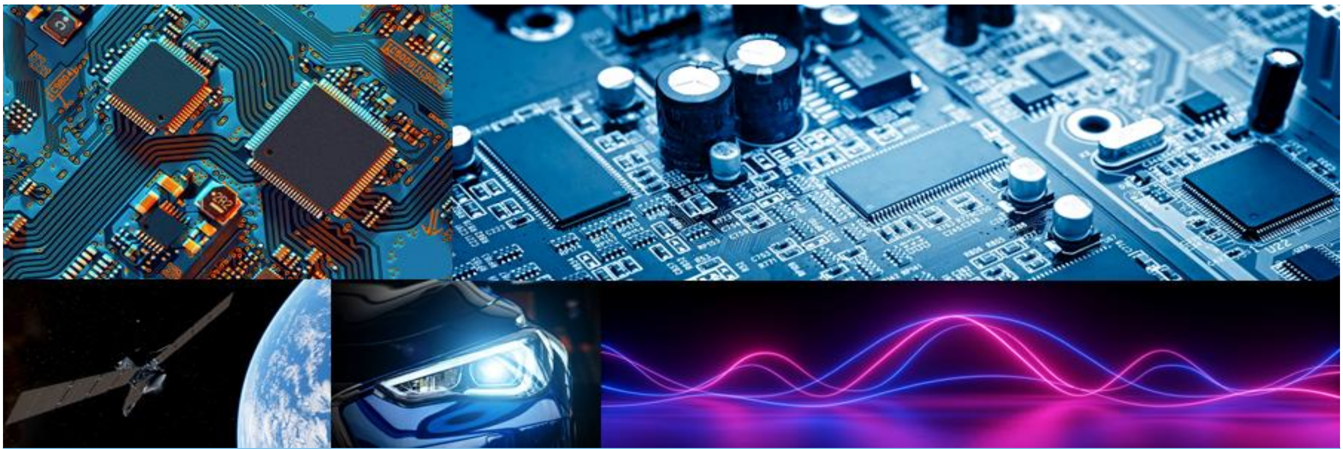
SCIENCE FOR POLICY BRIEF

Raw Materials & the war in Ukraine

Rare Gases (Krypton, Neon, Xenon): Impact assessment for supply security



HIGHLIGHTS

→ Russia and Ukraine are significant sources of rare gases (krypton, neon, xenon). Russia's invasion of Ukraine affects the rare gases supply.

→ Industry stockpiles could mitigate the impacts in the short term. The supply disruption might be severe with associated price inflation until production capacity is developed elsewhere combined with conservation/recycling/substitution strategies to handle shortages.

→ As Ukraine is a leading producer of purified neon gas, a critical input for the manufacture of semiconductors, neon's supply disruption poses the greatest challenges. A neon scarcity worldwide could substantially impact industrial supply chains reliant on semiconductors.

→ The EU sourced about half of its rare gases imports from Russia and Ukraine in 2021. China and the US are the potential sources for EU's import diversification.

→ EU's resilience to supply chain disruption in the short term is reinforced through its sizable production base for rare gases. In addition, domestic capacity could be theoretically expanded and EU-based companies are world leaders in air separation. EU's ambition to strengthen its semiconductor industry by 2030 requires the expansion of production capacity for rare gases to prevent shortages in the medium term.

→ Impacts are probable in the broader EU manufacturing sectors by worsening the shortage of imported semiconductors for key industries.

QUICK GUIDE – This briefing is one of a series of overviews about potential supply disruption of non-food, non-energy raw materials due to Russia's war against Ukraine.

Joint Research Centre

The rare gases[1] krypton (Kr), neon (Ne), and xenon (Xe) are used for the production of semiconductors and other electronic equipment, as well as in the automotive, lighting, construction and space industries. Neon is a vital material for producing semiconductors, krypton is mostly used in insulated windows, and xenon is employed as a propellant for spacecraft's electric propulsion systems.

IMPACT ASSESSMENT

Short-term impacts and medium-term outlook globally

Pressures in the global supply of rare gases (Kr, Ne, Xe) were underway in 2021 before Russia's aggression against Ukraine, as demand was approaching the global production level. As the generation of rare gases is closely related to the steel industry (Box 1), the temporal suspension of Chinese steel plants to alleviate pollution for the Winter Olympics from September 2021 to March 2022 further compounded the tight supply (Betzendahl, 2022). Russia's invasion of Ukraine in February 2022 exacerbated supply challenges, as Ukraine and Russia are among the world's largest suppliers of rare gases, according to available estimates.

Firstly, the operation of Ukrainian steel plants producing crude rare gases was suspended. Furthermore, producers of purified gases in Ukraine ceased their operation, halting a significant portion of the world's rare gas exports. International sanctions on Russia that are isolating Russian industries from the global markets may also restrict the global supply of rare gases.

