11 GERMANIUM

11.1 Overview

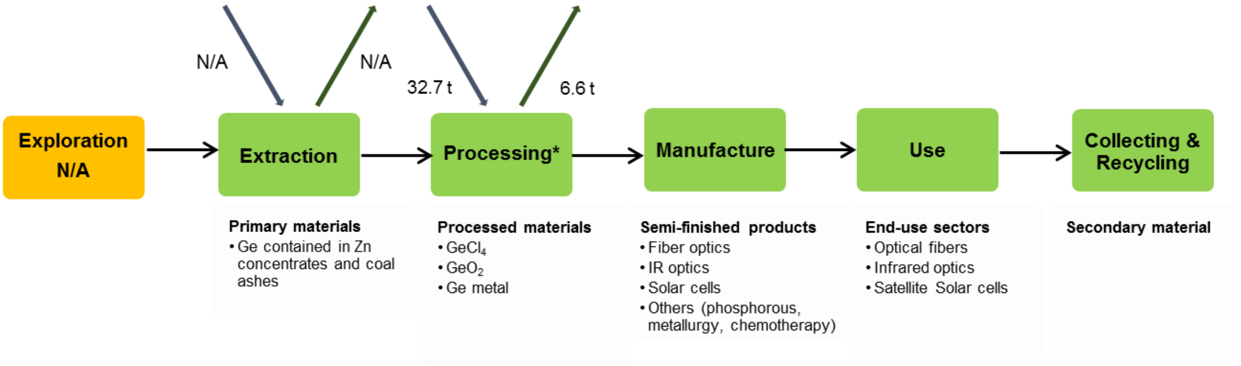
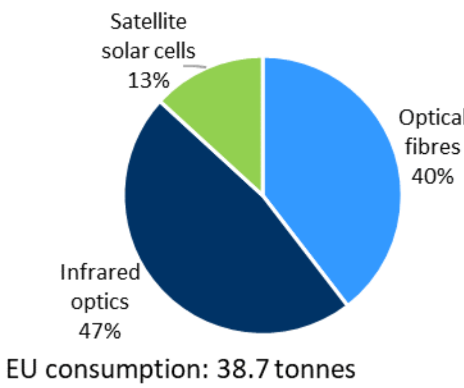


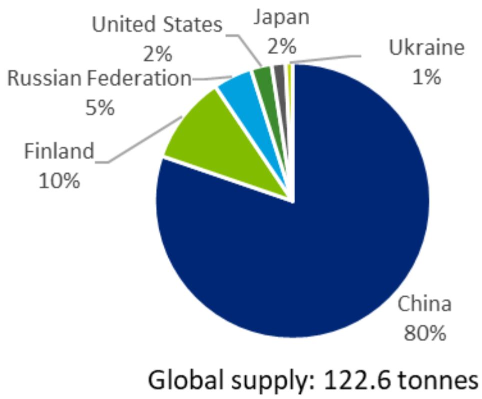
Figure 139: Simplified value chain for germanium[99] for the EU, averaged over 2012-2016

Germanium is a chemical element with symbol Ge and atomic number 32. It is a lustrous, hard, brittle, crystalline and greyish-white metalloid in the carbon group, chemically similar to its group neighbours tin and silicon. It resembles a metal; however, it also displays non-metal characteristics, such as semi conductivity. Purified germanium is a semiconductor, with an appearance most similar to elemental silicon. Like silicon, germanium naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive to be found naturally on Earth in the free (native) state. Germanium was on the list of CRMs in 2011, 2014 and 2017.

The criticality of germanium is assessed at processing stage. The trade codes considered in this factsheet are the following (Eurostat Comext, 2019):

- Unwrought germanium and germanium powders (trade code CN8 81129295),
- Germanium oxides (GeO_2)(Trade code CN8 28256010),
- Germanium tetrachloride ($GeCl_4$) (no trade code)





[99] The import figure at processing stage in the EU is the sum of germanium metal, $GeCl_4$, and GeO_2. The quantity of EU import of $GeCl_4$, and GeO_2 was based on the figures in Critical Raw Materials Assessment 2017 since no new data was available. The export figure in green arrow at processing stage refers to the EU export of germanium metal, reported in Eurostat-Comext database.

Figure 140: End uses (SCREEN, 2019) with estimated quantity of EU consumption and global supply of germanium[100], (average 2012-2016)

Due to the lack of reliable and up-to-date figures on EU import of all germanium products, the EU import and EU consumption figures reported in this factsheet are based on estimation. Consequently, the supply risk of germanium in this assessment is based on the global supply.

