SCRREEN2

This project has received funding from the European

Union's Horizon 2020 research and innovation programme

under grant agreement No 958211.

Start date: 2020-11-01 Duration: 36 Months

Solutions for CRitical Raw materials - a European Expert Network

FACTSHEETS UPDATES **BASED ON THE EU FACTSHEETS 2020**

HELIUM

AUTHOR(S):

TABLE OF CONTENT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

HELIUM

OVERVIEW

Helium (chemical symbol He) is a chemically inert, noble gas. It is second lightest gaz after hydrogen and its boiling point is the lowest among all the elements (–269°C).

Helium constitutes about 23% of the mass of the universe and is thus second in abundance to hydrogen in the cosmos. Below 2.17 kelvin (-270.98°C), the isotope ^{4}He becomes a superfluid (its viscosity nearly vanishes). Most helium on Earth is ^{4}He, which is produced by radioactive decay deep inside the planet. Over hundreds of millions of years, it migrates up to the crust, where it is released through tectonic activity.

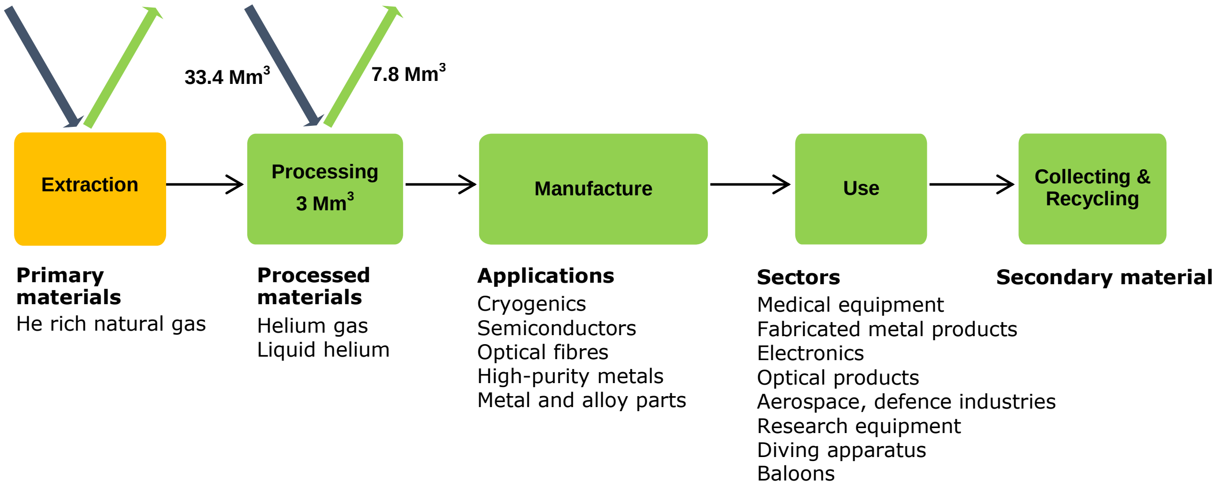

Figure 1. Simplified value chain for helium in the EU[1]

Table 1. Helium supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
26 453	USA 56%	5 830	22%	Qatar 35%	100%
	Qatar 30%			Algeria 27%	
	Algeria 8%			USA 24%	
	Australia 3%			China 4%	
	Russia 2%			UK 3%	

Prices: There is no global 'spot' market (price) for helium. The prices and their volatility vary significantly across helium markets, market segments and regions (cf. Elsner, 2018). The USA are the major producer of helium, and the US Bureau of Land Management (BLM) crude helium price has been used as basis for (long-run) helium contracts worldwide; its trend is correlated with the price trends observable at other helium markets (cf. Elsner, 2018; European Commission, 2020).

---

[1] JRC elaboration on multiple sources (see next sections)

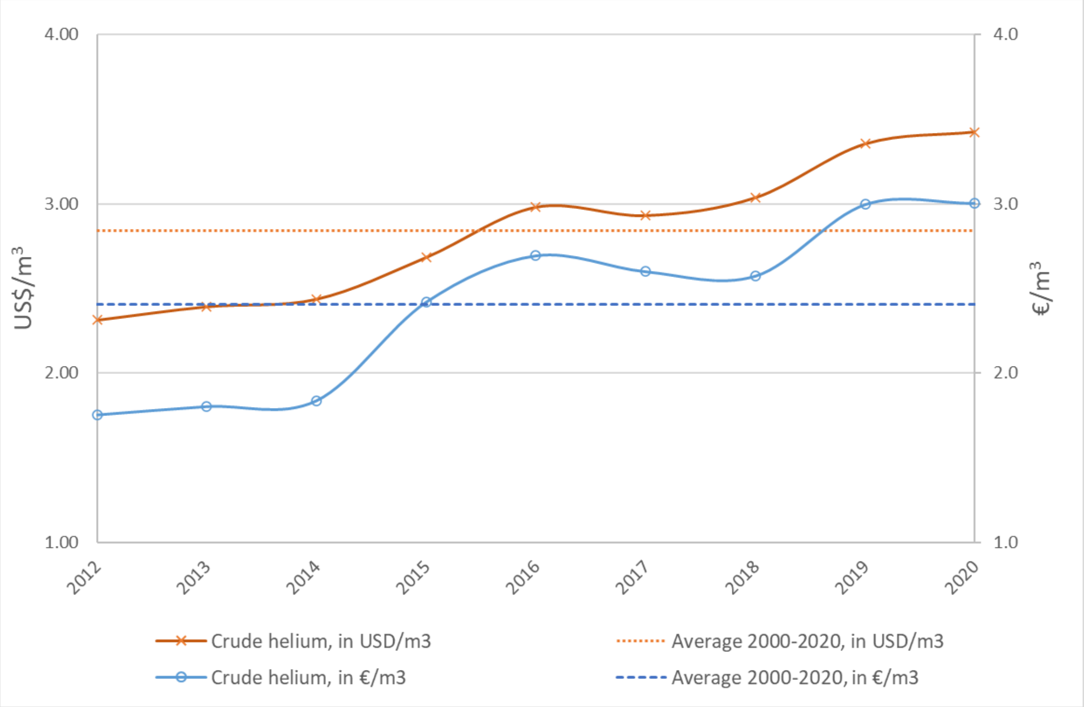

Figure 2. Annual average price of helium between 2000 and 2020 (USGS, 2021)2.

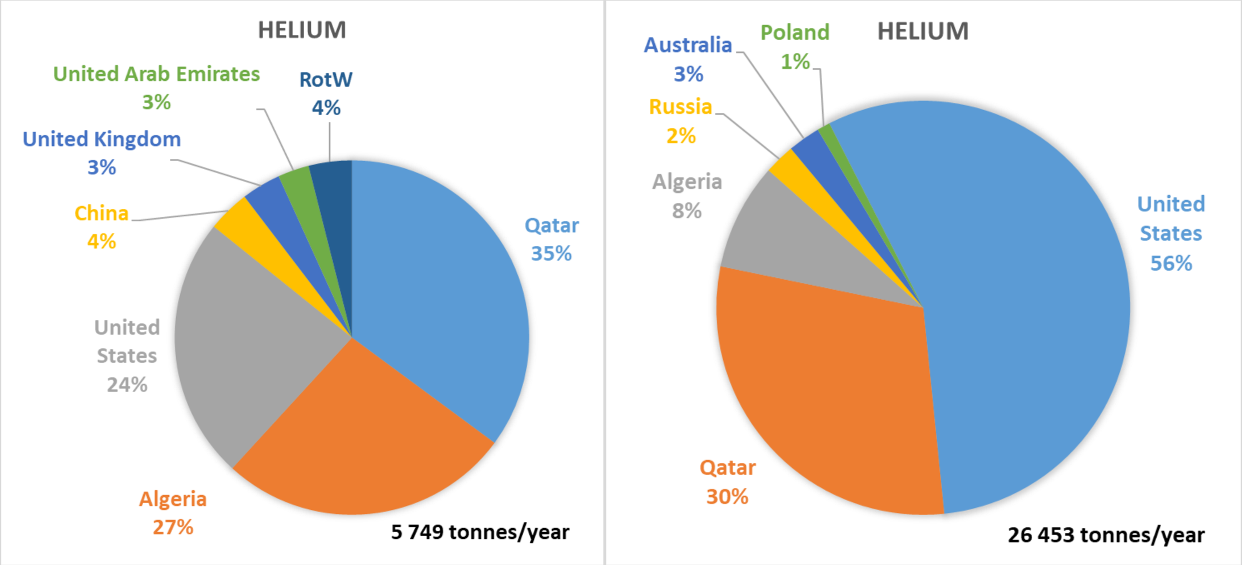

Figure 3. EU sourcing of helium (Eurostat 2022) and global mine production (USGS 2022) (average 2016-2020)

Primary supply: The world annual average supply of helium was stabilized around 160 Mm3 over the period 2016-2021 (USGS, since 2000) with the major producer being: USA (48%), Qatar (31.8%) and Algeria (8.7%) (USGS, since 2000). The US supply came from active natural gas wells and from the federal government

---

[2] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

National Helium Reserve which is an underground stockpile known as the Bush Dome Reservoir in the Cliffside gas field, in Texas.