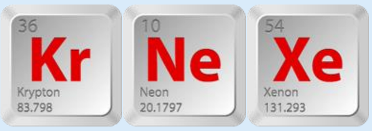
The most significant implications are expected for neon's supply disruption. Neon is an essential raw material for semiconductor manufacturing (Box 2), and Ukraine is a top producer of purified neon (Box 3). Also, Russian crude neon is purified in Ukraine and is reportedly being released into the atmosphere due to a lack of storage capacity (Betzendahl, 2022). Additionally, the production sites for crude or purified neon are less diversified worldwide compared to krypton and xenon (Figure 6). The Russian invasion of Ukraine introduces a new bottleneck in the global supply chains of semiconductor chips and, consequently, in the production of technologies that embed semiconductors (e.g. automotive, consumer electronics etc.). The world's semiconductors market is already in short supply, and demand is expected to rise strongly in 2022-2024.

Industry stockpiles could weather the impacts of supply disruption in the short term. Several estimates provided by media reports vary widely about the inventory levels of neon gas chipmakers keep, i.e. from 1 to 12 months[2,3]. Large semiconductor manufacturers are likely to hold extensive inventories that could last a few months (Athanasia and Arcuri, 2022), but smaller companies are more vulnerable to supply shocks because of their lower stocks[4]. A neon scarcity after stockpile depletion could have a ripple effect in the electronics industry if neon production is not expanded elsewhere.

Air separation units (ASUs) attached to steel mills provide significant amounts of the world's rare gases as by-products. Therefore, it could be argued that existing ASUs in the steelmaking plants worldwide could initiate production of rare

Box 1: The production of rare gases

The rare gases krypton (Kr), neon (Ne), and xenon (Xe) are only present in the air in trace amounts. Ne is found in greater abundance in the atmosphere than other rare gases (air is composed of 0.0018% Ne, 0.00011% Kr, and 0.000009% Xe). The rare gases are obtained exclusively from air in large air separation units (ASUs) by fractional separation (cryogenic distillation) of liquefied air. The main atmospheric gases oxygen and nitrogen, and sometimes argon, are the typical products of an ASU (Gasworld, 2012). Only the largest ASUs can separate rare gases at commercial quantities after processing huge volumes of air because of rare gases' tiny concentration in air (USITC, 2022). For example, to produce 1 m^3 Xe (5.9 kg) under normal conditions (1,013 hPa, 0 °C), more than 10 Mm^3 (12,920 t) of air must be processed (Elsner, 2018). Large scale ASUs with an oxygen capacity of more than 1,000 tonnes per day are needed for economically viable extraction of rare gases (Gasworld, 2012). Large ASUs are mostly co-located with the steel industry to feed oxygen to the oxygen-based steelmaking process. ASUs producing crude rare gases can be also associated with the chemical industry.



Kr and Xe are usually extracted with oxygen. The production sequence for their yield involves a second column in the ASU in which liquid oxygen is obtained containing approximately 0.3% of Kr and Xe. The pre-enriched gas mixture is then shipped to an enrichment plant to remove oxygen. In a subsequent purification step, the crude Kr/Xe blend is separated and purified to about 99.999% (Gasworld, 2012). Xenon's yield is approximately 10 times lower than that of krypton. The production of pure Kr is almost always associated with Xe, and 90% of pure Xe is derived from crude Kr/Xe gas mixtures (Betzendahl, 2017). Around 40% of the world's xenon is produced in ASUs that supply oxygen to chemical plants rather than steelworks (Elsner, 2018).

Different ASUs are tailored for Ne separation versus those targeting Kr and Xe extraction. Ne has different physical properties compared with Kr and Xe and it is normally extracted, in a crude mixture with helium, along with the nitrogen fraction in air separation. The enrichment and purification process is simpler because the crude product typically contains about 50% Ne. The crude gas mixture obtained through air separation is then purified by a separate plant to a purity level dictated by end-use requirements (Gasworld, 2012).

[1] Also known as noble gases. The group of noble gases includes helium, argon, neon, krypton, xenon and radon.
[2] https://www.ft.com/content/ac8733c4-bfea-4499-8a48-4997a77ad33f
[3] https://www.cnbc.com/2022/03/25/russia-ukraine-war-laser-neon-shortage-threatens-semiconductor-industry.html
[4] https://foreignpolicy.com/2022/04/19/russia-war-neon-semiconductor-microchip-economy/

gases and bridge the supply gap that Ukrainian producers have left. Though, swift diversification of supply chains is unlikely as it would take many months to add capacity (e.g. 1-3 years (Betzendahl, 2022)). Additionally, capacity can be added only to very large ASUs (Box 1). The extent of supply disruption depends on which ASUs can be modified to also extract neon and/or other gases. Moreover, even if alternative supply sources are secured, certification of a new gas source for purity and quality may take several months or even more than a year (USITC, 2022).

Previous shortages of rare gases did not last more than two years. Over-pricing prompted mainly conservation and recycling strategies (Box 4) to reduce consumption as the price volatility (Figure 13) may have discouraged investments in new capacity. Companies may also be unwilling to invest if the supply crisis is considered as temporary. High prices may also trigger substitution. For example, argon could be used in insulating windows instead of krypton, or LED lamps could substitute for halogen lamps that require xenon or krypton (Elsner, 2018). On the other hand, replacing neon with helium in excimer lasers is not feasible as performance is considerably deteriorated (Ozin, 2022).

