10 GALLIUM

10.1 Overview

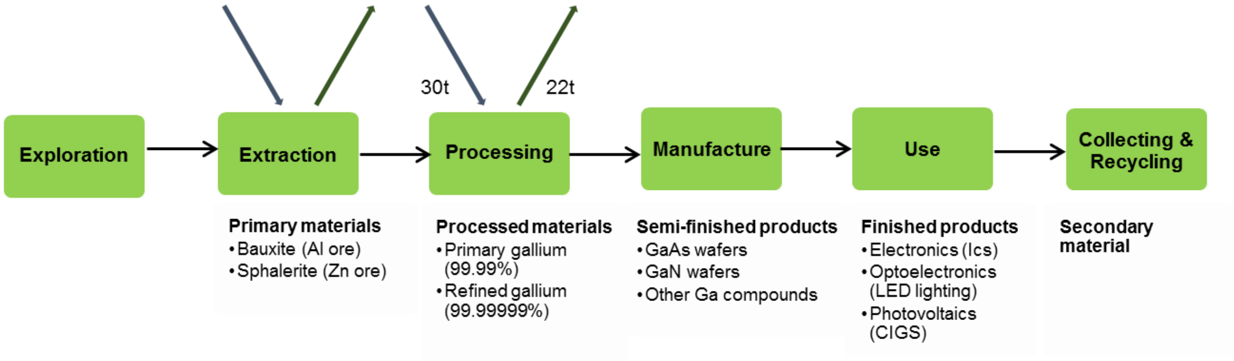

Figure 131: Simplified value chain for gallium[90]

Gallium (chemical symbol Ga, from Gallia) is a soft, silvery-white metal. It is an excellent conductor of both electricity and heat, has a very low melting point (30°C), and is a magnetic material. Gallium's abundance in the upper continental crust is 17.5 ppm, which is comparable to the one of lead (Rudnick and Gao 2013b). However, gallium does not occur in its elemental form in nature but mostly substitutes for other elements in certain minerals such as gallite ($CuGaS_2$) (Butcher, 2014). The term "primary gallium" in this factsheet (or its synonyms "virgin gallium", or "crude gallium") refers to the gallium metal of a purity of 3N (99.9%) or 4N (99.99%) obtained after the first steps of processing. "Refined gallium" refers to a purity of 6N (99.9999%) or 7N (99.99999%) obtained after further processing (European Commission 2017b). The main commercial form of gallium is 4N galllium metal.

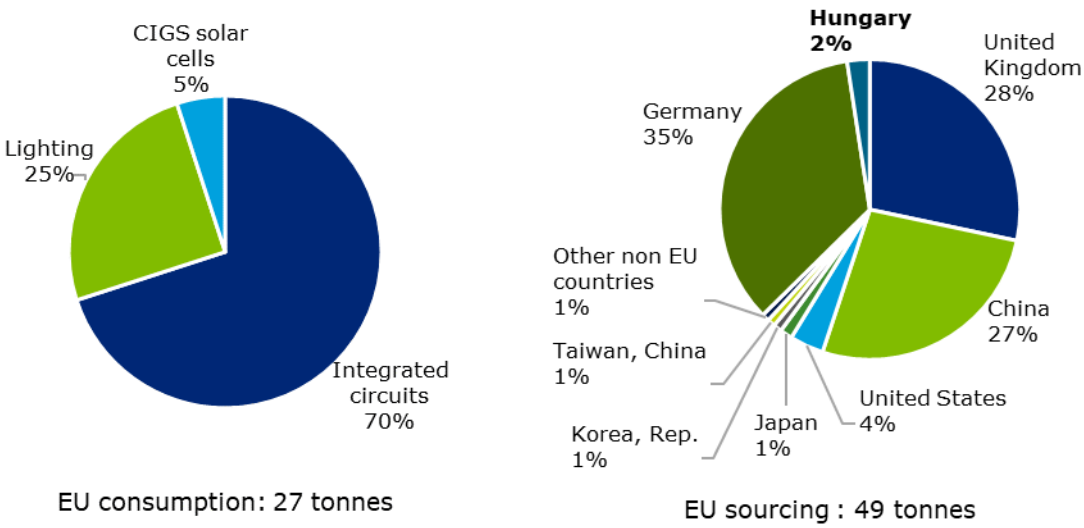

Figure 132: End uses of primary gallium metal (SCRREEN, 2019) in the EU and EU sourcing of primary gallium metal[91], annual average 2012-2016

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[90] In the Study on the review of the list of critical raw materials 2017, the estimated amount of gallium resource in the EU was 21,400 t; a figure that needed to be interpreted with caution.

[91] The import figure from UK may refer to refined gallium, not primary. The term "primary gallium" in this factsheet (or its synonyms "virgin gallium", or "crude gallium") refers to the gallium metal of a purity of 3N (99.9%) or 4N (99.99%) obtained after the first steps of processing.

This assessment focuses on primary gallium (Trade code CN 81129289 for "Unwrought Gallium, Gallium powders"). As a by-product of other metals (mainly aluminium and zinc), the supply risks of gallium availability is related to the capacities for its recovery.

Gallium is not traded on any metals exchange, and there are no terminal or futures markets where buyers and sellers can fix an official price. The prices are negotiated bilaterally between suppliers and customers on a long term base (Huy, D and Liedtke, M. ,2016). Between 2010-2014, the quantity of unwrought gallium exported to the global market was estimated at about 170-200 tonnes per year (Huy, D and Liedtke, M. ,2016). The prices of primary gallium (purity <99.99%) varied from USD 188 and USD 349 per kg in between 2012 and 2016 (BGR, 2020). According to USGS, refined gallium with a (purity of >99.9999%) prices varied between USD 529 per kg to USD 690 per kg in the period 2012-2016.