The world market traded about 150 tonnes of germanium in 2018, and it is expected to rise to a minimum of 165 tonnes by 2020 only with glassfibre applications at a rate of 3.5% per year (Fraunhofer ISI, 2018). The majority of germanium is traded on annual contracts and only small amounts are sold on the open market. The price of germanium dioxide (GeO_2) was USD 1100 per kilogram in 2018, one and a half times higher than the price in 2017. Similar to prices of GeO_2, the price of germanium metal in 2018 was at USD 1300 per kilogram, an increase of 20% in comparison to 2017's price (USGS, 2017b).

The EU imported germanium in the form of germanium metal, germanium dioxides, and germanium tetrachloride. The import figure was only available for germanium metal. The annual EU consumption of germanium over the period 2012-2016 was roughly estimated at 38.7 tonnes per year, considering the EU import of germanium dioxides and germanium tetrachloride in 2010-2014. China, United Kingdom, Russia, and United States were the main providers of germanium while the EU domestic production of germanium took place in Finland.

Germanium is used in several applications such as optical fibres, IR optics, wafers for satellites solar cells, IT applications, PET catalyst etc. Some of these end-uses, such as PET catalysts and IT applications, are not occurring in the EU(SCRREEN, 2019).

Various alternatives are available for the substitution of germanium in some its applications (mainly the IT applications and catalysts applications, not relevant for the EU scope). However, many of these substitutes result in a loss of performance.

Germanium is an emerging substrates used for photovoltaic solar cells in satellite applications with higher efficiency than with silicon. Germanium may contribute to achieving the objectives of the "European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy"[101]. Under this strategy, the transition to clean and renewable electricity is expected to decarbonize also other sectors such as heating, transport and industry.

The available resources of germanium are associated with certain zinc and lead-zinc-copper sulfide ores as well as coal ashes (USGS, 2019). Around half of total known resources are located in Russia (17,500 tonnes, all from coal ashes) and one quarter is located in China (10,860 tonnes, including 4,200 tonnes in zinc ores and slag, the remaining in coal ashes) (Melcher, F. and Buchholz, P.,2012). In the EU, resources of germanium are known to exist is Czechia, France, and Austria (Melcher, F. and Buchholz, P.,2013).

World known reserves for germanium are estimated at 8,600 tonnes in 2012 (Bio Intelligence Service, 2015), including 3,500 tonnes of proven reserves of germanium in China (European Commission, 2014). There are no reserves of germanium in the EU

[100] EU consumption is estimated and includes germanium oxides and germanium tetrachloride, based on the quantity of EU import for both products reported in criticality assessment 2017

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

because historic European deposits (St Salvy, Bor, Bleiberg, Freiberg, Sardaigne) are drained (Bio Intelligence Service, 2015).

According to the data reported by World Mining Data (2019), the world average production of refined germanium from the year 2012 to 2016 was 122 tonnes per year. China was the major producer with 80% of share of global production, followed by Russian Federation (5% of share), United States and Japan (2% of global supply each), and minor production from Ukraine (1% of global supply). The EU production of germanium was 12.6 tonnes, located in Finland. However, the production in Finland stopped in 2015.

USGS (2019) estimated that around 30% of global germanium production is supplied by recycling, mostly from scrap generated during the manufacture of fibre-optic cables and infrared optics. Due to the value of refined germanium, this scrap is reclaimed and fed back into the production process at a rate of 60%. There are two large global recyclers and refiners of zinc with combined germanium production in the EU (Melcher, F. and Buchholz, P.,2013).

Germanium is a non-toxic element, except for a few compounds. Germanium in the ppm range, when dissolved in drinking water may cause chronic disease.

China, one of the EU suppliers for germanium applied a 5% export tax on germanium oxide throughout 2012-2016 (OECD, 2019). No trade agreements existed between China and the EU regarding germanium trade (European Commission, 2019).

11.2 Market analysis, trade and prices

11.2.1 Global market analysis and outlook

Over the five years period from 2012 to 2016, China was the leading global producer of germanium metal and germanium compounds. China recovered germanium from germanium-bearing coal fly ash and zinc ore (USGS, 2016). Several events that took place in China have contributed to the change in price of germanium during this period, such as the application of export tax on germanium dioxide, the closure of a Chinese germanium dioxide plant owing to environmental concerns, stockpiling activities, and the collapse of FANYA metal exchange (USGS, 2016, 2017a, 2019).

Primary germanium was also recovered from zinc residues in Belgium and Canada (concentrates shipped from the united States), zinc residues in Finland, and coal ash in Russia (USGS, 2016).