Short-term impacts and medium-term outlook in the EU

The possible sources for reshuffling EU import flows away from Ukraine and Russia are limited, as few countries worldwide produce rare gases. Actually, China and the US are the only potential alternative sources, but the surplus for export might be restricted.

The EU has many facilities that can handle production and purification of rare gases (Figure 6). ASUs associated with the steel industry, where rare gases are presently not produced (Figure 8), provide a theoretical potential for capacity expansion. The technical and financial viability of expanding production to rare gases in these ASUs depend on the factors mentioned above, as well as on prevailing high prices for long enough to stimulate investment. It is also important to point out that EU-based companies (e.g. Linde AG, Air Liquide) have great expertise and know-how as they have built, own and operate production installations and purification capacities in multiple sites worldwide. Finally, it is noted that the EU is a net exporter of rare gases in value terms. All the above increase the EU's resilience to a supply shock in the short term.

However, medium-term impacts might be severe if domestic production of rare gases does not grow proportionally with the expansion of the European semiconductor industry that the EU's strategy[5] is aiming for.

DEMAND

Prominent applications for krypton gas are the manufacturing of insulated windows where it is used as a filling gas, and lighting (halogen lamps with krypton filling for car headlights). The semiconductors segment (excimer lasers) had a low share of total krypton demand in 2017 (Figure 1).

Figure 1 – Krypton's applications in EU manufacturing sectors, 2017

Applications	Industry producing end-use products	Industrial Ecosystem	Share (%)
Insulating glass	C23.12 Shaping and processing of flat glass	Construction	51%
Lighting (car headlights)	C27.40 Manufacture of electric lighting equipment	Mobility-Transport-Automotive	40%
Excimer lasers	C26.11 Manufacture of electronic components; C26.12 Manufacture of loaded electronic boards	Electronics	4%
Other (R&D, Geiger counters, scintillation counters used in PET or in SEM, cathode sputtering etc.)	C26.51 Manufacture of instruments and appliances for measuring, testing and navigation; C26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment; C26.11 Manufacture of electronic components; M72.19 Other research and experimental development on natural sciences and engineering	Electronics; Health	5%

Source: JRC based on Eurostat (2008) and data from Elsner (2018)

Neon gas is a critical input in semiconductor manufacturing. The laser lithography process of chip-making is by far the most significant use of neon (Figure 2) accounting for about three quarters of global demand. The remainder is consumed primarily by industrial lasers, medical applications (e.g. laser eye surgery) and display components.

Figure 2 – Neon's applications in EU manufacturing sectors, 2017

Applications	Industry producing end-use products	Industrial Ecosystem	Share (%)
Excimer laser mixtures (Semiconductors)	C26.11 Manufacture of electronic components; C26.12 Manufacture of loaded electronic boards	Electronics	72%
Excimer laser mixtures (Other)	C26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment; C26.11 Manufacture of electronic components	Electronics; Health	11%
Display components (Plasma, LPTS, LCD)	C26.11 Manufacture of electronic components	Digital	14%
Lighting (illuminated advertising)	C27.40 Manufacture of electric lighting equipment	Retail	1%
Other (nuclear physics & cryogenics in aerospace, medical, semiconductor and other applications)	C26.11 Manufacture of electronic components; C28.25 Manufacture of non-domestic cooling and ventilation equipment; C30.30 Manufacture of air and spacecraft and related machinery; C26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment; M72.19 Other research and experimental development on natural sciences and engineering	Aerospace & Defence; Electronics; Health	2%

Source: JRC based on Eurostat (2008) and data from Elsner (2018)

The lighting (halogen lamps in car headlights) and space industry, where Xe has been the typical choice of propellant for many electric propulsion systems (including Hall thrusters), are the largest users of xenon (Figure 3). The semiconductor industry also uses xenon (or krypton) to produce high-end flash memories.

[5] *COM(2022) 45 final. A Chips Act for Europe*

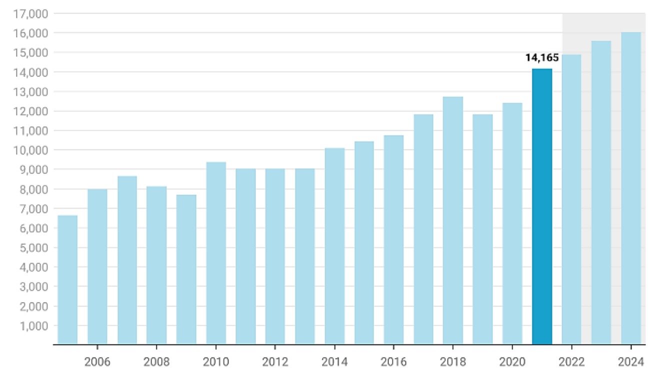
Figure 3 – Xenon's applications in EU manufacturing sectors, 2017