The EU consumption of primary gallium over the period 2012-2016 was estimated at 26.9 tonnes per year, which was fulfilled through imports and domestic production. United Kingdom, China and United States were the main suppliers of primary gallium into the EU. Between 2012 and 2016, the EU production of gallium occurred in Germany and Hungary. The EU was a net importer of gallium with 31% of import reliance.

Gallium is used in high-tech application. The main compounds of gallium, representing 94% of consumption are gallium arsenide (GaAs) and gallium nitride (GaN) (Huy, D and Liedtke, M. ,2016). These compounds are mostly used insemiconductors and optoelectronics. As for many minor metals, gallium has specific properties which make it unique in its main applications. Nevertheless, in case of disruption or price constraints, some alternative technologies or materials can usually substitute, often at lower cost but with loss of performances.

Given its use in photovoltaics, gallium can play a role in enabling low-carbon energy solutions in the EU economy, contributing to achieve the objectives of the "European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy".[92]

There is no mining extraction of gallium in the EU. Gallium is rarely found in sufficient quantities by itself to enable economic extraction and is extracted as a by-product of aluminium production, and to a much a lesser degree,of zinc production. Being a by-product, the estimation of gallium resource is linked to bauxite and zinc resource. According to USGS estimates in 2019, gallium contained in world resources of bauxite would exceed 1 million tonnes, with a considerable quantity potentially contained in world zinc resources (USGS, 2019). Nevertheless, only less than 10% is potentially recoverable from these resources. In 2011, Indium Corporation estimates of gallium resources were more conservative with 760,000 tonnes worldwide (European Commission, 2014a). In Europe, bauxite resources are reported as being present in many countries such as Bulgaria, France, Germany, Greece, Hungary, Italy, or Romania (Minerals4EU, 2019) representing potential gallium resources.

The average world annual production of primary gallium over 2012-2016 reached a quantity of 214.5 tonnes per year with 81% of production in China (WMD, 2019). The EU production of primary gallium was reported at 19 tonnes per year from Germany and 1.6 tonnes per year from Hungary during the same period (World Mining Data, 2019). However, the gallium production in Hungary stopped in 2013 (Fekete, 2019).

At present, no gallium is recovered from post-consumer scrap (Huy, D and Liedtke, M. ,2016). The rate of recovery of gallium from end-of-life products reported by UNEP is near

[92] COM(2018) 773 final A Clean Planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

0% (UNEP, 2011). The low recovery rate of gallium is due to the difficulty and cost to recover it in items where it is highly dispersed.

Since 2014, gallium arsenide is mentioned in Annex XVII to REACH regulations in the category carcinogenic, mutagenic or reprotoxic substances. However, none of gallium compounds is on the list of substances of very high concern (ECHA, 2014). Globally, there were no trade restrictions imposed on gallium in the year 2012-2016 (OECD, 2019).

10.2 Market analysis, trade and prices

10.2.1 Global market analysis and outlook

In general, data on the global trade of gallium are difficult to obtain as they are often incomplete and partially contradictorily. From 2010 to 2014, the quantity of unwrought gallium exported to the global market was estimated at about 170-200 tonnes per year year (Huy, D and Liedtke, M. ,2016).

China remained the major producer of primary and refined gallium over the period 2012-2016. The primary gallium production capacity of China was estimated at 550 tonnes in 2014, mostly from alumina production and 170 tonnes from upgrading and recycling of gallium (Huy, D and Liedtke, M. ,2016). At company level, the Chinese company Zhuhai SEZ Fangyuan Inc. was among the major producers of primary gallium with annual production capacity of 140 tonnes, as reported by Huy, D and Liedtke, M. , (2016).

Between 2010 and 2015 Chinese capacity for primary gallium has grown from 140 tonnes per year to 600 tonnes per year, in expectation of growing demand for GaN LEDs for backlighting in tablet computers, mobile phones and TVs. As a consequence, the large surplus of primary gallium from China would most likely restrict output non-China producers of gallium, such as Japan, the Republic of Korea, Russia, and Ukraine (USGS, 2018).

Apart from China, the production capacities for primary gallium is estimated at 120 tonnes by December 2016, distributed in Germany, Kazakhstan, South Korea, Ukraine, Russia, Japan, and Hungary (USGS, 2016).

At refining stage, the main producers of refined gallium from primary material were China, Japan, the United Kingdom, the United States, and Canada (see section Refining and purification and gallium).

Growing demand in all sectors of the semiconductors/semi-insulator market will lead to increasing consumption of gallium in the coming years (Huy, D and Liedtke, M. ,2016). Integrated circuits would most likely still drive most of the future gallium demand towards 2035. A slight upward trend of gallium demand should be expected. The main drivers of future demand of gallium used smartphones and computers in this study are among others, growth of demand related to social needs (on-line social network, applications, etc), the trend for smaller and more integrated devices (Monnet, 2018).

Table 56: Qualitative forecast of supply and demand of primary gallium

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Gallium	x		+	+	+	?	?	?

10.2.2 EU trade

The EU changed from being a net exporter of primary gallium in 2012-2013 to a net importer in 2013-2016 (Figure 133). The EU import reliance of primary gallium was estimated at 31% (average of 2012-2016). The production in Hungary stopped in 2013. In 2016 Germany stopped its production due to high operating costs and cheap Chinese material available.