Germanium supply depends largely on future demand of germanium and its price. As a by-product, germanium production is heavily dependent on zinc production and production from coal ashes. Since the market for germanium is small, it tends to be highly volatile. A higher price may result in increased interest shown by zinc refineries. According to experts, today’s supply situation, which largely depends on China, is not a resource depletion issue, but the result of commercial terms (Umicore, 2019).

The future supply for germanium will most likely be driven by in germanium’s largest emerging end-market: fibre optics (Fraunhofer ISI, 2018). The demand for germanium in fiber optic cables 56 tonnes (39% of the the quantity of refinery production in 2013). The future demand for germanium for this application is estimated to grow to 118 tonnes in 2035, reaching 81% of refinery production capacity in 2013 (Fraunhofer ISI, 2018).

Table 59: Qualitative forecast of supply and demand of germanium (European Commission, 2017)

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
Germanium	x		+	+	?	+	+	?

11.2.2EU trade

Over the period 2012-2016, the EU was a net importer of germanium metal (unwrought and powders), corresponding to 12.2 tonnes per year of germanium contained (Eurostat, 2019a). The EU export of germanium metal was reported at 6.6 tonnes per year, half of the EU import. According to the information reported in Eurostat, France, Germany, Belgium, and Latvia are among the EU exporters of germanium metal.

The EU also imported germanium in the form of germanium dioxides, and germanium tetrachloride. However, the data on EU trade of germanium dioxide and germanium tetrachloride were not available in Eurostat Comext database. In 2015, the annual EU import of germanium dioxide and germanium tetrachloride was estimated at 15.3 tonnes and 5.1 tonnes subsequently (Bio Intelligence Service, 2015).

Between 2012 and 2014, some crude germanium dioxide (GeO_2) was produced in Finland from cobalt concentrates (mined in Congo by the owner of the Finnish refinery) (Bio Intelligence Service, 2015). The crude GeO_2 produced in Finland was used in the EU to produce germanium processed materials (GeO_2, $GeCl_4$ and Ge metal), with most of them (80%) being exported outside the EU. The EU net production of refined germanium was only 2.5 tonnes of germanium contained, whereas it imported 36.7 tonnes.

China, one of the EU suppliers for germanium applied a 5% export tax on germanium oxide throughout 2012-2016 (OECD, 2019). The export tax was first introduced in 2010, since the Chinese Government attempted to limit exports of raw materials (European Commission, 2014). In order to protect germanium resources, China has taken multiple measures in recent years, including stockpiling and increase in tariffs, which resulted in significant decline in export of germanium and products thereof (European Commissoin, 2017). At the same time, China encouraged the export of more processed products through export tax rebates on products such as germanium ingots and optical lenses (European Commission, 2014). Other than China, Russia imposed a tax on the export of germanium waste and scrap (6.5%).

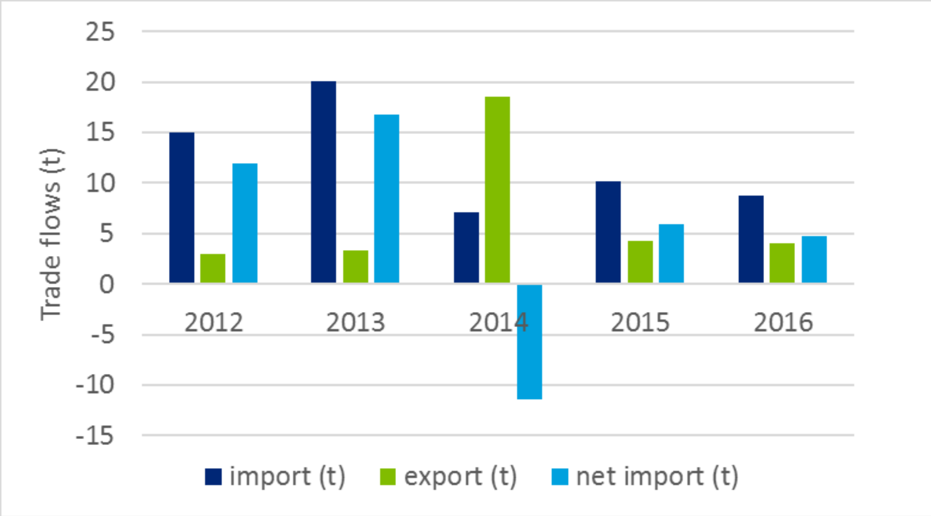


Figure 141: EU trade flows for unwrought germanium metal (Eurostat, 2019a)