Applications	Industry producing end-use products	Industrial Ecosystem	Share (%)
Lighting (car headlights)	C27.40 Manufacture of electric lighting equipment	Mobility-Transport-Automotive	34%
Satellites	C30.30 Manufacture of air and spacecraft and related machinery	Aerospace & Defence	23%
Anesthetics	C21.20 Manufacture of pharmaceutical preparations	Health	8%
Photolithography	C26.11 Manufacture of electronic components; C26.12 Manufacture of loaded electronic boards	Electronics	8%
Lasers	C26.11 Manufacture of electronic components	Electronics	6%
Plasma/AMOLED Screens	C26.30 Manufacture of communication equipment	Digital	1%
Other (Black Matter R&D, diagnostic medical equipment, various detectors and instruments, radars, etc)	C26.60 Manufacture of irradiation, electromedical and electrotherapeutic equipment; C26.51 Manufacture of instruments and appliances for measuring, testing and navigation; M72.19 Other research and experimental development on natural sciences and engineering	Electronics; Health	20%

Source: JRC based on Eurostat (2008) and data from Elsner (2018)

The semiconductor industry is the largest consumer of the three rare gases. The global semiconductor market has been increasing rapidly, i.e. by a compound annual growth rate (CAGR) of 7.1% in the last 20 years. In 2021, semiconductor sales were worth USD 556 billion[5] and demand reached a record level; the amount of silicon processed to produce semiconductors — the most widely used semiconductor raw material — grew by 14% compared to 2020 (Figure 4). Shipments of silicon wafers in Q1 2022 increased 10% from the amount reported in Q1 2021 (SEMI, 2022), surpassing the previous record high in Q3 2021. The acceleration of digital transformation will double the demand for semiconductors by the end of the decade[5]; therefore, the demand for rare gases (particularly neon) is expected to increase strongly.

Figure 4 – Shipments of silicon materials[6] globally (2005-2021) and shipments forecast (2022-2024), in millions of square inches (MSI)



Source: Background data from SEMI (2021), SEMI (2022)

European headquartered companies have a share of about 10% in the global production value of semiconductors. Europe represents about 20% of the global sales value based on the device end-user's location[7]. The EU is a net importer and heavily dependent on third-country suppliers for semiconductor chips (Ciani and Nardo, 2022). The EU aims to expand domestic capacity to produce at least 20% of the world's semiconductors by value (including processors) by 2030, focusing on cutting-edge models[8].

Box 2: The semiconductor industry and the rare gases

Semiconductors are at the core of the digital and green economy. Semiconductor chips are used in almost all electronic devices and are embedded in virtually every technology. Semiconductors are also crucial for key technologies in the ongoing digital revolution, such as artificial intelligence, quantum computing, 5/6G communications, the internet of things etc.) (Ciani and Nardo, 2022).

Europe and other world regions have witnessed disruptions in the supply of semiconductors in 2020-2021, causing shortages and harming the production of goods across multiple downstream sectors (e.g. automotive, consumer appliances). The disruptions in the highly complex and interconnected supply chains of semiconductors resulted from multiple factors, such as the growing demand driven by digital transformation and accelerated by the pandemic. The shortage will likely extend into 2022 and potentially even beyond if new production capacity is not made available soon enough. The main world producers are currently expanding capacity but it will take between 18 and 24 months to reach commercial production (Ciani and Nardo, 2022).

Rare gases possess unique properties that have made them a key enabler of the semiconductor industry, e.g. they make easier to control desired chemical reactions at the molecular level, allowing the manufacture of ever more complex devices (Stockman, 2018). Particular grades (highly purified) are required for semiconductor production. Ne is used in laser lithography systems for advanced silicon semiconductor operations, i.e. Deep Ultraviolet (DUV) excimer lasers that print circuit patterns onto silicon wafers. Ne comprises as much as 95% of the gas mixture (excimer gas) required in the DUV lithography technology (Ozin, 2022). Ne is indispensable to minimise defects during the photolithography process and increase the overall yield of usable chips (USITC, 2022). Demand continues to grow for these advanced processes (Corbett et al., 2022). Kr and Xe are employed in excimer lasers for the advanced high aspect ratio (HAR) etch processes required in leading-edge memory manufacturing, e.g. 3D NAND flash memories. The demand is also expected to grow substantially over the next years as the industry adopts the "layer stacking" strategy to enhance scaling and gain greater bit density (Corbett et al., 2022).

SUPPLY

Global production

Production data for rare gases are not published, and available information is minimal; thus, it's hard to assess the relatively obscure structure and dynamics of the supply side. According to estimates published by the German Mineral Resources Agency (DERA) based on a few sources, the output of crude

[6] Shipments refer to semiconductor applications only and do not include solar applications
[7] SWD(2022) 147 final. A Chips Act for Europe

[8] COM(2021)118 – 2030 Digital Compass: the European way to the Digital Decade.

neon in 2017 was 720 million litres (corresponding to approximately 360 million litres of pure neon) (Figure 5).