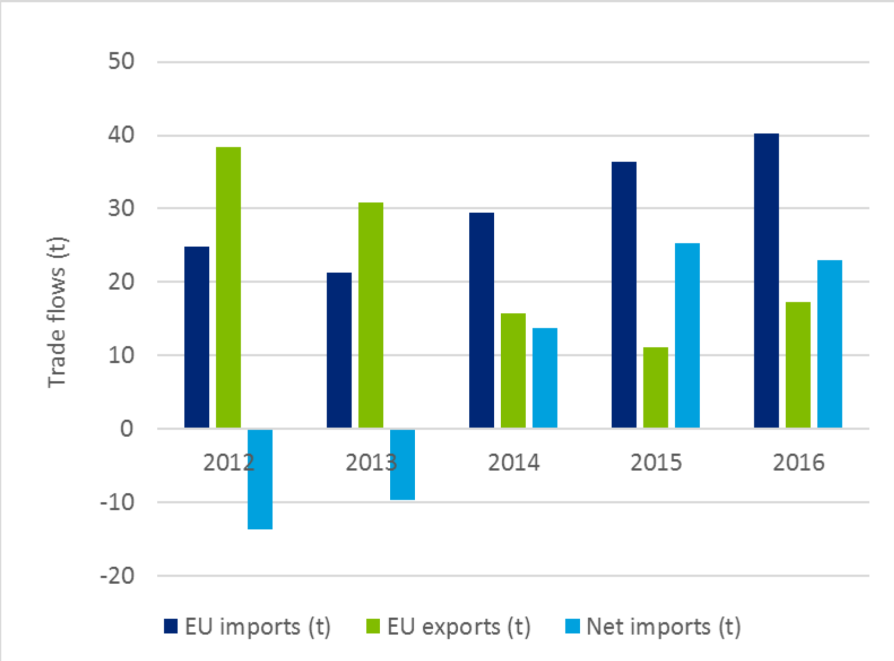


Figure 133: EU trade flows for gallium CN8 code 81129289 (Eurostat, 2019a)

Based on the trade data from Eurostat Comext, CN8 code 81129289 (Unwrought Gallium; Gallium powders), China and the United Kingdom were by far the first source of EU supply for this period (Figure 133). However, according to expert, the UK exported refined gallium produced from the German primary gallium (BGR, 2019).

In smaller quantities, the following countries also supplied primary gallium to the EU in 2012-2016: United States, Japan, Korea, Canada. For some countries like United States, Canada or Russia, imports include secondary material (new scraps) for treatment within the EU. There was no export restrictions targeting gallium from the supplying countries to the EU during the period 2012-2016 (OECD, 2019).

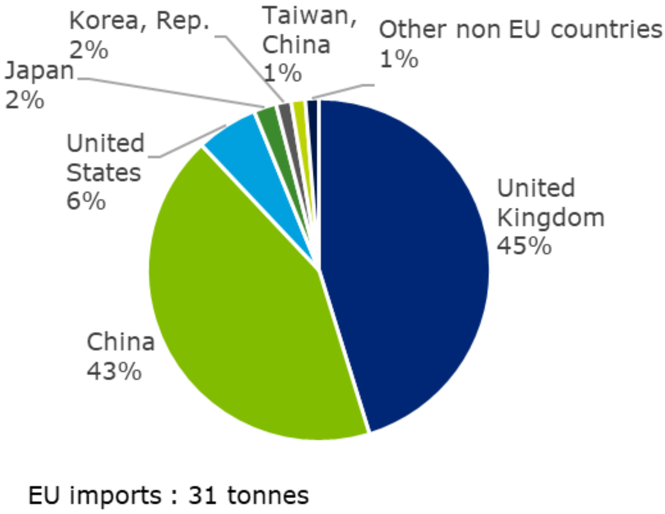


Figure 134: EU imports of primary gallium CN8 code 81129289. Average 2012-2016 (Eurostat-Comext, 2019)

10.2.3Prices and price volatility

Gallium is not traded on any metals exchange, and there are no terminal or futures markets where buyers and sellers can fix an official price. Gallium prices are negotiated bilaterally on a long term base between suppliers and customers (Huy, D and Liedtke, M. ,2016). References for prices are obtained through averages of past deals between private parties, generally available through paid subscription (e.g. Asian Metal, Metal Pages).

Figure 135 shows the trend of prices of high purity 7N gallium (99.99999%). In 2011 gallium 7N price reached USD 688 per kg. Since then, there was a progressive decrease to USD 318 per kg in 2015, in great part due to oversupply in China.

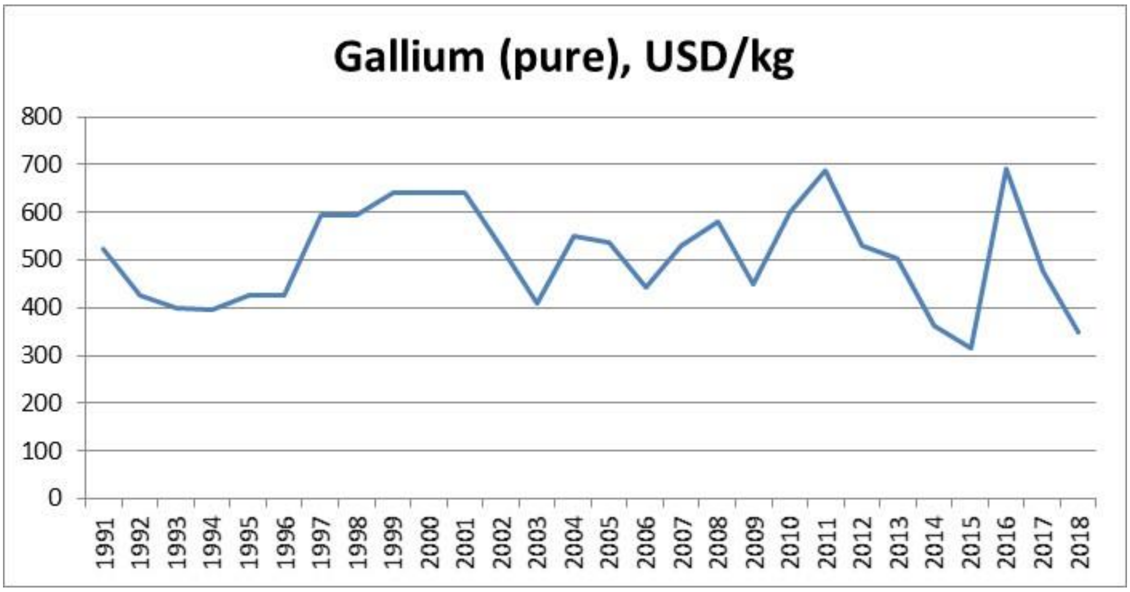


Figure 135: Gallium price trend (purity min. 99.99999 %) (Data from USGS)

