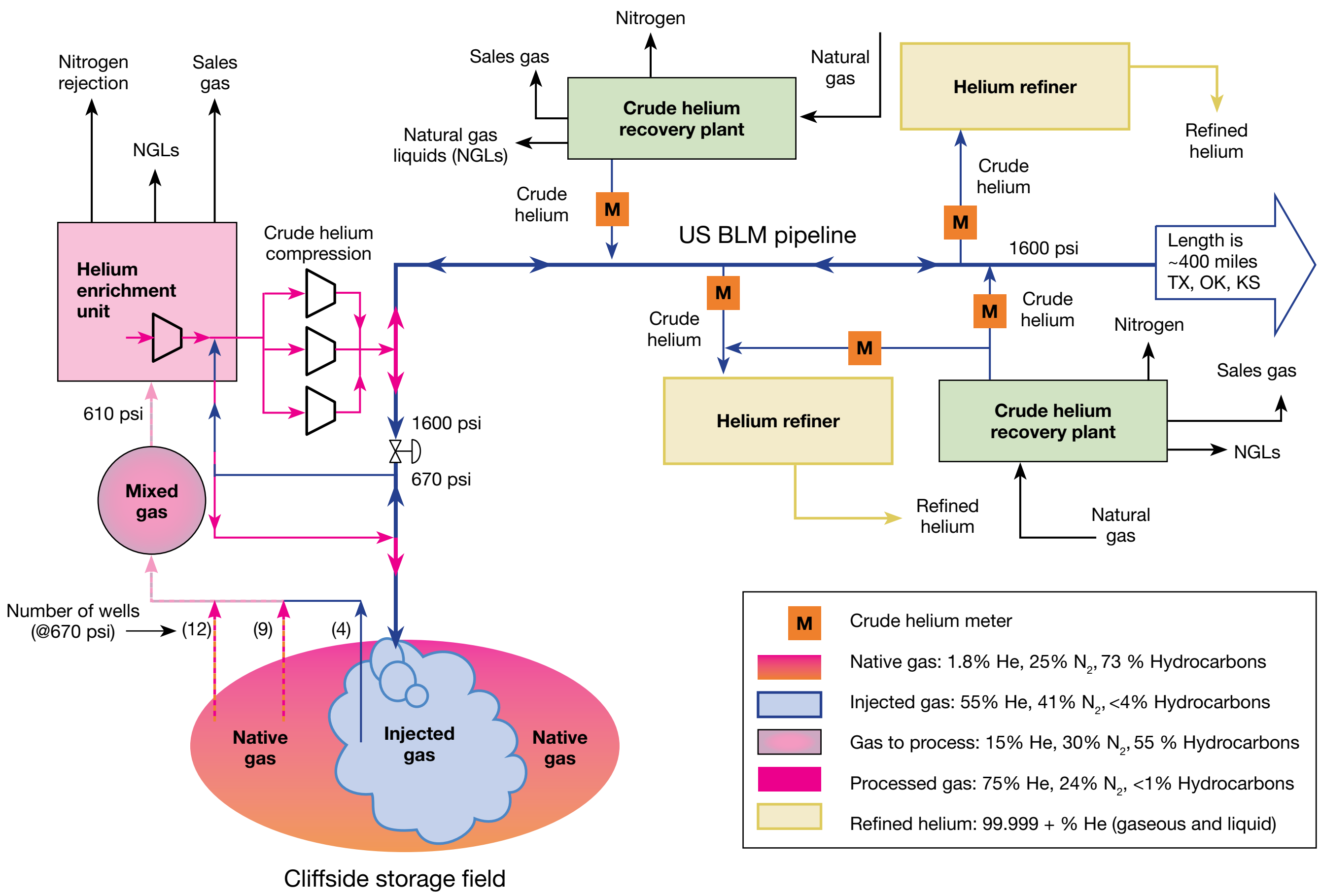
*Figure1: The crude helium enrichment unit helps extend the working life of the Cliffside reserve (source: Linde)*



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To meet the needs of the Apollo space programme and Cold War defence, the Federal agency responsible, the Bureau of Mines, now the Bureau of Land Management (BLM), built up a huge strategic stockpile of helium in Texas but, in doing so, incurred a US treasury debt of US$1.4bn. Two decades later, many questioned the need for a government stockpile of helium, and Congress was persuaded to pass the HPA. By October 2013 the HPA was obsolete: the debt had been paid, yet a third of the stockpile still remained.