Secondary supply: Cost issues and uncertainties about helium supply have led to the development of recovery and recycling technologies in certain end-user applications and an increasing usage of helium recovery and purification systems in both scientific R&D and industrial applications. However, USGS (2019) reports that helium used in large-volume applications is rarely recycled. Overall, the end-of-life recycling input rate has been estimated at 1%.

Uses: Helium has many uses, the key ones being as cryogenic liquid and as inert gas for work under controlled atmosphere

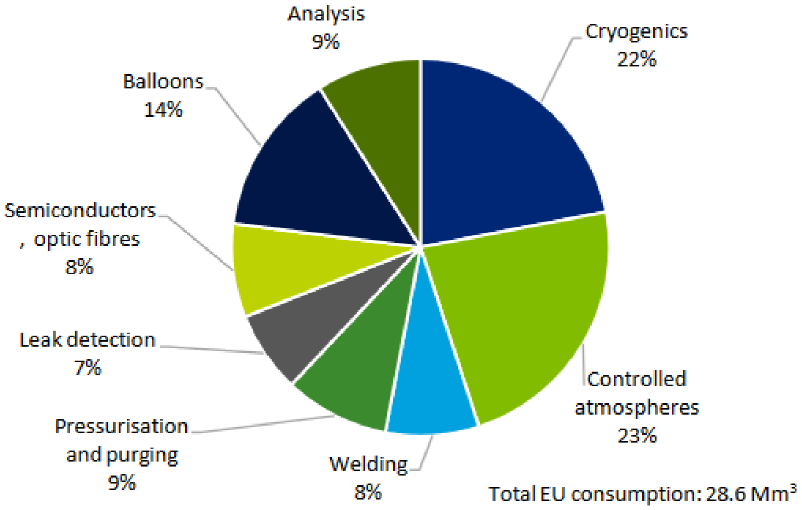

Figure 4: EU uses of helium

Substitution: Due to its unique properties (the best refrigerant, superfluidity below 2.18 Kelvin: viscosity-free fluid flow and extraordinarily high thermal conductivity, the highest ionization potential, very high specific heat and thermal conductivity, chemically and radiologically inert), helium can be substituted only in some of its applications.

Table 2. Uses and possible substitutes

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Controlled atmospheres	23%	Argon	50%	Similar or lower costs	Similar
Balloons	14%	Hydrogen	50%	Similar or lower costs	Similar
Analysis	9%	Hydrogen	1%	Similar or lower costs	Reduced

* EU end uses of helium. Average figures for 2012-2016 (CRM Experts, 2019). No data updates available from SCRREEN Expert and Validation workshops 2021, 2022)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

Other issues: Helium can be absorbed into the body by inhalation causing dizziness, dullness, headache and in severe cases suffocation. Contact with liquid helium may cause frostbite in the skin and eyes (LENNNTECH n.d.). Oxygen content in the area should be evaluated as diluting the concentration of oxygen in air below the levels necessary to support life (Occupational Safety and Health Administration of the United States Department of Labor 1970). No environmental issues were found in the scientific literature review. In addition, no LCAs studies could be found related to any life cycle stage or specific use of the material during the scientific literature review.

MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 3. Helium supply and demand (extraction) in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
26 453	USA 56% Qatar 30% Algeria 8% Australia 3% Russia 2%	5 830	22%	Qatar 35% Algeria 27% USA 24% China 4% UK 3%	100%

Historically, global helium supply has been limited to 4–5 (or even fewer) major helium producers supplying 80% (or more) of global and U.S. consumption (Kornbluth, 2015) (Kornbluth, Praxair-Linde merger—Major new helium competitor, 2017).

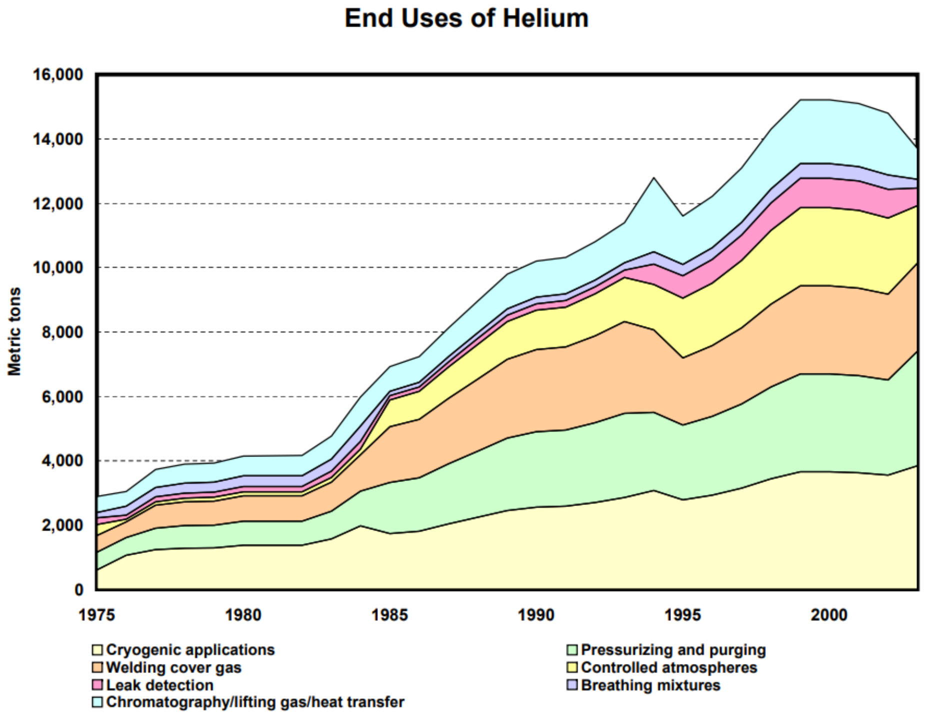

Figure 5. End uses of Helium. Reproduced from (USGS, 2005)

The helium market is segmented by phase, application, end-user industry, and geography. By phase, the market is segmented into liquid and gas. By application, the market is segmented into breathing mixes, cryogenics, leak detection, pressurising and purging, welding, controlled atmosphere, and other applications. By end-user industry, the market is segmented into aerospace and aircraft, electronics and semiconductors, nuclear power, healthcare, welding and metal fabrication, and other end-user industries. MRIs accounted for

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

20% of worldwide consumption; this was followed by use in analysis and spectrometry, 15%; a sector that included leak detection, pressurization, purging, and other uses, 15%; use as a lifting gas, 14%; the electronics and semiconductors sector, 11%; diving (for breathing mixtures), 6%; fiber optics, 6%; science and engineering research, 6%; welding, 5%; and use in controlled atmospheres, 2% (Anderson 2018)

Major players for helium globally include Air Liquide, Exxon Mobil Corporation, Gulf Cryo, Linde Plc, Messer Group GmbH, PGNIG SA, Renergen, Air Products and Chemicals, Inc., Gazprom, Iwatani Corporation, Matheson Tri-Gas Inc., NexAir LLC, Qatargas Operating Company Limited, Weil Group (Globe News Wire, 2021).

Helium is traded on contract based with long term (10+ years) take-or-pay supply contracts with industrial gas companies. Because of the nature of the supply and the contract structure of the industry, storage is particularly important in helium market, having also a big influence in helium price. Currently, the predominant economic source of helium is that contained in natural gas. Thus, substantial volumes of helium resources could be effectively lost to both current and future consumers, whenever the host natural gas is produced and the helium content is vented (Anderson, 2018). For the few helium resource owners with access to the U.S. Federal Helium Reserve (FHR), resource owners with access to the FHR, helium storage and re-extraction costs could be quite low, but storage costs could be much higher for most of the worlds helium producers. If alternative storage facilities are not developed before the FHR is closed to private consumers, it is unlikely that the global helium industry will be able to compensate for a sudden loss of one of its few major suppliers (such as Qatar) (Anderson, 2018).

EU TRADE

For the purpose of this assessment, helium is evaluated at the processing stage.

Table 4. Relevant Eurostat CN trade codes for helium

Mining		Processing/refining	
CN trade code	**title**	**CN trade code**	**Title**
		28042910	Helium

Figure 6 shows the EU trade in helium, in tonnes, between 2000 and 2021. In this period, the EU was a net exporter of helium; the year 2000 marks an exception. Imports of helium varied from 4 kt (2020) to 7.7 kt (2008), while helium exports ranged between 0.7 kt (2009) and 2.4k t (2019), when neglecting the peak of 5.3 t in 2000 (the numbers in parentheses indicate the years for which the quantities were reported).