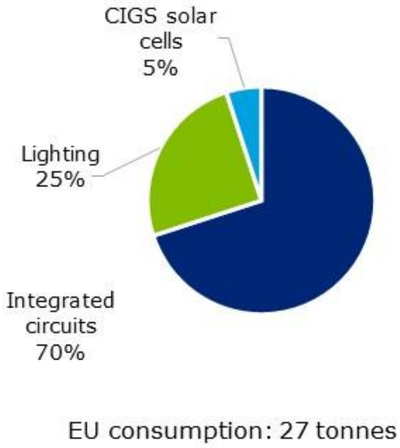
10.3 EU demand

10.3.1 EU demand and consumption

Apparent consumption figures (EU production + EU imports - EU exports) are not reliable due to uncertainties related to the share of gallium produced, traded, or integrated in finished goods at all levels. CN code used for the EU supply is 81129289 (Unwrought Gallium; Gallium powders). These figures may include secondary gallium (new scraps) for some countries like United States, Canada, Russia (European Commission, 2017).

10.3.2 Uses and end-uses of gallium in the EU

The final end-uses of gallium in the EU has not changed since 2010-2014. It can be estimated that 70% of gallium consumption has been for Integrated Circuits (ICs), 25% for lighting applications (mostly LED technology) and around 5% in the Copper-Indium-Selenium-Gallium photovoltaic technology (USGS, 2015; Mikolajczak, 2016)(Figure 136).



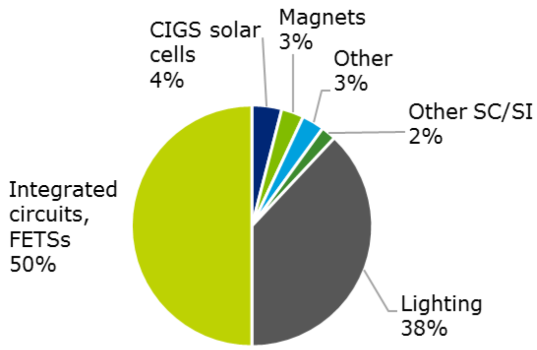


Figure 136: EU end uses of gallium average 2012-2016) (left) (SCRREEN, 2019) and global end uses of gallium (right) (data source: USGS, 2019)

The most common gallium compounds used in semiconductors technology are gallium arsenide (GaAs) (92%), gallium nitride (GaN) (8%) (BRGM, 2016). One of the reasons why GaN is produced in reduced quantities is that GaAs is composed of two metals whereas GaN is formed from a metal and a gas, which is much more difficult and costly to make. Different end-uses require different qualities of substrate crystal, with integrated circuits (ICs) and microwave devices requiring the highest quality.

In integrated circuits application, a few examples of electronic devices where Integrated Circuits are critical components include:

- Mobile phones; mostly in Power Amplifiers (PAs). The PAs in a mobile phone are the vital components that amplify signals, both voice and data, to the appropriate power level for them to be transmitted back to the network base-station. The more advanced the generation used (3G, 4G), the more PAs it needs;
- Wireless communication systems; where semiconductors are employed in a number of different contexts (fibre optics, sensors, etc.);
- Military applications; for radar, satellite, night vision or communication high performance devices.

In lighting, semiconductors are used in an optoelectronic capacity, because of their ability to convert electrical input into light output. Some of their main applications are Infrared Emitting Diodes (IREDs), Laser Diodes (LDs) and Light Emitting Diodes (LEDs); the latter being one of the fastest growing markets in the past few years (Grady, 2013).

In photovoltaics, gallium's main use is Copper-Indium-Selenium-Gallium (CIGS) technology. It is a thin-film technology that involves the deposition of a thin layer, only a few micrometres deep, of semiconducting material on various different surfaces. However, since 2010, the market for this technology has dropped, the vast majority of solar cells for terrestrial applications using crystalline silicon (c-Si, both mono- and multi-crystalline) technology (Fraunhofer, 2016). CIGS technology is preferred for specific terrestrial applications where flexibility is required (Butcher, 2014). Quantities of gallium currently used in solar-cell production thus remain small.

Other end-uses for gallium metal or chemicals include eutectic alloys, pharmaceutical compounds (gallium nitrate) or NdFeB magnets (wher Ga can be added in small quantities to improve magnetic properties and corrosion resistance), which remain minor at the industrial level.

Figure 136 reflects the global end-uses of gallium, which includes also the shares of these "other end-uses". Relevant industry sectors for gallium, described using the NACE sector codes, are reported in Table 57.

Table 57: Gallium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	2-digit NACE sector	4-digit NACE sectors	Value added of NACE 2 sector (M€)
Integrated circuits	C26 - Manufacture of computer, electronic and optical products	C2610- Manufacture of electronic components	65,703
Lighting	C27 - Manufacture of electrical equipment	C2740-Manufacture of electric lighting equipment	80,745
CIGS solar cells	C26 - Manufacture of computer, electronic and optical products	C2610- Manufacture of electronic components	65,703

10.3.3Substitution

In semiconductors, silicon or silicon-based substrates are usually the main substitutes for GaAs or GaN substrates, such as SiGe (CRM InnoNet, 2015). But it can only be for a limited number of applications, as silicon presents a lesser electron mobility and is therefore significantly less efficient. GaAs-based semiconductors also operate at higher breakdown voltages and generate less noise at high frequencies (>250 MHz). Pure GaAs substrates finally have the great advantage of being semi-insulating, whilst silicon substrates are semiconducting.

In lighting, LEDs present many advantages such as their low-energy consumption, non-toxicity, and longevity (up to 100,000 hours). Organic LED (OLED) could be a substitute to solid state LED but so far, they are not competitive in terms of price and durability (CRM InnoNet, 2015).