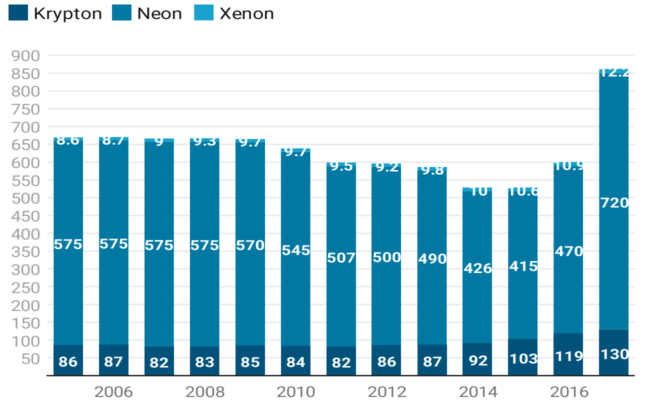
Box 3: The rare gases industry in Ukraine

Transparent data on the global supply of each rare gas are unavailable. Several sources report that Ukraine accounts for a significant percentage of the world's semiconductor-grade neon production. According to (DeCarlo and Goodman, 2022), Ukraine supplies an estimated half of the world's neon gas. According to Reuters estimates, about _half_ of the world's semiconductor-grade neon comes from Ukraine. Other sources suggest that Ukraine represents between _40%_ and _70%_ of the world's neon production and accounts for almost _70%_ of the world's neon gas capacity. It also reported that _40%_ of the world's krypton comes from Ukraine. In 2014, Ukraine had a higher share in global neon supply, ranging between 70% (DeCarlo and Goodman, 2022) and up to _90%_. Other estimates suggest that at present Ukraine accounts for 10% and Russia for 15% of total global production of all crude rare gases (Betzendahl, 2022). Ukraine's leading position is largely attributable to the legacy of the former Soviet Union steel industry when all oxygen ASUs for steel mills were equipped with Kr, Ne and Xe purification capabilities (Betzendahl, 2015)(DeCarlo and Goodman, 2022). In addition, Ukrainian companies achieved over time neon's purification to ultra-high-purity levels (to more than 99.999%) for use in laser gases (Ozin, 2022).

Two of the three Ukrainian producers of purified rare gases, the Mariupol-based _Ingas AE_ and _Cryoin Engineering Ltd_ in Odessa, _reportedly_ have stopped operation after Russia's invasion. Mariupol hosted the Ingas purification plant, which used to have as feedstock crude neon from Russian steel manufacturing (Elsner, 2018), and two ASU's serving steelmaking plants (PJSC Azovstal and PJSC Ilyich) that produced the crude gases for subsequent purification. The city was devastated during Russia's invasion and is _currently_ under Russian occupation. The third Ukrainian supplier, _ArNOX_ in Kiev, _announced_ after the war broke out that it was unable to fulfil its contracts; according to other _statements_ the plant has stopped running after having been bombed. Hence, rare gas facilities in Ukraine are unlikely to resume operations anytime soon.

[9] In 2022, the first plant in South Korea for crude and purified neon will commence production with an annual capacity of 22,000 Nm^3 (about 3% of the 2017 global production, and 16% of South Korean demand for neon) _https://www.ajudaily.com/view/20220112162636793_

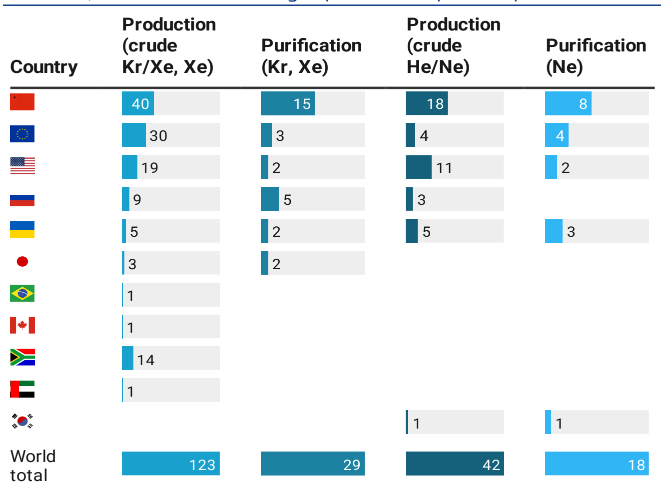
Figure 5 – Global production of crude rare gases, in million litres



Source: Based on estimates reported or derived from Elsner (2018)

The production volume of pure neon is larger by around three times compared to krypton and 30 times greater than xenon. However, according to the data gathered by DERA, the number of facilities worldwide separating or refining neon is much lower compared to krypton and xenon (Figure 6). Purified neon is produced by less than 20 installations worldwide located in a handful of countries, i.e. China, the EU, the US and Ukraine[9]. China has the majority of ASUs worldwide for crude Kr/Xe (33%) and crude He/Ne (43%) production, as well as refineries for the production of pure Kr and Xe (44%) and pure Ne (52%).