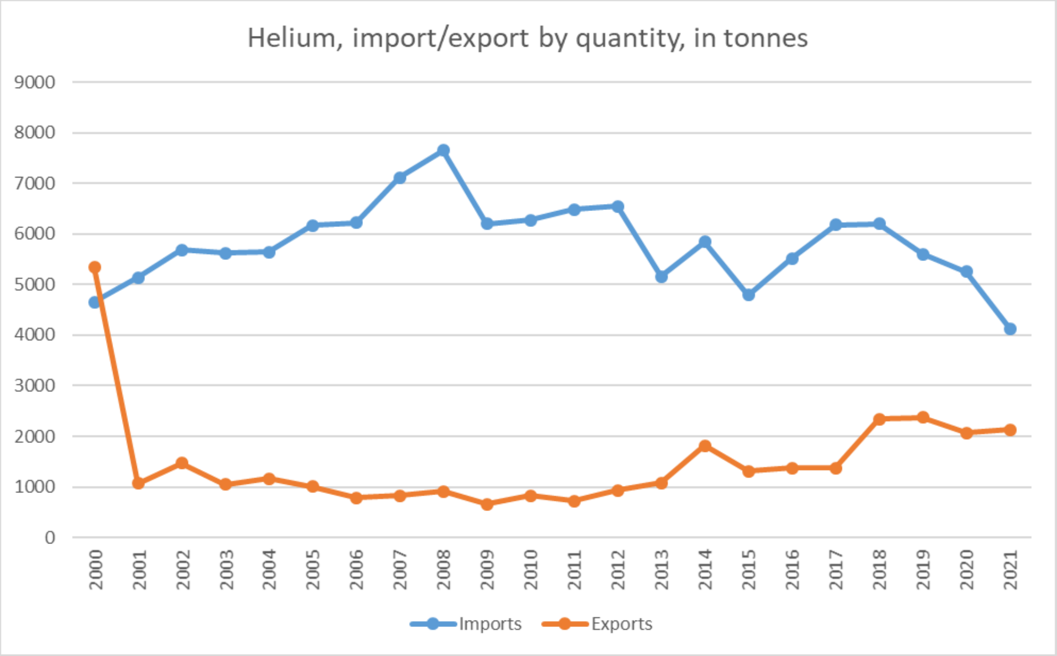

Figure 6. EU trade flows of helium from 2000 to 2021 (based on Eurostat, 2021)

Figure 7 presents the average EU imports of helium, by country, for the period 2000-2021. Throughout the period, Algeria and United States were the major helium suppliers to the EU. They covered 38% and 33% of EU's total helium imports, respectively. Over the period, Qatar has replaced Russia as one of EU's major helium suppliers and became EU's largest helium supplier in the late 2010s.

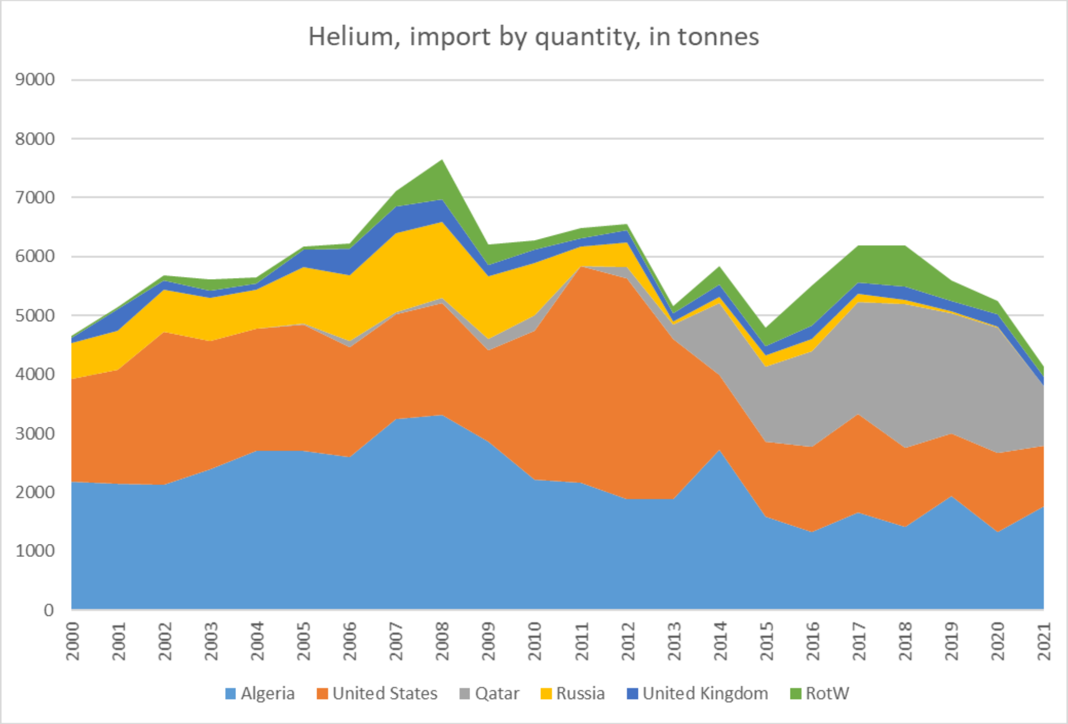

Figure 7. EU imports of helium by country between 2000-2021 (based on Eurostat, 2021).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

PRICE AND PRICE VOLATILITY

There is no global 'spot' market (price) for helium. The prices and their volatility vary significantly across helium markets, market segments and regions (cf. Elsner, 2018). The USA are the major producer of helium, and the US Bureau of Land Management (BLM) crude helium price has been used as basis for (long-run) helium contracts worldwide; its trend is correlated with the price trends observable at other helium markets (cf. Elsner, 2018; European Commission, 2020). The price increased almost steadily from € 1.8/m3 to € 3.0/m3 over the period 2012-2020, where the increases in the last years reflect the consumer price inflation (BLM, 2021). Calculated on the basis of the data depicted in Figure 8, the average log return in 2016-2020 was 3.5%, and the average price was € 2.4/m3 between 2012 and 2020. The price for grade-A helium provided by the private industry is estimated at ca. € 3.0/m3 for 2020 (USGS, 2021).

The volatility of the BLM crude helium price in the period 2016-2020 (as measured by the standard deviation of the data points depicted in Figure 8) was around 4.8%; the maximum (absolute) year-on-year rate of price change in the period 2012-2020 was ca. 11%. The (effective) price volatility as implied by, e.g., the dynamics of import-price indices for Europe, Japan and South Korea was significantly higher than the volatility of the BLM crude helium price (cf. Elsner, 2018). For example, after decreasing for several years, the unit prices of EU-helium imports and exports (as shown by the Comext trade data on CN code 28042910) increased by ca. 20% and 26%, respectively, between 2018 and 2019.

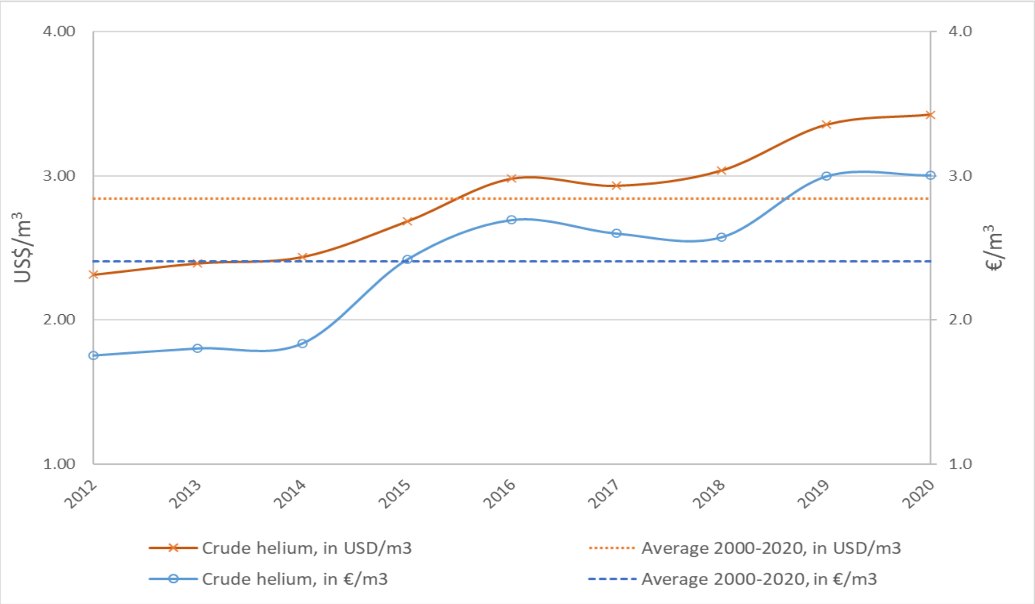

Figure 8. Annual helium price between 2012 and 2020, in US$/m3 and €/ m3 (based on 'in-kind' crude-helium prices posted by BLM, 2021)3. Dash lines indicate average prices for 20122020.