In photovoltaics, Crystalline silicon technologies currently represent more than 90% of the market for terrestrial applications, even though conversion efficiency is reduced from 18-22% to 8-15% when silicon is used rather than CIGS in photovoltaic cells. Other thin film technologies include cadmium telluride (CdTe) and copper indium selenide (CIS) (Fraunhofer, 2016).

10.4 Supply

10.4.1 EU supply chain

The EU supply chain of gallium is quite mature; players adapt to market conditions.

All levels of the gallium supply chain are present in the EU:

- Based on the annual production figure in World Mining Data (2019), the average EU production of primary gallium over the years 2012-2016 was estimated at 19 tonnes per year. Between 2012 and 2016, the EU production mainly took place in Germany (17 tonnes per year) and for a minor quantity (approximately 1 tonne per year), in Hungary, accounting for a total of 9% of global primary gallium supply. The production of both countries have reportedly stopped. Inga Stade GmbH, Germany's sole producer of primary gallium, stopped their production in 2016. The primary gallium produced by Inga Stade was shipped to the refining in the UK and in the USA to further treat primary gallium up to 7N purity (Monnet, 2018). The production in Hungary stopped in 2013 (Huy, D and Liedtke, M. ,2016). Hungary's production came from crude gallium extraction from Bayer liquor with a purit of 4N to 7N. The estimated capacity of production in Hungary reached 8 tonnes per year. In the past, there was also production of primary gallium in Slovakia, however, it stopped in 2010. Despite its production, the EU remained dependent on its foreign imports of primary gallium for the period 2012-2016. The average annual EU import of primary gallium in the period 2012-2016 was approximately 31 tonnes. On the other hand, EU exports of primary gallium was 22.7 tonnes. The EU import reliance of primary gallium was 32%.
- At processing stage, some of the few companies in the world producing refined high-purity gallium (6N or 7N) are located in the EU, for exampleCMK[93] in Slovakia and PPM Pure Metals[94] in Germany).
- At manufacturing stage, there are processors and wafer manufacturers in Germany (e.g. Freiberger Compound Materials) and in Belgium (Umicore, which commercializes trimethylgallium). Both companies are suppliers of downstream European microelectronic and optoelectronic industrials.
- At recycling stage, some manufacturers are also active in closed-loop recycling, with facilities often located abroad. Intra-companies material transfers are frequent in this activity. Part of gallium consumption also occurs in the form of imported manufactured products.

[93] http://cmk.sk/

[94] http://www.ppmpuremetals.de

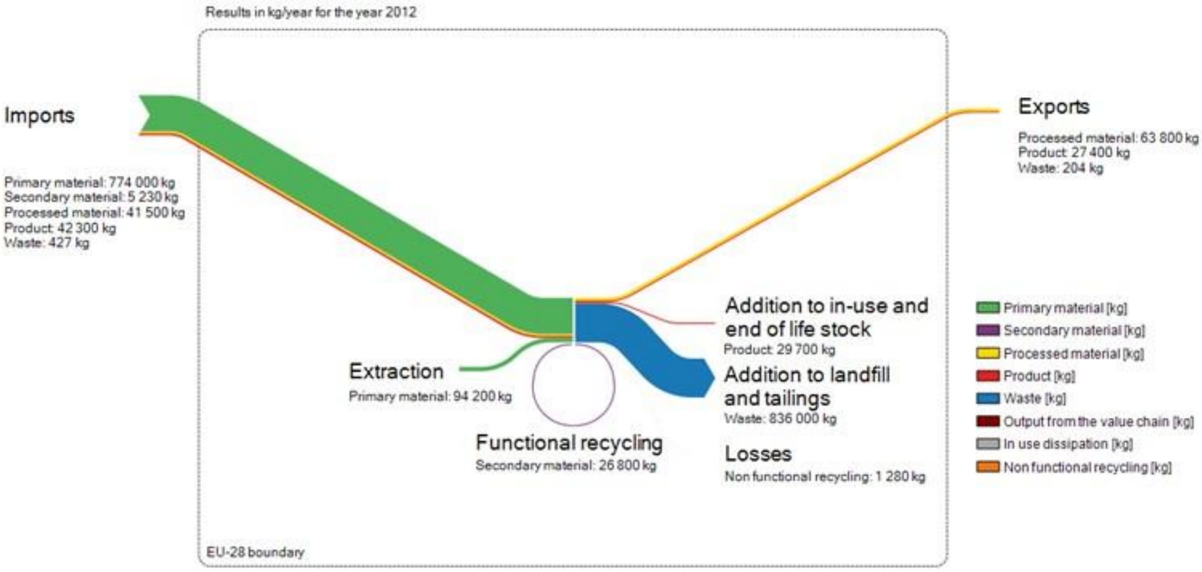


Figure 137: Simplified sankey diagram of material system analysis of gallium (reference year 2012) (BIoIntelligence, 2015)

10.4.2Supply from primary materials

10.4.2.1 Geology, resources and reserves of gallium

Geological occurrence: Gallium is not found in its elemental form and does not form economically recoverable concentrations . Gallium is almost exclusively obtained as by-product during the processing of other metals, mainly aluminium and zinc (Huy, D and Liedtke, M. ,2016).

Recovery as a by-product of aluminium processing

The production of gallium from bauxite, the main ore of aluminium, is the primary source of supply. Gallium is present in bauxite as a trace element. It would originate from minerals such as feldspar or nepheline (Deschamps et al., 2002). Both aluminium and gallium are released from these minerals during weathering processes and their similar geochemical properties result in the enrichment of both elements in bauxite (Dittrich et al., 2011). The ratio of gallium to aluminium, and therefore the concentration of gallium, in bauxite increases with greater intensity of weathering. Gallium also appears to be more abundant where the bauxite was derived from alkali source rocks (Weeks, 1989). The gallium content in bauxite can vary from 10 to 160 ppm (Mordberg et al., 2001; Bhatt, 2002). On average, it is reported to be 57 ppm (Schulte and Foley, 2014).