Just in time, the Helium Stewardship Act (HSA) became law on 2 October 2013. It enables the BLM to carry on producing helium from the Cliffside helium reserve located near Amarillo, Texas. For now, one third of the world's helium supply originates from that reserve and the new Act requires part of the output to be auctioned.

As anyone who purchases helium knows, retail prices have seen annual double-digit percentage rises for nearly ten years. Yet some scientists, notably Nobel Laureate Robert Richardson, have argued that today's prices are not high enough to preserve vital supplies for research. This is why the HSA has a provision to hold back a part of the helium stockpile for government and research use in the 2020s.

Even though the HSA is now in place there needs to be a reality check. The Cliffside field has been producing flat out since the HPA came into effect in 1998 and the reservoir pressure is falling. New compressors are required to keep the crude helium enrichment unit operational (see Figure 1). Other production measures may be needed to allay concerns about water flooding the reserve. Output from Cliffside is expected to decline steeply until around 2020, after which the remaining reserves will be allocated by the US government.

## where next?

If Cliffside and the Hugoton-Panhandle fields have had their heyday, where will tomorrow's helium come from? Significant reserves are being produced in Wyoming and there is much activity outside the US. Since the mid-1990s it has been clear that low-grade helium sources can be produced from natural gas when it is liquefied in an LNG plant. Helium refineries attached to such plants in Algeria (Arzew started up in 1995), Qatar and at Darwin in Australia will together produce as much helium as Cliffside once did.

The Ras Laffan 2 helium plant is now fully operational. Crude helium from Qatar's LNG plants is purified and liquefied in the world's largest liquefier built by Air Liquide. Hundreds of 40,000 l cryogenic ISO-containers are used to ship liquid helium all over the world, and increasingly to Asia, where there is great demand for helium in high-tech industries. The very pure liquid is decanted or compressed in trans-fill facilities (see Figure 2[3]) through which the needs of both liquid and gas users are met. This is a delicate balancing act and it is here that gas for party balloons is bottled, whether from recycled helium or from incoming gas that might otherwise go to waste.

Unconventional sources of helium are beginning to make an impact on the supply side too. In several US states there is small-scale helium production from reserves that are predominately nitrogen[4]. There the drilling target is helium as there is little or no fuel value in the well gas. During the coming decade Russia expects to open up huge natural gas fields in Siberia that contain up to 0.58% helium[5]. Helium extraction and storage is a priority for Gazprom. Other potential sources include Iran's South Pars field, India's geothermal wells[2]; Arizona's St John's $CO_2$ field; Shell's Pearl gas-to-liquids project in Qatar; the Mount Kitty field in central Australia and even Italy where its natural gas grid contains up to 0.1% helium that can be traced to gas imported from Algeria[6]. In Colorado, another $CO_2$ reserve at Doe Canyon is expected to start producing helium by 2015. Nevertheless, the global helium supply situation will remain quite challenging over the next few years.

## not just for balloons

Perhaps stimulated by its apparent abundance, helium has become an essential, but mostly unseen, component of modern technology – ranging from welding, to leak detection, rockets and semiconductor fabrication. Much of it (29%) is used in cryogenics (see Figure 3) – and 75% of that is used to cool magnetic resonance imaging (MRI) machines.

In the UK, the upper Thames Valley near Oxford is a hotspot for cryogenics such is the diversity and extent of helium-using science and industry there. The Siemens MRI factory alone produces 30% of the superconducting niobium-titanium (Nb-Ti) magnets used in MRI machines found in hospitals around the world. Engineers there focus on ways to minimise each machine's helium use. Helium demand persists, however, because the MRI market is growing strongly, such is the diagnostic capability of these machines.