For the greatest part of the period 2012-2020, supply-shortages have not driven the global helium price – the implementation of the Qatar Helium 2 project in 2013 led to global excess-supply until 2017 (European

---

[3] Values in €/kg are converted from original data in US$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank

Commission, 2020). However, the Qatar embargo in June 2017 as well as the depletion of US reserves (natural depletion in the Hugoton-Panhandle complex and the reduction of the strategic BLM reserves) have led to supply deficits and related price pressures since 2018 (Edison Investment Research, 2021; European Commission, 2020). Moreover, helium production decreased worldwide due to the Covid-19 epidemic (USGS, 2021). In the longer run, the supply-related price pressures are expected to decrease following the establishment of additional production capacities in Russia and Quatar (Edison Investment Research, 2021; European Commission, 2020). On the demand side, the major factor behind helium-price growth is the low substitutability of helium in its applications, which is due to its unique physical and chemical properties, in conjunction with demand growth from its applications in medical equipment and electronics/semiconductor industries (Edison Investment Research, 2019; European Commission, 2020). The Covid-19 epidemic has depressed helium demand and, thus, resulted in lower price pressure.Outlook for supply and demand

With only a few major helium producers in the world and the US FHR being the only helium storage facility of its kind, major helium supply disruptions have occurred, and it is reasonable to expect that they will continue to occur in the future (Kornbluth, Helium - A Market Update, 2016). Owing to its unique physical properties, however, there are still no substitutes for helium in many cryogenic applications (including enabling superconductors and MRI machines to function) if temperatures below – 429F are required (Hamak, 2017), as in order to attain the necessary superconductive state, the magnets in MRI scanners need to be cooled to a temperature that can be attained only by using helium (Anderson, 2018).

Global helium demand is projected to grow at a CAGR of 4,65% during the 2015-2030 period. Growing demand from healthcare industry where it is used in magnetic resonance imaging (MRI) for magnet cooling and semiconductor and electronics industry where it is used in the manufacturing of LED screens is expected to drive the demand of helium during the forecast period (Globe News Wire, 2021). Stringent government regulations regarding usage of helium and expensive extraction process might hinder the demand growth during the forecast period. Additionally, the growing demand for ultra-low temperature freezers is expected to push the demand further during the forecast period.

Medical gases were among the most affected industries during the COVID-19 pandemic, which impacted the demand of helium for the first half of 2020. Although the demand for semiconductors and electronics fell during the pandemic, the overall demand for helium grew. Region wise, Asia pacific region holds the major share of global demand for helium due to increasing demand of healthcare and semiconductors and electronics. Moreover, increasing population and per capita income in emerging economies like India and China coupled with growing number of industries using helium is another factor influencing demand growth in the Asia Pacific region.

Major factors playing on the supply side are the privatisation of US-based Federal Helium Reserve under the Helium Privatisation Act of 1996 and the new players announced for the global helium market: Renergen (2019), Qatar 3 (2020), Irkutsk (2021) and Amur (2021- 2026), a Gazprom project of gas processing plant in Siberia. Gazprom estimates that Amur facility will add to the world supply 60 Mm3 per year once fully operational (expected in late 2024) and thus Russia will become an important global supplier of helium.

(https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958211

Overall, the enlarged capacity production of the new facilities is likely to smooth the production fluctuations and secure a supply that can follow better the demand trends. Helium production in 2020 decreased in the United States and worldwide in response to the COVID-19 pandemic. In April 2020, the Bureau of Land Management (BLM) announced plans for disposal of the remaining Federal helium inventory and assets by September 2021, after which the General Services Administration would complete the disposal process. Federal in-kind users would continue to have access to helium until September 30, 2022 (USGS, 2021).

DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

The EU net consumption amounted to about 28.6 Mm^3 (4 800 tonnes) per year on average during the period 2010-2016 (USGS, 2019).

Helium processing stage EU consumption is presented by HS code CN 28042910 Helium. Import and export data is extracted from Eurostat Comext (2021). Production data of helium is extracted from Eurostat Prodcom (2021) using PRCCODE 20111140 Helium.

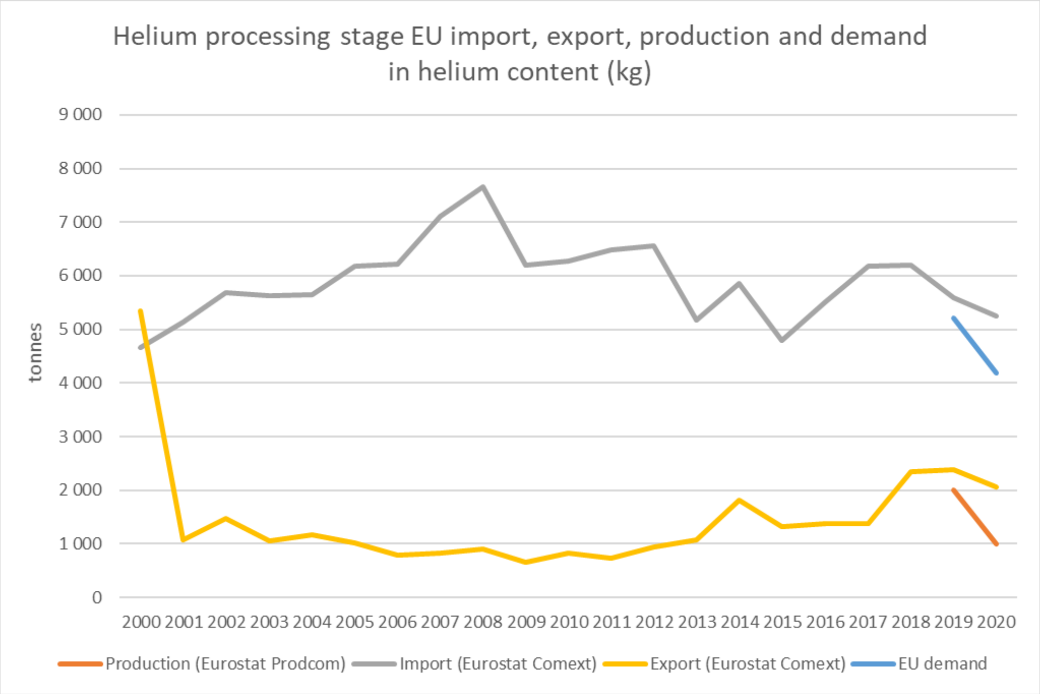

Figure 9. Helium (CN 28042910 Helium) processing stage apparent EU consumption. Production data from Eurostat Prodcom (2021) is available only for 2019-2020. Helium is presented in kg content (Conversion: 1 kg = 5.988 m^3 He). Consumption is calculated in helium content (EU production+import-export).

Based on Eurostat Comext (2021) and Eurostat Prodcom (2021) average import reliance of helium at processing stage is 69.0 % for 2019-2020.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

GLOBAL AND EU USES AND END-USES

Figure 10 presents the main uses of helium in the EU.

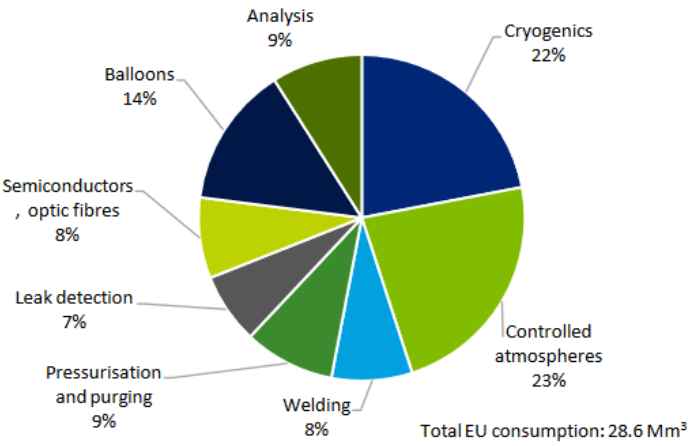

Figure 10. EU end uses of helium. Average figures for 2012-2016 (CRM Experts, 2019). No data updates available from SCRREEN Expert and Validation workshops 2021, 2022)

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors. The value-added data corresponds to 2018 figures, unless indicated otherwise (Table 5).

Table 5. Helium applications, 2-digit and associated 4-6-digit NACE sectors, and value added per sector (Eurostat 2019).

Applications	Shares	2-digit NACE sector	6-digit CPA
Cryogenics	22%	C32 - Other manufacturing	32.50
Controlled atmospheres	23%	C24 - Manufacture of basic metals	24.45
Welding	8%	C25 - Manufacture of fabricated metal products, except machinery and equipment	25.62.20 25.11
Pressurisation and purging	9%	C32 - Other manufacturing	32.99.11
Leak detection	7%	C33 - Repair and installation of machinery and equipment	33.12
Semiconductors, optic fibres	8%	C26 - Manufacture of computer, electronic and optical products	27.31.1 26.11.22 26.30
Balloons	14%	C32 - Other manufacturing	32.99
Analysis	9%	C32 - Other manufacturing	32.99

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

In 2018, an estimated 25% of global helium was consumed in liquid form, with this share being higher in developed regions (HIS Markit, 2019). In the major consuming regions—the United States, Western Europe, Japan, China, and Other Asia — MRI was the largest application for liquid helium, followed by fibre optics, semiconductors/electronics, and metals processing (welding cover gas).