Recovery as a by-product of zinc processing

Gallium concentrations in the zinc ore, sphalerite, are known to increase as the temperature of deposition decreases, although it can still be present in intermediate and higher-temperature deposit types (Stoiber, 1940; Cook et al., 2009).

In the hydrometallurgical route for zinc production, zinc oxide is first produced by roasting the zinc sulphide (sphalerite). The gallium-bearing zinc oxide is then leached with sulfuric acid to produce a zinc sulphate solution. The impurities, which include gallium, are removed through the addition of antimony or arsenic trioxide, zinc dust or proprietary reagents. The gallium is then extracted from the resulting separated solids or 'cement residues' by electrolysis (Butcher, 2014). In 2011, this source accounted for less than 1% of total gallium supply (Roskill, 2011).

Global resources and reserves[95] According to USGS (2019) estimates, gallium contained in world resources of bauxite would exceed 1 million tonnes, with a considerable quantity also potentially contained in world zinc resources. Quantitative estimates of reserves were not available (USGS, 2019)

EU resources and reserves[96]

In the Minerals4EU (2019) project, no quntitative information was reported concerning gallium. Bauxite resources are reported as being present in many EU countries such as Bulgaria, France, Germany, Greece, Hungary, Italy, or Romania representing potential gallium resources. There has not been any updates of the information in Minerals4EU.

The only existing estimates of EU gallium resources are provided in the 2014 criticality assessment at 21,400 tonnes, a quantity based on identified bauxite deposits (Moss R.L. et. a., 2011). This number should be interpreted with appropriate caution though, as it does not comply with international standards of reporting (UNFC) and is very likely to be overestimated, as well as being uneconomic in current market conditions.

10.4.2.2 World and EU mine production

The annual global production of primary gallium between 2012 and 2016 was estimated at 218 tonnes by the World Mining Data (2019).

Primary gallium production is known to have increased between 2012 and 2014, in large part due to major expansion of both capacity and output in China. The overcapacity from China led many producers other than Chinese to stop their gallium operations during this period.

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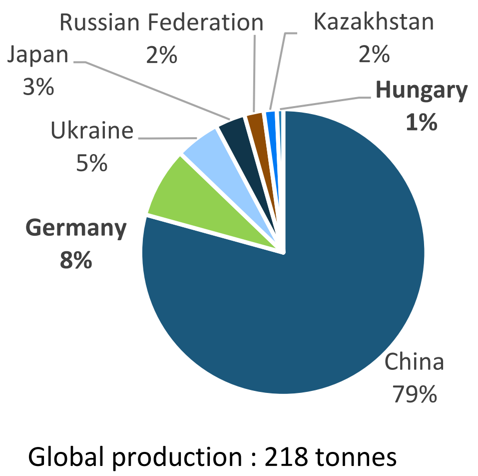
[95] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of gallium in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template.[95], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[96] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for gallium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for gallium, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for gallium the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However a very solid estimation can be done by experts.



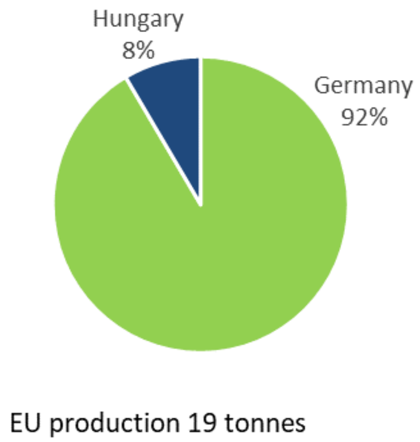


Figure 138: Global (left) and EU (right) mine production of primary gallium in tonnes and percentage. Average for the years 2012-2016. (WMD, 2019)

The EU production occurred in Germany and Hungary, accounting for an average 19 tonnes per year from 2012 to 2016.

According to company reports, Hungarian production stopped in 2013 (MAL Magyar Alumínium Termelő). The production in Germany (Dadco Alumina) stopped in 2016.

10.4.3Supply from secondary materials/recycling

At present, no gallium is recovered from post-consumer scrap (Huy, D and Liedtke, M. ,2016). The rate of recovery of gallium from end-of-life products is near 0% (UNEP, 2013).

The low recovery rate of gallium is due to the difficulty and cost to recover gallium in items where it is highly dispersed. Gallium in its major application, semiconductor devices such as integrated circuits (ICs) and light emitting diodes (LEDs), is used in a few microns thick deposition layer on top of a much thicker substrate and therefore require very little gallium per device (Weimar, 2011). Current recycling processes of waste electrical and electronic equipment in which they are contained rather favour the recovery of precious metals or copper, while gallium ends up as an impurity in recycled metals or in waste slags (UNEP, 2013).

However, as for many other metals, pre-consumer recycling (i.e. from industrial scrap) is more common source of secondary supply for gallium. The manufacture processes of gallium arsenide (GaAs) and gallium nitride (GaN) wafers are estimated to be the metal's most important secondary source, with some 60% scrap generated and recycled in a 'closed loop' (Butcher, 2014). As for gallium used in thin film photovoltaic production, CIGS technology in particular, material yields assuming sputtering deposition is typically 30-60%, which also allow material recovery and recycling (Marwede, 2014).

Worldwide production capacity of secondary gallium is estimated at 200 t (Huy, D and Liedtke, M. ,2016). In the United States, high/purity gallium new scrap is known to be recovered from GaAs-based devices (USGS, 2019). There are a few companies in the EU with operations for Ga recycling, for example CMK in Slovakia, who refined from low purity primary gallium (3N, 4N) and from recycled waste material containing gallium (gallium arsenide, chloride, oxide). The recycling and refining capacities was reported at 25 tonnes per year for the years 2006 – 2009 (Huy, D and Liedtke, M. ,2016).