Helium re-condensers, such as the Gifford-McMahon and pulsed-tube machines, operate at -269°C. They ensure

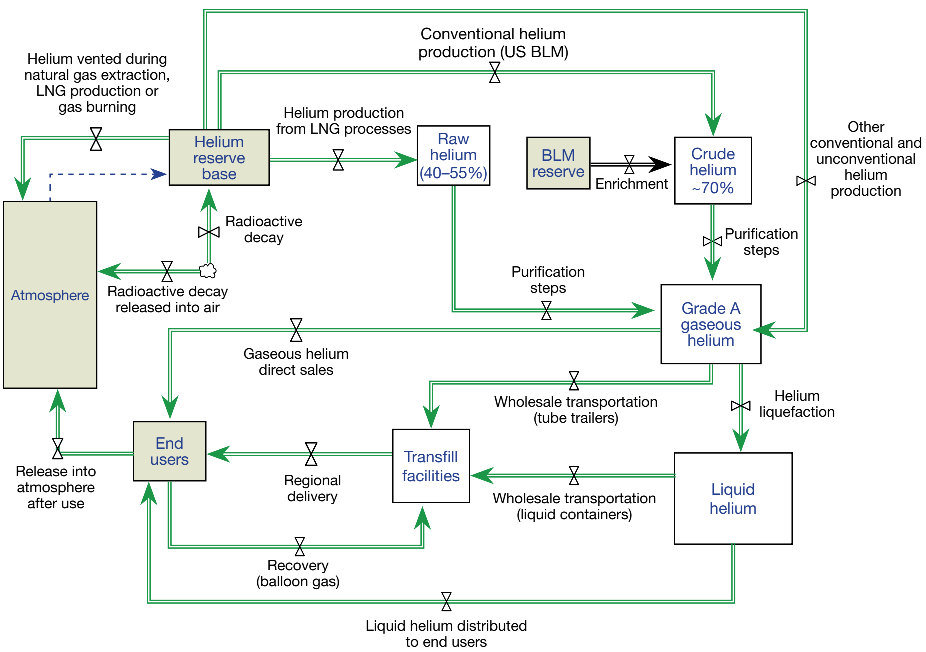



*Figure 2: The upstream helium market, showing how helium sources connect to end-users (Cai et al[3])*

that the liquid helium bath in a modern MRI machine needs only be filled once every 5–10 years. As leak rates fall, it is the helium inventory (per machine) that could dominate demand.

Since 2000 there have been three helium crises when the supply chain has become bottlenecked, and we are in one right now. But let us be clear. These are short-term shortages caused by upstream market disturbances, not long-term problems. Partly these disruptions can be traced back to the HPA's pricing mechanism and the BLM's large market share. This, some argue, has dissuaded helium refiners from entering or staying in the market.