CRYOGENICS

The largest use for liquid helium is in cryogenics where it is used mostly to cool superconductive magnets of MRI (Magnetic Resonance Imaging) scanners and, to a much less extent, in particle physics research facilities.

Cooling by rapid expansion: A third method is the use of the Joule-Thompson effect. This involves cooling gases by an abrupt expansion of volume or an equally fast pressure drop. This method is extensively used in liquefying hydrogen and helium (DEMACO, 2022).

Because it is the coldest substance on earth and does not conduct heat, helium is an excellent low-temperature refrigerant. For example, wherever strong magnetic fields are generated, such as in superconducting magnetic coils in magnetic resonance imaging (MRI), nuclear magnetic resonance (NMR) or in other low-temperature processes (Gase Partner, 2018).

CONTROLLED ATMOSPHERES

To create controlled atmospheres when gas inertness is necessary: heat treatment and manufacture of high-purity metals etc. It is a component of breathing gas in deep diving activities in offshore oil and gas exploration and underwater pipe maintenance

Dealing with breathing gases containing helium allows diving depths where the tolerable limits of oxygen and nitrogen would be exceeded. In technical diving, depending on the planned diving depth, oxygen and nitrogen are removed from the breathing gas and replaced by helium. The result is an increased ability to concentrate and the toxicity of oxygen is eliminated.).

Helium's low viscosity also helps recreational divers breathe better underwater. Thus, various mixtures with helium act as breathing gas. This is because our normal breathing air changes under pressure at water depths. Nitrogen, for example, has a narcotic effect under high pressures and oxygen causes nerve damage (Gase Partner, 2018). Thanks to its low viscosity, helium has proven itself as a breathing gas for asthmatics in the form of a helium-oxygen mixture (80:20). This makes it easier to breathe than air (Gase Partner, 2018).

ARC WELDING

The major use for gaseous helium is in arc welding, where it provides an inert gas shield to prevent oxidation during welding of aluminium, magnesium, copper, and stainless steels. Depending on the type of weld and the metal, helium will usually be blended with argon (in a share of 25% to 75% in the gas mix). Pure helium is generally only used for some specialized tungsten inert gas (TIG) welding applications (Air liquid, 2019).

Since helium is an inert gas, i.e. an active gas, and therefore does not react with other substances, it is also often used as a shielding gas in welding. In this way, welders protect their molten metal from the reactive oxygen. Spatter is also avoided and the penetration depth and welding speed are increased with the help of helium. Helium is mainly used for processing aluminium and stainless metals (Gase Partner, 2018).

Helium is also used for metals which have a very good level of thermal conductivity, such as aluminium or copper. .

PURGING AND/OR PRESSURISING GAS

As purging and/or pressurising gas in aerospace, defence, and nuclear industries (e.g. NASA, Ariane).

LEAK DETECTION

Helium is used in leak detection as a tracer gas to check for leaks in containers, pressure vessels, buried pipes, etc. because of the helium small atom size.

Helium is also used for leak detection in chemical plants. The same principle is also used by manufacturers of petrol tanks for cars or in the production of heat exchangers for air conditioning systems (Gase Partner, 2018).

In the case of helium leakage detection, a test gas is applied in (high) vacuum technology inspection on several different test objects for detection of leaks. The tightness inspection is one of the destruction-free testing methods.

Tightness inspections are used on a large scale in industrial manufacture and quality inspection.

Helium is used for vacuum devices as the most highly diffusible leakage detection gas (through evacuation of the vacuum apparatus using a pump and hanging a mass spectrometer behind the pump). When the apparatus is blasted with helium from the outside, only locally to detect leakages, a possible penetration of helium into the apparatus can be detected and the leakage rate measured using the mass spectrometer (Wissel, 2022). .

SEMICONDUCTOR WAFER

Used in semiconductor wafer and chip fabrication for its inertness, heat conducting and cooling properties. It is used as a cooling gas in the strand spinning operations in the manufacture of optical fibre cables.

BALLOONS

Used as a lifting gas in party balloons, weather balloons, advertising blimps, balloons for upper atmosphere studies.

NUCLEAR TECHNOLOGY AND OTHERS / R&D

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958211

Helium is also applied in advanced R&D projects in areas such as: nuclear technology, magneto hydrodynamics studies and behaviour of materials at very low temperatures. The nuclear fusion research programme is part of the European Fusion Development Agreement.

SUBSTITUTION

Table 6. Potential substitution options for helium in main uses

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Controlled atmospheres	23%	Argon	50%	Similar or lower costs	Similar
Balloons	14%	Hydrogen	50%	Similar or lower costs	Similar
Analysis	9%	Hydrogen	1%	Similar or lower costs	Reduced

* EU end uses of helium. Average figures for 2012-2016 (CRM Experts, 2019). No data updates available from SCRREEN Expert and Validation workshops 2021, 2022)

Due to its unique properties (the best refrigerant, superfluidity below 2.18 Kelvin: viscosity-free fluid flow and extraordinarily high thermal conductivity, the highest ionization potential, very high specific heat and thermal conductivity, chemically and radiologically inert), helium can be substituted only in some of its applications, as follows:

CRYOGENICS

There is no substitute for liquid helium in cryogenic applications if temperatures below 17°K (-256°C) are required (USGS, Helium factsheet 2022). Other cryogenic substances are used in other temperature conditions.

PURGE AND PRESSURIZATION

There is no substitute for applications requiring inertness and ultra-low temperature.

WELDING

Argon can be used as a substitute for both gas metal arc welding and gas tungsten arc welding.

The shielding gas argon 4.6 is used in welding. It is characterised by its purity of 4.6, which means that the noble gas has a purity level of 99.996%, which means a slight impurity of 40 ppm. Thus, it usually contains about 25 ppm nitrogen, 5 ppm moisture and 5 ppm hydrogen, but no helium (GPC, 2022).

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958211

SEMICONDUCTOR & OPTICAL

Semiconductor and optical fibre manufacturing: For semiconductor industry, helium can be substituted by argon or hydrogen or nitrogen depending on its application. There is presently no substitute for helium in optical fibre production process (Borersen, 2013).

To achieve optimal results in inductive soldering (copper-wire bonding), the copper wire is melted and bonded to the wafer under a protective atmosphere (DIN ISO 857-2). This ensures that no impurities, for example from the ambient air, react with the material and reduce the quality of the semiconductors or that the material oxidises during the soldering process due to the oxygen in the ambient air. Gas mixers are often used to generate the protective gas, with helium or argon being used in the protective atmosphere (WITT, 2022).

LIFTING GAS

Hydrogen can be substituted for helium in some lighter-than-air applications in which the flammable nature of hydrogen is not objectionable (USGS, Helium factsheet 2022).

CONTROLLED ATMOSPHERES AND BREATHING GAS

Argon can be used as a substitute. In the chamber plasma spraying process (plasma in controlled atmosphere) helium or argon (or hydrogen) can be used as process gases.

Hydrogen is also being investigated as a substitute for helium in deep-sea diving applications below 305 meters (1,000 feet) (USGS, Helium factsheet 2022).

There is no substitute for breathing mixtures.

LEAK DETECTION

Some helium users could use a mix of 5% hydrogen and 95% nitrogen -which is classified as non-flammable - as an alternative (EC, 2020).

ANALYSIS: HYDROGEN AND NITROGEN

Hydrogen and nitrogen are used as carrier gas for chromatography. Hydrogen provides the fastest analysis time over a broad linear velocity range, but safety concerns must be addressed. Nitrogen is a slow carrier gas, so its use is limited to situations where longer analysis times are acceptable (Wallace, 2011).

A substitution of helium in gas chromatography consists of an automatic, software-controlled switchover of the carrier gas from helium to e.g. nitrogen during standstill periods (standby). This alternative ("Helium Conservation Module" by Agilent Technologies) with a so-called sleep mode under purging with cheap nitrogen is much better than the complete cooling down and shutting down of a gas chromatograph, as this can easily lead to impurities, leaks and thus oxygen intrusion (Brodacz, 2015).

SUPPLY

EU SUPPLY CHAIN

The EU is a net importer of helium and the import reliance is >90% (averaged since 2019). In Europe, the extraction of helium occurs mainly in Poland. About 31 Mm^3 of helium were imported, while only 2 Mm^3 were produced in EU in 2020 (Eurostat 2020).

SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF HELIUM

GEOLOGICAL OCCURRENCE

Helium is concentrated in stars, where it is synthesised from hydrogen by nuclear fusion. Helium occurs in the Earth's atmosphere only to the extent of 1 part in 200,000 (0.0005%), and small amounts occur in radioactive minerals, meteoric iron, and mineral springs. Great volumes of helium are found as a component in natural gases. The helium that is present on Earth is not a primordial component of the Earth but has been generated by radioactive decay. Helium is produced in the natural environment continually by the radioactive decay of uranium specifically within uranium and thorium-rich sedimentary sequences in the earth's crust e.g., black shales (Selley, 1985) and escapes into the atmosphere.

Since the concentration of helium in air is very minimal, extraction of helium from air is not economically viable. Helium is mainly extracted from helium-bearing natural gas.

GLOBAL RESOURCES AND RESERVES

The most important resources and reserves exist in US region. The volume of recoverable helium within the known geologic natural as reservoirs in the United States was estimated to be 8,490 million cubic meters excluding the remaining 85.7 million cubic meters in the Federal helium inventory. The estimated mean for the Alaska region was 1.11 million cubic meters, the Gulf Coast region, 12.5 million cubic meters, the Midcontinent region, 4,330 million cubic meter, the North Central region, 52.7 million cubic meters and the Rocky Mountain region 4,110 million cubic meters. Helium resources in the rest of world are estimated at 31.3 billion cubic meters. Major resources (in billion cubic meters) exist in: Qatar (10.1), Algeria (8.2), Russia (6.8), Canada (2.0) and China (1.1) (USGS, 2022), However the exact estimation of worldwide reserves is challenging (Table 7).

Table 7. Global reserves of helium (USGS, 2022)

Country	million cubic metres (Mm3)
USA	8,500
Algeria	1,800
Russia	1,700

Poland	24
Other countries: Australia, Canada, China, Qatar	Not available
World	Not available

EU RESOURCES AND RESERVES

Helium occurs in numerous natural gas fields in the Polish Lowland. Its content in the natural gas varies from 0.02% to 0.45%. The resources of helium were documented within 18 fields where its content in the natural gas is varying from 0.22% to 0.42%. The total volume of Polish helium resources is estimated at 23.82 million cubic meters (pgi.gov.pl, 2021).

The Aphrodite gas field (AGF) is the first gas field to be discovered and granted a production license in the eastern Mediterranean Sea, offshore Cyprus. It was discovered in 2011 and it is estimated to hold up to 4.5 trillion cubic feet (Tcf) of recoverable gas reserves. AGF is located within Block 12 of the Cypriot Exclusive Economic Zone (EEZ) in the eastern Mediterranean Sea, approximately 160km south of Limassol port, Cyprus. The initial production phase is expected to involve five production wells capable of producing up to 800 million cubic feet (Mcf) of gas per day. The field lies in a water depth of 1,700m and covers an area of approximately 120 km2 (**nsenergybusiness.com, 2019**). There are no available data concerning the He concentration in this natural gas occurrence so far.

WORLD AND EU PRODUCTION

The world annual average supply of helium was stabilized around 160 Mm3 over the period 2016-2021 (USGS, since 2000) with the major producer being: USA (48%), Qatar (31.8%) and Algeria (8.7%) (USGS, since 2000). The US supply came from active natural gas wells and from the federal government National Helium Reserve which is an underground stockpile known as the Bush Dome Reservoir in the Cliffside gas field, in Texas. Large amounts of helium had been stored in this reservoir from the early 1960s to the mid-1990s. The Helium Privatization Act of 1996 and the Helium Stewardship Act of 2013 mandated the resell of most of the federal stockpiles. The Bureau of Land Management (BLM) manages the federal helium reserve (USGS,2019).

The Global helium production in Mm^3 by country between since 2000 can be seen in Figure 11 (USGS, since 2000). USA, Algeria and Qatar are the main producers.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

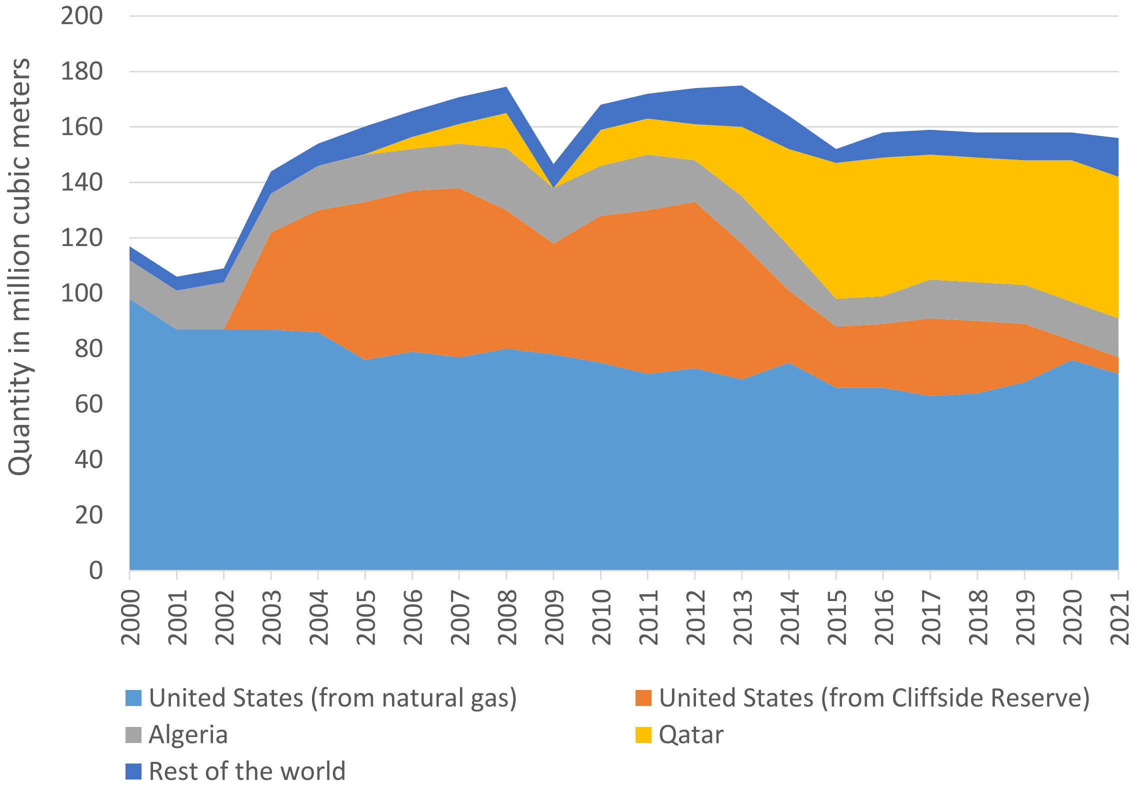

Figure 11. Global helium production in Mm^3 by country since 2000 (USGS, since 2000).

According The Central Geological Database of Poland, in this country the recovery of helium from ten fields reached 750 km3 in 2018. The volume does not include the recovery from the fields in which a helium admixture has not been documented. The total pure helium production by Polish Oil and Gas Company (POGC – in Polish PGNiG) – Odolanów Branch, recovered from the exploited natural gas in Poland, amounted to 3.08 m3 in 2018 (Polish geological institute, 2019). According to DERA (Elsner, 2018) helium is supplied:

a) **In the liquefaction of natural gas to liquefied natural gas** (LNG) in LNG facilities - In Algeria, Australia and Qatar. In the majority of cases, the helium is also liquefied, to make its transportation and commercialisation easier.

b) **During denitrification of natural gas** - in the US, Russia and Poland. In order to reduce the excessive levels of non-combustible nitrogen in some natural gas reservoirs, nitrogen and helium are converted by pressure swing adsorption or separated at low temperatures by cryogenic fractionating distillation.

c) **In the purification of natural carbon dioxide gas**. Carbon dioxide is used in fracking in the US, and gas producer Air Products and Chemicals, Inc. decided to process a highly CO_2-rich natural gas, thereby producing helium as a saleable product.

d) **From the nitrogen fraction in air separation** - in Leuna in Germany, Ukraine and China. Helium is obtained as a by-product of neon production, where it is present in the crude neon–helium fraction at up to 24%. Because helium and neon levels in air are very low, this form of helium production is highly complex and expensive. The volume of helium produced compared to helium production methods a) and b) is very low.

Large quantities of ^{3}He are therefore created in nuclear reprocessing plants, nuclear weapons factories and nuclear reactors. There are several exploration projects worldwide, but no detailed information for EU has been found.

OUTLOOK FOR SUPPLY

Helium world demand by 2040 will vary from 187 to 250 million cubic meters. The main factors for maintaining sustainable production of helium in the world are the prospects for the implementation of gas production projects and various geopolitical factors. The rapid development of the helium industry impeded due to the distance between the production centers (USA, Qatar and Algeria) and the centers of consumption (Asia-Pacific region, the USA and Europe). There will be no rapid development of helium markets. In developed countries, stagnation will be observed, and in developing countries (APR) — an increase in accordance with the rates of economic growth (**Provornaya et al. 2022**). In terms of security of supply, it is concerning that by the late 2020s, 75% of global helium supply will come from Qatar, Russia and Algeria - in comparison to 50% in 2020 (**edisongroup, 2021**).