Figure 6 – Number of ASUs for the production of crude rare gas mixtures, and number of rare gas purification plants by location[10]



Source: Data from Elsner (2018) (except for South Korea[8])

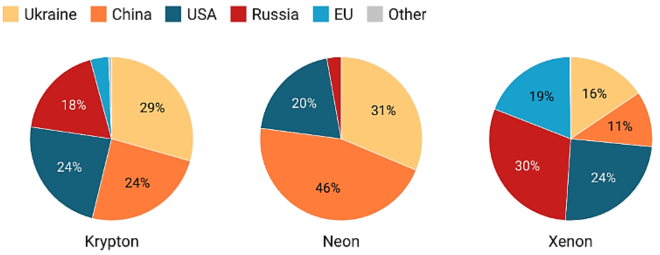
Global trade

Data in international trade statistics for rare gases are not available at a material level[11]. Figure 7 shows import data from South Korea, a major industrialised country and Asia's leading consumer of electronic speciality gases (Corbett et al., 2022). China is the dominant exporter of neon gas to South Korea and a noteworthy supplier of krypton, the US is a major exporter of all three rare gases, Ukraine is a significant supplier of krypton and neon, and Russia is the top exporter of xenon. The EU is a

[10] The list of ASUs and purification plants is not exhaustive.
[11] The relevant HS code 280429 'Rare gases other than argon' aggregates helium together with krypton, neon and xenon.

notable exporter of xenon (Figure 7). EU exports of rare gases to South Korea originate mostly from France.

Figure 7 – South Korean[12] import value of krypton, neon and xenon by origin, annual average 2019-2021



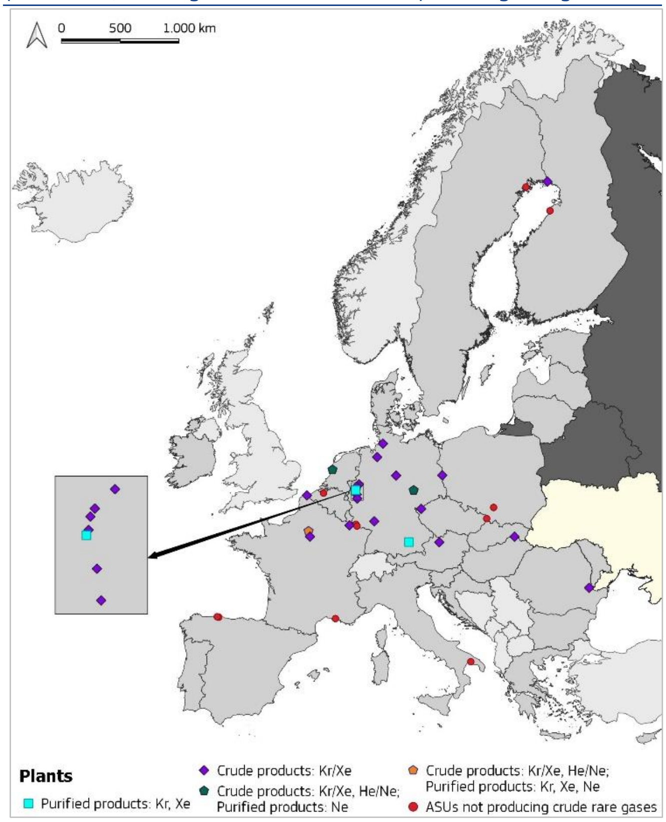
Source: JRC based on background data from KITA (2022)

EU IMPORT DEPENDENCY

EU production

Most of the ASUs equipped to separate and purify rare gases are in Germany (Figure 8). On the basis[13] of the number of air separation units (ASU) and purification plants operating in the EU and compared to the rest of the world (Figure 6), the supply chain of rare gases in the EU is mainly developed for crude Kr/Xe production (24% of the total number of ASUs) and Ne purification (22% of the total number of Ne refineries).

Figure 8 – ASUs producing crude rare gases[14], refineries for crude gas purification, and large ASUs[15] which are not producing rare gases.



Source: JRC based on Elsner (2018), GSPT (2022)

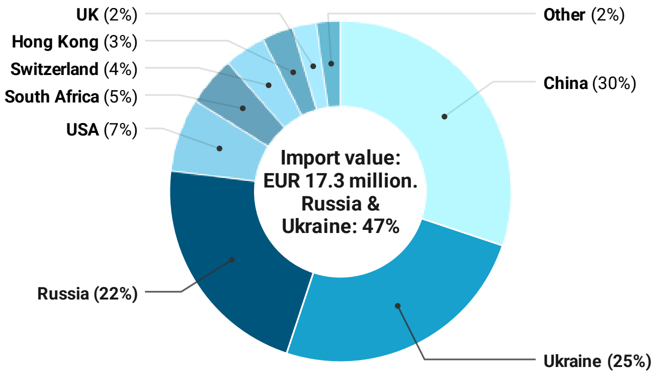
As regards the production of crude He/Xe gas mixture and the purification of Kr and Xe, 10% of the world's installations is located in the EU. Purified Kr and Xe are produced in 3 plants in Germany and France, and purified Ne is produced in 4 plants in Germany, France and the Netherlands. A few big players operate facilities in the EU, i.e. Linde, Air Liquide, Nippon Gases, and BASF.