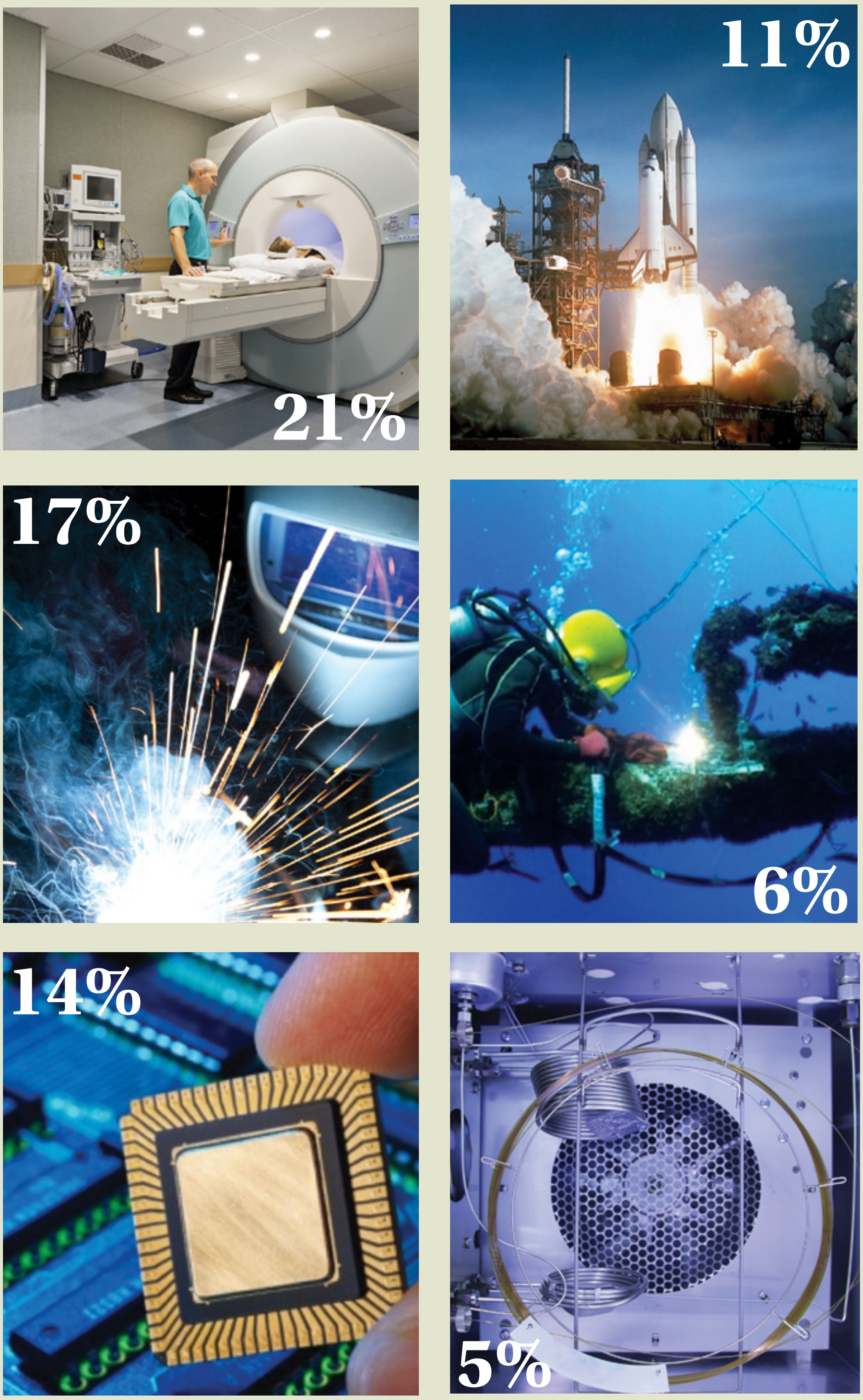
The world will not run short of helium for many decades to come, but nevertheless now is the time to start to address the serious long-term problems that will hit helium supply when the world eventually moves away from fossil fuels.

There is also the 'shale gas effect'. Shale gas contains virtually no helium. As more natural gas has come into the market, US gas prices have fallen to a point recently where it has not been economic to develop new shale gas wells. A side-effect of these low prices is that some conventional gas production has become uneconomic. This is what has happened at the Keyes field in Oklahoma. In the 1960s the Keyes plant was one of the most important helium sources in the world. Now production has stopped. Of course, the US may start exporting LNG but whether this will bring more helium to the market remains an open question, even if natural gas prices rise again.

## wasted opportunity

A fact that surprises many helium users is that about half of all helium molecules unearthed during natural gas production never make it to the market. This is called venting. There are two main reasons for this. Firstly, helium is nearly always co-produced with natural gas, so the requirements of the 1,000-times-bigger natural gas industry takes precedence. Secondly, if the helium concentration in natural gas is low it may not be economical to recover it. In Qatar the concentration is around 0.04%, but historically 0.3% was considered the breakeven point. In the LNG process most of the heavy components (ethane, propane etc) are removed and the methane is condensed. The main condenser has a purge line to prevent inert gas blanketing, and it is this stream, sometimes rich in helium, that is then purified and liquefied for export.