SUPPLY FROM SECONDARY MATERIALS/RECYCLING

Cost issues and uncertainties about helium supply have led to the development of recovery and recycling technologies in certain end-user applications and an increasing usage of helium recovery and purification systems in both scientific R&D and industrial applications. However, USGS (2019) reports that helium used in large-volume applications is rarely recycled. Overall, the end-of-life recycling input rate has been estimated at 1%.

Several German universities and research institutes also collect the gaseous helium they use and return it to the respective gas suppliers, partly in the gaseous state, partly liquefied, for a fee. Here, good recovery rates are between 90% and 95%. The price for a complete plant such as this, with liquefaction, is said to be around 2 million euro (Elsner, 2018).

Helium is used in the cooling system of the magnets of nuclear magnetic resonance (NMR) spectrometers. Its freezing point at -272.2°C, renders it an excellent cooling mean. It is reported that 10,000 litres of liquid helium are consumed only in two pharmacy and medicine laboratories in US (UCSF Schools of Pharmacy and Medicine). The recycling of helium in these laboratories was achieved through its collection and purification. The collection of spent gaseous helium is achieved viaits warming, through a structure of copper pipes ending up into big black bags, each the size of an SUV, where it is stored. The purification of helium by water and nitrogen impurities is achieved by a freezing process taking advantage of the different freezing points of He, N_2 and water.. The purified, gaseous helium is finally sent to a cold condenser where it is turned back into a liquid before re-used in the supercooling system of NMR magnets (**pharmacy.ucsf.edu, 2021**).

McGill university has developed a similar pilot-scale system for the daily recycling of 20 litres of He used in NMR magnet devices. The recycling system enables the recovery of He with a yield around 90%. Helium to be recycled flows through copper pipes to a compressor which either directs it to a liquefier or compresses it into medium pressure cylinders for storage. The liquefier holds 150 L helium and liquefies 20 L / day. From the

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

liquefier, the gas is purified by passing through a nitrogen-cooled purifier, and finally it is condensed to liquid helium via a cryocompressor. At this point, the cycle is completed by transferring the recovered liquid helium into the NMR magnets (**mcgill.ca, 2021**).

PROCESSING OF HELIUM

Helium is extracted from natural gas of average content 0.1%-0.5%, usually produced as a by-product of natural gas processing. Natural gas contains methane and other hydrocarbons and smaller quantities of nitrogen, water vapour, carbon dioxide, helium and other non-combustible materials. Helium is extracted through fractional distillation from natural gas? as it presents the lower boiling point in comparison to the other gaseous elements, therefore, low temperature and high pressure is applied to liquefy nearly all the other gases. The obtained 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. Once separated from the natural gas, crude helium which contains nitrogen along with smaller amounts of argon, neon, and hydrogen is purified to commercial grades (99.99+%). This is typically done using either activated charcoal absorbers at liquid-nitrogen temperatures and high pressure or pressure-swing adsorption (PSA) processes (**US National Research Council, 2010**). The following successive steps are taking place:

Initially, heavy hydrocarbons, acidic gases and water vapor are removed in a pretreatment process. Subsequently and before the expansion of feed to produce a multi-phase stream having an intermediate pressure, the feed gas is cooled to liquid. The multi-phase stream generated in flash tank produces one gaseous and one liquid stream. The main amount of helium along with nitrogen impurities in the feed stream is transferred into the gas phase, while the helium free liquid stream is stored as LNG by depressurizing it to around atmospheric pressure. The gas stream output of the flash tank, concentrated in helium, is then directed to the helium extraction unit where helium is recovered by cooling. The gas stream enriched in helium still contains significant amounts of nitrogen and methane, therefore it is submitted to condensation upon passing through the heat exchanger. Due to the low boiling point of helium compared to other components, much amount of helium remains in the gas phase, while methane and nitrogen are condensed. The produced gas stream contains more than 50% helium with remaining primarily composed of nitrogen. Finally, helium is purified up to 99.999%(V/V) in the helium recovery unit using a pressure swing adsorption (PSA) system (**Figure 2**) (**Soleimany et al. 2017**).

For natural gas fields with sufficient concentrations of helium and other non-fuel gases such as CO_2 and sulphur, helium may be directly processed. Helium could be recovered during the production of liquefied natural gas (LNG) which consists mainly of liquefied methane. (U.S. National Research Council, 2010). In an LNG production plant, most of gaseous impurities are removed during the process resulting in partial helium enrichment in the stream. Thus, installation of a helium extraction unit after an LNG production unit is more economically attractive than extracting helium from crude natural gas.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958211

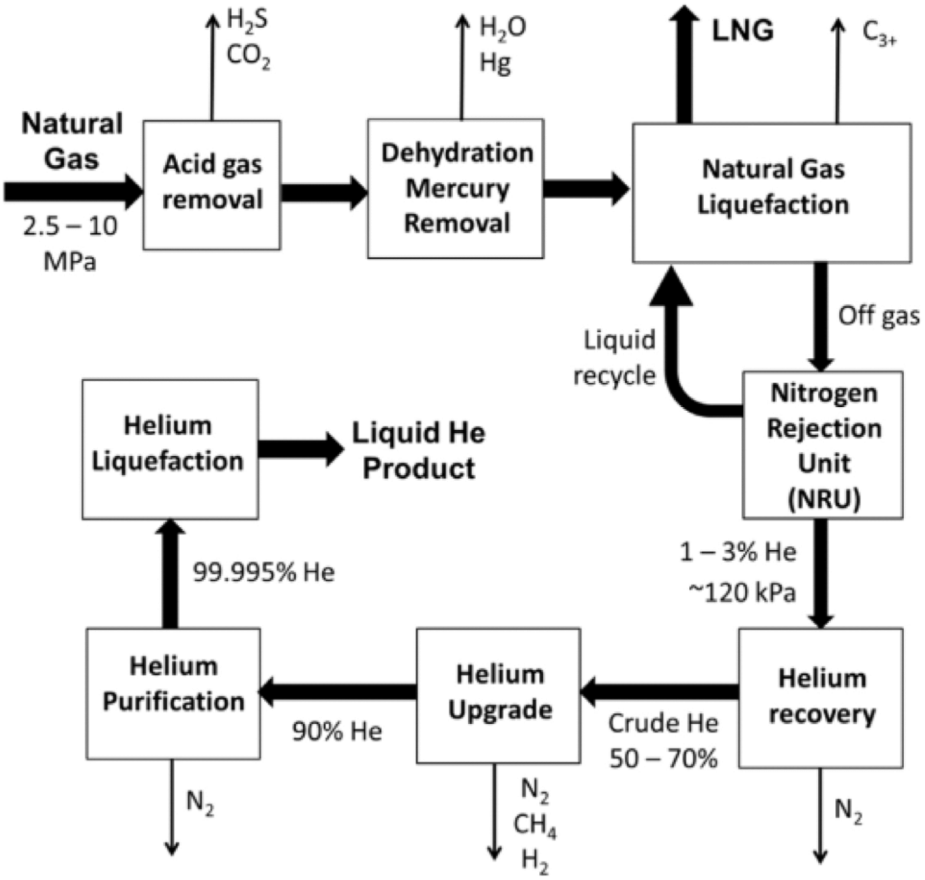

Figure 12. The process of He production by natural gas (Scholes et al. 2016; Soleimany et al. 2017).

Helium production through the diffusion of crude natural gas using specific semipermeable membranes and other barriers has recently attracted the interest of the scientific community. Gas separation technique through a membrane is based on the difference in component permeation rates through the membrane. The penetration rate of each component depends on its specifications, partial pressure difference of components on either side of the membrane and the membrane specifications as well as the interactions involved. Inorganic materials such as silica and carbon-based structures as well as polymers including cellulose acetates and polyphosphazene and polycarbonates have been successfully tested as He recovery and purification membranes. The necessity of operating at elevated temperatures and the complexity of large scale membrane fabrications are the main obstacles for the commercialization of the technique (**Soleimany et al. 2017**).

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Helium can be absorbed into the body by inhalation causing dizziness, dullness, headache and in severe cases suffocation. Contact with liquid helium may cause frostbite in the skin and eyes (LENNNTECH n.d.). Oxygen content in the area should be evaluated as diluting the concentration of oxygen in air below the levels necessary to support life (Occupational Safety and Health Administration of the United States Department of

Labor 1970). Helium, substituted for nitrogen in "mixed-gas diving," can cause an effect called High-Pressure Nervous Syndrome beyond 500 feet of salt water (Occupational Safety and Health Administration n.d.; American Chemical Society 2021).

When helium is contained in a cylinder it should be handled and stored appropriately. When moved it shouldn't be slid, dragged or come into contact with sharp edges. Only Genie cylinders in an upright position should be used. Self-contained breathing apparatus should always be worn when entering the area where oxygen depletion may have occurred. Safety goggles, gloves and shoes or boots should be worn when handling cylinder('Helium Safety Data Sheet, Airgas' n.d.; American Chemical Society 2021).