10.4.4 Refining and purification of gallium

Optoelectronic applications generally require gallium (and arsenic) of at least 6N purity (99.9999%) and electronic applications require 7N purity metal. Purities of 6N or 7N are achieved by gradual crystallization of liquid gallium. Two methods exist and rely on the fact that impurities tend to remain in the liquid phase and cannot contaminate the growing crystal. There are many impurities of concern such as Ca, C, Cu, Fe, Mg, Ni, Se, Si, Sn, Te. Concentrations of these elements should be less than 1 ppb in the gallium (and arsenic) used for GaAs semiconductors manufacture. Lead, mercury and zinc concentrations must also be lower than 5 ppb. Mass spectrometry is used to analyse final high purity gallium for such impurities (Roskill, 2011).

The capacity for refining gallium into high-purity gallium (6N or 7N) worldwide is estimated at around 160 tonnes according to USGS and it is and less concentrated in China. It is only mastered by a few companies, some of them located in the EU, for example, CMK[97] in Slovakia and PPM Pure Metals in Germany[98].

10.5 Other considerations

10.5.1 Environmental and health and safety issues

Since 2014, gallium arsenide has been mentioned in Annex XVII to REACH regulations in the category carcinogenic, mutagenic or reprotoxic substances. However, none of gallium compounds is on the list of substances of very high concern (ECHA, 2014).

10.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. The results for both economic importance and supply risk for gallium stayed relatively stable compared to 2017's result. Therefore, the change in economic importance was caused by the difference in value added figures by sector since the end-use application remained the same compared to criticality assessment 2017.

The slight change in supply risk might have been influenced by the increasing production from China, raising from 73% of global supply to 79% over the year 2012-2016. The absence of production from Hungary has also influenced the increasing score of supply risk. The results of criticality assessment 2020 and of the earlier assessments are shown in Table 58.

Table 58: Economic importance and supply risk results for Gallium in the assessments of 2011, 2014, 2017 and 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Gallium	6.5	2.5	6.3	1.8	3.2	1.2	3.47	1.26

[97] http://cmk.sk

[98] www.ppmpuremetals.de

10.7 Data sources

10.7.1 Data sources used in the factsheet

Bhatt, C.K. (2002). Estimation of gallium in a bauxite-ore deposit using an energy-dispersive X-ray fluorescence technique. Radiation Physics and Chemistry 65, 193–197.

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) (2019). Personal communication during CRM review process

BGR (Bundesanstalt für Geowissenschaften und Rohstoffe) (2020). Personal communication during CRM review processBio Intelligence Service (2015). Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials – Final Report. Prepared for the European Commission, DG GROW

BRGM (2016). Fiches de criticité - Le gallium, éléments de criticité. [online] Available at : www.mineralinfo.fr/page/fiches-criticite

Butcher T., Brown T. (2014). Gallium. In Critical Minerals Handbook. ed. G. Gunn. Publisher J. Wiley &Sons. Chapter 7, pp 257-305.

Cook, N.J., Ciobanu, C.L., Pring, A. Skinner, W., Shimizu, M., Danyushevsky, L., Saini-Eidukat, B. and Melcher, F. (2009). Trace and minor elements in sphalerite: a LA-ICPMS study. Geochimica et Cosmochimica Acta 73, 4761–4791.

CRM InnoNet (2015). Critical Raw Materials Substitution Profiles_Gallium. http://www.criticalrawmaterials.eu/documents/

Cui, R., Guo, J., Yin, L., Huy, D., Liedtke, M. (2016). Supply and Demand of Lithium and Gallium. P. 28 – 50. ISBN 978-3-943566-33-8. Bundesanstalt für Geowissenschaften und Rohstoffe - BGR, Hannover, Germany.

Deschamps Y., Bailly L., Bouchot V., Gentilhomme P., Hocquard C., Lerouge C., Milesi J .P., Nicol N., Ollivier P., Pelon R., Salpeteur I. avec la collaboration de Save M., Thomassin J.F. (2002). Métaux rares à forte demande industrielle. Tantale, germanium, indium et gallium. Etat de l'art en économie, traitement des minerais, gîtologie. Rapport BRGM/RP-51558-FR, 284 p. 22 fig., 45 tabl., 32 ann.

Dittrich, T., Seifert, T. and Gutzmer, J. (2011). Gallium, can future demand be met by geological and technological availability? Department of Mineralogy, Technische Universität Bergakademie Freiberg, Germany.

ECHA (2014). Gallium arsenide. European Chemicals Agency. [online] Available at: https://echa.europa.eu/substance-information/-/substanceinfo/100.013.741

European Commission (2011). Critical raw materials for the EU. [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2014)a. Report on Critical Raw Materials for the EU. Critical Raw Matetrials Profiles [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2017). Report on Critical Raw Materials for the EU. Critical Raw Matetrials Profiles [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Eurostat (2019)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

Eurostat (2019)b. Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). [online] Available at: http://ec.europa.eu/eurostat/en/web/products-datasets/-/SBS_NA_IND_R2

Fekete, Istvan, (2019) personal communication in September 2019.

Fraunhofer (2016). Photovoltaics report - Fraunhofer Institute for Solar Energy Systems (ISE). November 2016. [online] Available at: https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf

Grady T., Thompson K., Crow A. M., Ridsdale D. (2013) LED Spotlight. Edison Investment Research. London, UK [online] Available at: www.edisoninvestmentresearch.com/sectorreports/LEDreportJune2013.pdf

Marwede M., Reller A. (2014). Estimation of life cycle material costs of cadmium telluride- and copper indium gallium diselenide-photovoltaic absorber materials based on life cycle material flows. J. Ind. Ecol. 2014,18 (2), 254−267.

Mikolajczak C. (2016). Indium Corporation, communication during the CRM workshop held in Brussels on 06/11/2016.