In future, large-scale processes such as air $CO_2$ capture may be developed. Possibly they could be adapted to economically co-extract atmospheric helium in industrial quantities. Willem Keesom, who in 1926




## Figure 3: The many global uses of helium

**Magnetic resonance imaging** 21%
(other cryogenic applications including physics research 8%)

**Pressurisation and purging** including rockets 11%

**Welding** 17% **Leak detection** 5%

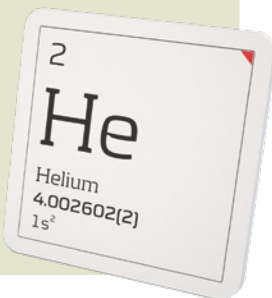
**Controlled atmospheres** including diving 6%

**Semiconductors, optic fibres** (heat transfer) 14%

**Analysis including chromatography** 5%

**Party balloons** 8% **Weather balloons** 5%

*(source: bit.ly/LGYh8J)*



**As the conventional US helium reserves diminish this decade, and in all likelihood the US starts importing helium, it is critical that the best helium recovery technologies are brought into production in the natural gas industry. Helium that is not separated and stored at source is not preserved.**

succeeded in freezing helium, mooted such an idea in his 1942 treatise about helium[7].

He believed that "helium reserves will become critical in a future that is not too far remote". Cryogenic air separation (ASU) technology provides one such route, and companies like Ukraine's Iceblick have developed processes that purify the ASU purge gases krypton, xenon, neon and helium. The main challenge is that even in a large ASU that produces, say, 1,000 t/d of oxygen the helium output would be just 1 $m^3$/h. Today, in at least one ASU where neon is a by-product, helium is also produced.

In practice, a crude helium-neon mixture would be compressed and transported to a central rare gas refinery. Richard Clarke and Roger Clare[2] estimate that Grade A (99.996%) helium could be produced by ASUs for around US$42,500/t (US$200/thousand $ft^3$), similar to today's wholesale price. But even if every large 'over-the-fence' ASU project recovered helium, the cumulative total volume produced over a 20-year period would only amount to 1 or 2% of current helium demand. However, the trend towards super-sized ASUs might enable the nascent 'oxy-fuel' combustion industry to develop. In that case, helium from air may one day produce ~3,000 t/y of helium.

As the conventional US helium reserves diminish this decade, and in all likelihood the US starts importing helium, it is critical that the best helium recovery technologies are brought into production in the natural gas industry. Helium that is not separated and stored at source is not preserved. At the same time dominant users, like the MRI industry, will continue their quest to become virtually helium independent.

Many researchers are now focussing on new materials that work at higher cryogenic temperatures, on processes that use less helium and on designs with less helium inventory. General Electric[8] has been investigating ways to significantly reduce the helium inventory of MRI magnets because Nb-Ti is still the superconductor of choice for MRI. It is cheap, malleable and effective.

Another approach being explored at the University of Cambridge is to use liquid hydrogen-cooled superconductors such as $MgB_2$ for combined power and hydrogen delivery to cities[9]. If a pressurised helium loop is used to transfer heat from a superconductor environment to a liquid hydrogen bath, then indirectly-cooled hydrogen technologies could break into the medical market as well[10]. The Open University is currently researching pathways to a future hydrogen economy including those in which cryogenic liquid hydrogen enters the market as a substitute for liquid helium.

In other industries (such as semiconductor and optic fibre manufacture) helium is often used just once and then vented to atmosphere. There is a real challenge to develop cost-effective recycling systems where the recovered helium purity is consistently good enough to expose to high value production streams. For now, though, the constant purity of liquid helium usually trumps recycling.

It is by no means clear which way the helium story will develop. Today, there are strong supply-side and demand-side changes taking place. Ultimately, helium from natural gas may be just a stepping stone towards an age where sustainable helium will come from the air. Meanwhile the medical imaging industry, in response to supply shocks and increasing price, is reducing its dependence on helium – even though global helium production continues to climb, as new and unconventional helium sources come to market. **tce**

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## further reading

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### Chemical Engineering Matters

The topics discussed in this article refer to the following lines on the vistas of IChemE's technical strategy document *Chemical Engineering Matters*:

Energy *Line 1*

Health and wellbeing *Lines 4, 11–12, 16–17, 27*

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