This substance is not restricted under REACH Regulation (EC) No 1907/2006 Annex XVII (Deutsche Forschungsgemeinschaft and Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area, 2002). However, the Occupational Safety and Health Administration of the United States in its Incorporation of General Industry Safety and Health Standards Applicable to Construction Work defined a CAS Registry Number 7440-59-7 which states that helium can cause simple asphyxiation setting the limit of oxygen concentrations to at least 19.5% when using helium and defining requirements for explosion (Occupational Safety and Health Administration of the United States Department of Labor 1970).

ENVIRONMENTAL ISSUES

No environmental issues were found in the scientific literature review. In addition, no LCAs studies could be found related to any life cycle stage or specific use of the material during the scientific literature review.

NORMATIVE REQUIREMENTS RELATED TO THE USE AND PROCESSING OF HELIUM

Technical rules for the use of helium can be found in the GESTIS Substance database[4].

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF HELIUM FOR EXPORTING COUNTRIES

There is no specific economic importance of exporting helium.

SOCIAL AND ETHICAL ASPECTS

No specific issues were identified during data collection and stakeholders' consultation.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

---

[4] See https://gestis-database.dguv.de/data?name=007020

a. R&D trends in terms of emerging LCGT

No research and development trends could be identified in the context of helium use in emerging LCGT.

b. R&D trends in terms of emerging application of RM in already existing LCGT

No research and development projects could be identified in the context of emerging applications of helium in already existing LCGT.

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Mapping Stellar Helium (ERC-STG - Starting Grant)[5]

Asteroseismic measures of helium will be used to construct a map from observable properties (fundamental, chemical or even dynamical) back to initial Helium. This is a challenge that can only be solved through the use of the latest asteroseismic techniques coupled to a rigorous yet flexible statistical scheme. I am uniquely qualified in the cutting-edge methods of asteroseismology and the application of advanced multi-level statistical models. The intersection of these two skill sets will allow solving the initial Helium problem.

REFERENCES

Anderson, S. T. (2018). Economics, Helium, and the U.S. Federal Helium Reserve: Summary and Outlook. Natural Resources Research, 27(4), 455-477. doi:DOI: 10.1007/s11053-017-9359-y

Air liquide (2019), Helium., https://industry.airliquide.com.au/sa-spec-helium,

BLM (2021). Bureau of Land Management Crude Helium Price. Retrieved from https://www.blm.gov/programs/energy-and-minerals/helium/federal-helium-operations

Boersen, B (2013), The Past, Present and Future of the Federal Helium Program, http://docs.house.gov/meetings/II/II00/20130214/100266/HHRG-113-II00-Wstate-BoersenB-20130214.pdf,

Böhm, G (2022), Underwater exploration filming services. Media di Mare., http://www.mediadimare.com/ ,

Brodacz (2015), Helium – das begehrte Edelgas mit begrenzten Ressourcen. Labo, https://www.labo.de/chromatographie/gegenstrategien-fuer-die-gc---helium---das-begehrte-edelgas-mit-begrenzten-ressourcen.htm,

DEMACO (2022), Cryogenius, https://demaco-cryogenics.com/,

Edison Investment Research (2019). Helium – Macro View Update. Retrieved from https://www.edisongroup.com/sector-report/helium-macro-view/23491/

Edison Investment Research (2021). Global helium market update: Market shifting to oversupply by mid-2020s. Retrieved from https://www.edisongroup.com/wp-content/uploads/2021/05/Helium_report050521_final.pdf

---

[5] See https://cordis.europa.eu/project/id/804752

edisongroup, (2021), available at: https://www.edisongroup.com/wp-content/uploads/2021/05/Helium report050521_final-3.pdf

eia.gov, 2021, available at: https://www.eia.gov/todayinenergy/detail.php?id=50196

Elsner, H. (2018). Edelgase – Versorgung wirklich kritisch? (D. R. S., Ed.) Retrieved from https://www.deutsche-rohstoffagentur.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen/ro

Elsner, H. (2018). Edelgase - Versorgung wirklich kritisch? (Datenstand: Oktober 2018). DERA Rohstoffinformationen: Vol. 39. Berlin: Deutsche Rohstoffagentur (DERA) in der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).

European Commission (2020), Study on the EU's list of Critical Raw Materials, https://ec.europa.eu/docsroom/documents/42883/attachments/2/translations/en/renditions/native,

European Commission (2020). Study on the EU's list of Critical Raw Materials (2020): Factsheets on Non-critical Raw Materials.

Eurostat (2019), Easy Comext database, http://epp.eurostat.ec.europa.eu/newxtweb/.,

Eurostat (2020). Comext International Trade [Online]. Available at: https://ec.europa.eu/eurostat/web/international-trade-in-goods/data/database

Eurostat Comext (2021), Easy Comext, http://epp.eurostat.ec.europa.eu/newxtweb/, 44683

Eurostat Prodcom (2021), Prodcom database. Statistics on the production of manufactured goods (PRODCOM NACE Rev.2), Prodcom - Statistics by Product. Available at: , https://ec.europa.eu/eurostat/web/prodcom/data/database, 44683

Eurostat. (2021). Comext Database. http://epp.eurostat.ec.europa.eu/newxtweb/

EWM. (2022), hich shielding gas should be used for TIG or MIG/MAG welding? , https://www.ewm-group.com/de/fachwissen/schutzgase.html,

Gase Partner (2018), Helium Beschaffungskrise, Heliumverknappung 2018/19,, https://gase-kaufen.de/blog/helium-das-sonnen-gas-die-wichtigsten-fakten-n5,

Globe News Wire. (2021). Outlook on the Helium Global Market to 2030. Récupéré sur GlobeNewswire News Release: https://www.globenewswire.com/news-release/2021/07/02/2256960/28124/en/Outlook-on-the-Helium-Global-Market-to-2030-Identify-Key-Drivers-and-Challenges.html

GPC (2022), Welches Argon brauche ich?, https://gase-kaufen.de/blog/welches-argon-brauche-ich-argon-46-48-und-50-im-vergleich-n13,

Hamak, J. E. (2017). Helium. In U.S. Geological Survey mineral commodity summaries 2017.

Institut für Thermische Energietechnik und Sicherheit (ITES) (2022), Fusionstechnologie, https://www.ites.kit.edu/339.php,

Kornbluth, P. (2015). Evolution of the global helium business—1990–2015.

Kornbluth, P. (2016). Hellium - A Market Update. Cornwall: Gasworld.

Kornbluth, P. (2017). Praxair-Linde merger—Major new helium competitor. . Lexington, Massachussetts: Gasworld US Edition.

mcgill.ca, (2021), available at: https://www.mcgill.ca/mc2/helium-recovery-system#overview

Mordor Intelligence. (2021). Helium Market. Récupéré sur Mordor Intelligence Industry reports: https://www.mordorintelligence.com/industry-reports/helium-market

nsenergybusiness.com, (2019), available at: www.nsenergybusiness.com/projects/aphrodite-gas-field/

pharmacy.ucsf.edu, (2021), available at : https://pharmacy.ucsf.edu/news/2021/06/helium-recycling-project-sets-new-standard-sustainability-ucsf

Polish Geological Institute. (2019). Mineral Resources of Poland. Retrieved from http://geoportal.pgi.gov.pl/surowce/energetyczne/hel/2018

Provornaya, et al. (2022), Prospects for the global helium industry development, Energy Reports, 8, PP. 110-115.

RTM Group (2022), Nuclear Technology., http://rtm-group.com/nukleartechnologie.html ,

Scholes, C.A., Ghosh, U. (2016). Helium separation through polymeric membranes: selectivity targets, J. Membr. Sci. 520, 221–230.

Selley, R. (1985). Elements of Petroleum Geology. San Francisco.

Soleimany, A., Hosseini, S.S., Gallucci, F. (2017), Recent progress in developments of membrane materials and modification techniques for high performance helium separation and recovery: A review, Chemical Engineering & Processing: Process Intensification 122, 296–318.

Statista, (2020), Production of helium worldwide, Available at: https://www.statista.com/statistics/925214/helium-production-worldwide-by-country/

US National Research Council. (2010). Selling the Nation's Helium Reserves. Washington, DC, US: The National Academies Press. Retrieved from https://www.nap.edu/read/12844/chapter/1

USGS (2021). Helium: Mineral Commodity Summaries.

USGS. (2005). Helium End-Use Statistics.

USGS. (since 2000). Mineral Commodity Summaries. (A. C. Tolcin, Ed.) Retrieved from https://www.usgs.gov/centers/nmic/helium-statistics-and-information.

Wissel (2022), Helium leakage detection, https://en.wissel-vakuum.de/helium-leakage-detection/,

WITT (2022), Halbleiterindustrie, ttps://www.wittgas.com/de/anwendungen/halbleiterindustrie/).,

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958211