It is calculated that 40% of the crude steel capacity in EU steel plants, which operate blast furnaces (BF) and basic oxygen furnaces (BOF) and require daily more than 1,000 tonnes oxygen generated in a nearby large ASU, are currently not linked with rare gas production (Figure 8). Thus, there is a theoretical potential for expanding domestic production of rare gases in existing ASUs.

EU imports

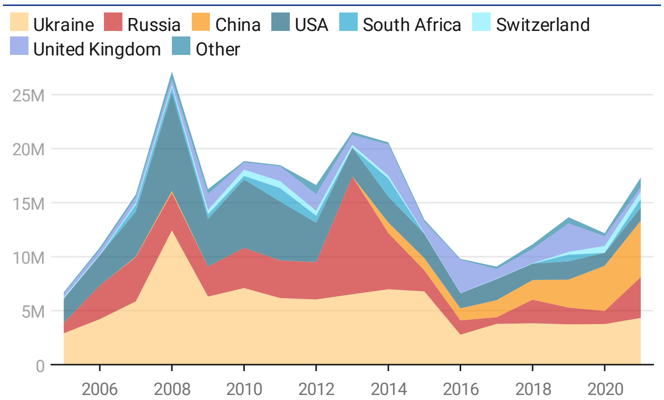
The EU sourced 47% of its rare gases imports from Russia and Ukraine in 2021 (Figure 9). Russia and Ukraine have been two of the largest EU suppliers in recent years (Figure 10), with a share in EU imports ranging from 39% to 54% in 2016-2021 by value.

Figure 9 – EU import value of rare gases[16] by origin, in 2021



Source: Eurostat Comext (2022).

Figure 10 – Structure of EU imports of rare gases by origin, in million EUR[16]



Source: Eurostat Comext (2022)

[12] South Korea is the only country among the major importers of rare gases which provide trade statistics separately for each of the rare gases. Data refer to the following codes of the Harmonized System of Korea (HSK): 2804292000 'Neon'; 2804293000 'Krypton'; 2804294000 'Xenon'.
[13] Production statistics or capacity data are not publicly available.
[14] The figure includes sites where more than one ASU is operating.
[15] ASUs associated with operating steel plants with blast furnaces (BF) and/or basic oxygen furnaces (BOF) with an estimated oxygen capacity of about 1 kt or more daily according to JRC's calculations based on BF/BOF capacity.
[16] Data for CN 28042990 'Neon, krypton and xenon'. The code comprises crude and purified gases.

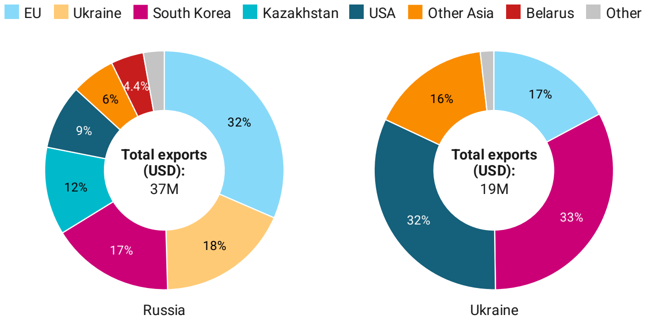
The EU is a net exporter of rare gases by value. However, the aggregation in trade statistics and the poor availability of public data do not allow us to properly assess EU's reliance on imports for each gas separately. It is also not possible to evaluate whether the EU primarily relies on imports of crude gases as raw materials needed for purification or purified gases.

TRADE FLOWS FROM RUSSIA AND UKRAINE

Global

Figure 11 shows Russia's and Ukraine's main trade partners for rare gases. Chip-producing counties in Asia and the US are the most significant destinations for Ukrainian exports. At the same time, the EU used to be the top destination for Russian exports.

Figure 11 – Destinations of Russian and Ukrainian exports of other than argon rare gases[17] by value, annual average 2018-2020



Source: UN Comtrade (2022)

The US, a major semiconductor-producing country, sourced 27% of its rare gases import value from Ukraine and 19% from Russia in 2018-2021 (USITC Dataweb, 2022). Regarding neon, Ukraine reportedly supplies 90% of the highly purified, semiconductor-grade neon used in the US (Athanasia and Arcuri, 2022). Finally, as shown in Figure 7, in the last three years (2019-2021), Ukraine and Russia together supplied South Korea — a major semiconductor and electronics producer — with 48%, 34%, and 46% of its krypton, neon and xenon imports, respectively.

EU

The EU relied on Russia and Ukraine for 15% and 27% of its rare gas imports, respectively, in 2019-2021 (Figure 12). Germany was the largest importer in the EU by value in 2019-2021, and Hungary was the most reliant on imports from Russia and Ukraine.