Minerals4EU (2019). European Minerals Yearbook. [online] Available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html

Monnet, A., Abderrahim, A.A. (2018). Report on major trends affecting future demand for critical raw materials. SCRREEN D2.2. Available online at: http://www.scrreen.eu/wp-content/uploads/2018/07/D2.2-Report-on-major-trends-affecting-future-demand-for-critical-raw-materials.pdf

Mordberg, L.E., Stanley, C.J., Germann, K. (2001). Mineralogy and geochemistry of trace elements in bauxites: the Devonian Schugorsk deposit, Russia. Mineralogical Magazine 65 (1) 81–101.

Moss, R L, E Tzimas, H Kara, P Willis, and J Kooroshy. 2011. "Critical Metals in Strategic Energy Technologies. Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies." Institute for Energy and Transport IET.

OECD (2019). Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials [Accessed September 2019]

Roskill (2011). Gallium: Global Industry Markets and Outlook, 8th Edition. Roskill Information Services Ltd., London, UK.

Rudnick, R.L. and Gao. S. (2003). Composition of the Continental Crust. In: Treatise on Geochemistry, Volume 3. Editor: Roberta L. Rudnick. Executive Editors: Heinrich D. Holland and Karl K. Turekian. pp. 659. ISBN 0-08-043751-6. Elsevier, p.1-64.

Schulte, R. F.; Foley, N. K. (2014). Compilation of Gallium Resource Data for Bauxite Deposits: U.S. Geological Survey Open-File Report 2013-1272; [online] Available at: http://pubs.usgs.gov/of/2013/1272/

SCRREEN workshop. (2019). Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre.Stoiber, R.E. (1940). Minor elements in sphalerite. Economic Geology 1 June 1940, 35 (4), 501–519.

UNEP (2011). Recycling Rates of Metals. A Status Report, A Report of the Working Group on the Global Metal Flows to the International Resource Panel; United Nations Environment Programme, [online] Available at: http://web.unep.org/publications/

UNEP (2013). Metal Recycling - Opportunities, limits, infrastructure. A Report of the Working Group on the Global Metal Flows to the International Resource Panel. [online] Available at: http://web.unep.org/publications/

USGS. (2015). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2

USGS. (2016). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2 Available at: https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/gallium/mcs-2016-galli.pdf

USGS. (2018). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2 Available at: https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/gallium/mcs-2018-galli.pdf

USGS. (2019). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2 Available at: https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-galli.pdf

USGS. (2018). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2 Available at: https://s3-us-west-2.amazonaws.com/prd-wret/assets/palladium/production/mineral-pubs/gallium/mcs-2018-galli.pdfWeeks, R.A. (1989). Gallium, Germanium and Indium Resources. In: Carr, D.D. and Herz, N. (eds.) Concise Encyclopedia of Mineral Resources, Pergamon Press, Oxford, UK. pp. 133.

Weimar, A. (2011). High brightness LEDs: Manufacturing and applications. International Conference on Compound Semiconductor Manufacturing Technology, CS ManTech: Indian Wells, California, 2011.

World Mining Data (2019). Bundesministerium für Nachhaltigkeit und Tourismus. Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

10.7.2Data sources used in the criticality assessment

Bio Intelligence Service (2015). Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials – Final Report. Prepared for the European Commission, DG GROW

Communication with Mr. Istvan Fekete (CEO of bauxite mine in Eoszen Ltd), 2019.

Cui, R., Guo, J., Yin, L., Huy, D., Liedtke, M. (2016). Supply and Demand of Lithium and Gallium. P. 28 – 50. ISBN 978-3-943566-33-8. Bundesanstalt für Geowissenschaften und Rohstoffe - BGR, Hannover, Germany.

Eurostat (2019)a. International Trade Easy Comext Database [online] Available at: http://epp.eurostat.ec.europa.eu/newxtweb/

European Commission (2017). Report on Critical Raw Materials for the EU. Critical Raw Matetrials Profiles [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

European Commission (2016). DG Trade. Agreements [online] Available at: http://ec.europa.eu/trade/policy/countries-and-regions/agreements/

European Commission (2014)a. Report on Critical Raw Materials for the EU. Critical Raw Matetrials Profiles [online] Available at: https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

Gunn, Gus (2014). Critical Metals Handbook. John Wiley & Sons.

OECD (2019). Export restrictions on Industrial Raw Materials. [online] Available at: http://qdd.oecd.org/table.aspx?Subject=ExportRestrictions_IndustrialRawMaterials [Accessed September 2019]

OLED-Info (expert group) - OLED lighting introduction and market status https://www.oled-info.com/oled-lighting

Pavel, Claudiu C, Alain Marmier, Evangelos Tzimas, Tobias Schleicher, Doris Schüler, Matthias Buchert, and Darina Blagoeva (2016). "Critical Raw Materials in Lighting Applications: Substitution Opportunities and Implication on Their Demand." Physica Status Solidi (A) 213 (11): 2937–46.

SCRREEN workshop. (2019). Validation Workshop on Critical Raw Materials, 10-12 September 2019, Thon Hotel Brussels City Centre.

Tercero Espinoza, L., Hummen, T., Brunot, A., Hovestad, A., Pena Garay, I., Velte, D., Smuk, L., Todorovic, J., van der Eijk, C. and Joce, C. 2013. "Critical Raw Materials Substitution Profiles. September 2013 Revised May 2015. CRM_InnoNet Available At:" http://www.criticalrawmaterials.eu/wp-content/uploads/D3.3-Raw-Materials-Profiles-final-submitted-document.pdf.

USGS. (2019). Gallium - Mineral Commodity Summaries. United States Geological Survey. Ed., Washington DC, pp.2 Available at: https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/mcs-2019-galli.pdf

World Mining Data (2019). Bundesministerium für Nachhaltigkeit und Tourismus. Austrian Federal Ministry of Sustainability and Tourism. [online] Available at: www.en.bmwfw.gv.at/Energy/WorldMiningData/Seiten/default.aspx

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