Figure 12 – Rare gases imports from Russia and Ukraine by Member State[18], annual average 2019-2021

Country	Import value (million EUR)	Russia (%)	Ukraine (%)
	14.4	15%	27%
	4.3	39%	23%
	3.6	6%	13%
	2.7	1%	62%
	1.4	0%	6%
	0.8	24%	76%
	0.4	0%	0%
	0.4	8%	0%
	0.2	0%	0%
	0.1	49%	2%
	0.1	0%	0%
	0.1	0%	70%

Source: JRC elaboration based on data from Eurostat Comext (2022)

PRICES

The rare gases market is opaque, and prices are not published. The few supplier companies in the global market mainly engage in confidential long-term contracts[19]; some uncontracted supply is also traded in the spot market[2]. Reports indicate that prices had already risen before the Russo-Ukrainian war due to constrained supply. For example, neon prices in China[20] and krypton prices in Japan[21] quadrupled in the first two months of 2022. Since Russia started the invasion, Ne prices in China soared tenfold in March 2022, while xenon and krypton prices rose by about 50%[22].

An example of potential price hikes due to the impending shortage of neon is the sixfold increase in its price in almost one day in 2014 (Cockerill, 2022) when Russia annexed Crimea, as most of the global crude neon supply came from Ukraine (70-75% in 2015) (Elsner, 2018). After the spike in neon prices, some chip manufacturers shifted their neon sources away from Ukraine (DeCarlo and Goodman, 2022), and the industry optimised processes to reduce neon usage (Box 4).

According to available data (Elsner, 2018), the annual neon price soared about 20 times in 2015 compared to 2013 because of the supply deficit in 2014-2015 (Betzendahl, 2015). Xenon's price was exceptionally volatile owing to the tiny market volume; it increased fourfold from 2007 to 2008 and threefold from 2012 to 2015 when demand exceeded supply because of the shutdown of large ASUs in Ukraine and Russia (Elsner, 2018). Finally, the krypton price continuously declined by more than ten times from 2009 to 2017 due to oversupply. As of summer 2018, the prices in Germany were reported at approximately EUR 0.1/lt for krypton and EUR 11/lt

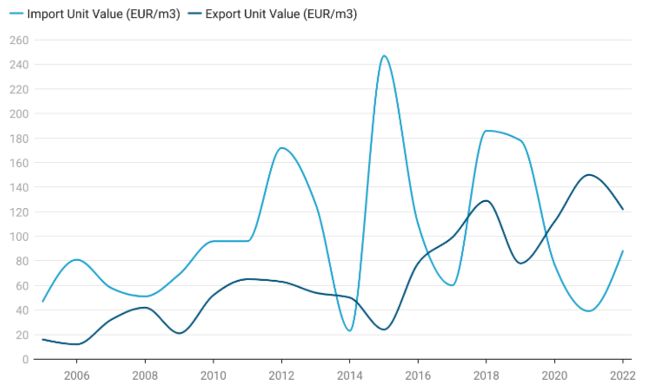
[17] Data for HS 280429 'Gases, rare; other than argon'. Alongside rare gases (krypton, neon and xenon), data refer also to helium gas.
[18] Annual average 2019-2021. Member States with an import value of less than <EUR 0.1 million are not shown.
[19] https://www.bloomberg.com/opinion/articles/2022-05-19/ukraine-war-mariupol-noble-gases-neon-helium-are-suffering-from-putin-s-war
[20] https://www.reuters.com/technology/exclusive-ukraine-halts-half-worlds-neon-output-chips-clouding-outlook-2022-03-11
[21] https://www.ft.com/content/950072f0-8c22-4050-bc63-631fa4b481eb
[22] https://technode.com/2022/03/25/a-brief-look-at-chinas-rare-gas-market/

Box 4: Recovery of rare gases

The increase in neon prices in 2015 triggered efforts to reduce the usage of neon gas. Manufacturers of excimer lasers achieved savings of 25%-70% of the previously required neon by adjusting software logic and by process optimisation (gas collection from lasers, impurity removal and injection back into the system). Xenon has been recycled for a long time, because of its rarity and high price, in the form of polluted gases for re-purification, e.g. xenon difluoride from plasma etching processes (Elsner, 2018) or exhaust gases out of satellite thrusters in the launch pad (Wright, 2022). On the other hand, there has been little interest in krypton recycling due to oversupply (Elsner, 2018).

for xenon (Elsner, 2018). Figure 13 shows the import/export unit value evolution in the EU to reflect price volatility.

Figure 13 - EU import and export unit value of rare gases (CN 28042990 'Neon, krypton and xenon'), 2005 to March 2022, adjusted for inflation



Source: Data from Eurostat Comext (2022)

The low cost of rare gases in comparison to the multi-million operating costs of the industries using them or the production cost of their downstream applications — for example xenon's cost used in satellites is minimal compared the overall cost of the satellite itself — make rare gas consumers to have little choice but to adapt to the higher costs to secure supply (Wright, 2022). Hence, prices of rare gases can rise sharply if supply is even slightly out of balance with demand.

CONCLUDING REMARK

Russia's military aggression against Ukraine will likely cause shortages in the supply of rare gases and lead to higher prices. Rare gases, and particularly neon, are a necessary resource for semiconductor production and Ukraine is a leading global supplier of purified neon gas. As supply chains around the world suffer from an ongoing semiconductor shortage, the squeeze on the supply of neon gas may have the most substantial implications.

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CONTACT INFORMATION

https://rmis.jrc.ec.europa.eu/
ec-rmis@jrc.ec.europa.eu