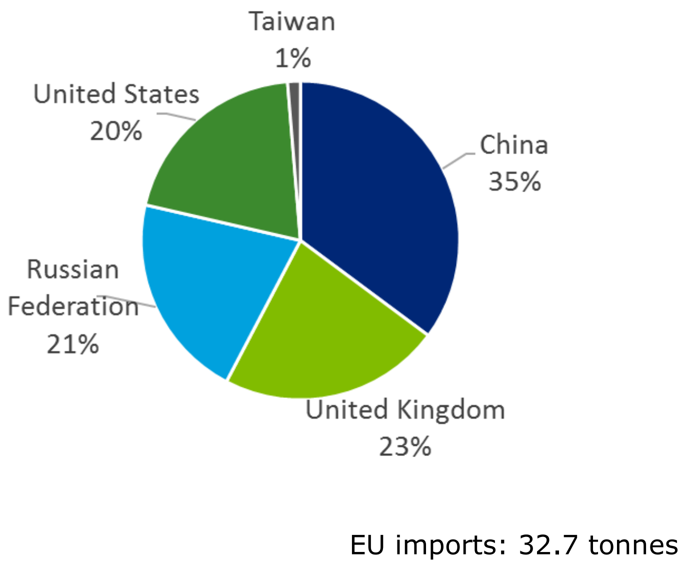


Figure 142: EU imports of unwrought germanium, 2012-2016 (Eurostat, 2019a)

11.2.3Prices and price volatility

Figure 143 presents the price trend of germanium metal and germanium oxides (GeO_2) from 2008-2018. The prices of germanium in 2009 and 2010 were low, following the global economic crisis in 2008. Later, the prices increased in 2012. This increase was believed to be related events that took place in China's supply: the closing of three Chinese germanium dioxide plants, the adoption of an export tax on germanium dioxide, and a limited supply available due to an amount reserved for a consumer specialised in solar and hydro projects (European Commission, 2014). Prices from 2012 to mid 2015 remained high also due to a combination of strategic government stockpiling of germanium metal and a speculative investors' demand organized by a Chinese minor metals trading platform, Fanya Metal Exchange (FME) (Industrial player, 2016).. The huge speculative demand by financial investors drove prices of minor metals such as indium, germanium, and bismuth to unprecedented levels in 2013-2014 (European Commission, 2017). On the other hand, high price in 2012 incited processors to increase collection and recycling of new scrap (Bio Intelligence Service, 2015)

After the collapse of Fanya trading platform in first half of 2015, prices significantly dropped. According to the USGS (2017b), the germanium dioxide (GeO_2) prices have decreased from USD 1,247 per kilogram (2011-2015 average) to only USD 830 per kilogram in 2016. In 2017, the price was even lower at USD 731 per kilogram.

The average prices of germanium metal over the period 2011-2014 reached the highest at USD 1,918 per kilogram in 2014. Similar to prices of GeO_2, the price of germanium metal was even lower in 2017 at USD 1,082 per kilogram following the collapse of FME.

However, starting from 2017, the price of GeO_2 and germanium metal gradually increased. The price increases were associated to the recovery in the germanium market following a period of low prices in 2016 after the collapse of FME in 2015.

The price of germanium metal reached USD 1,300 per kilogram and USD 1,100 per kilogram for GeO_2 in 2018. According to the USGS (2019), the increase in the price of germanium in 2018 were closely related to two main events: the partial force majeure at a refinery in Canada, and the implementation of stricter environmental standards in China.

The FME held several minor metal stocks including 92 tonnes of germanium before it collapsed. In early 2019, the government of China decided to put the stocks of these minor metals on auction (Argusmedia, 2019). There were concerns that a sudden release of stocks could cause prices to collapse.

Figure 143: Germanium historical price volatility (USD/kg). Figures for 2008-2018 (USGS, 2017b)

11.3 EU demand

11.3.1 EU demand and consumption

By taking into account the annual EU import of germanium unwrought (2012-2016), germanium dioxide and germanium tetrachloride (2010-2014), EU domestic production and EU exports, the EU apparent consumption of germanium processed materials is estimated at 38.7 tonnes per year over the period 2012-2016. The estimated quantity was approximately 29% of the world consumption in 2012-2016. Germanium entered in the EU is destined to the manufacture of germanium end-products.

11.3.2 Uses and end-uses of germanium in the EU

According to Asian Metals, the global use of germanium in 2016 are the following: fibre optics 24%, infrared optic 23 %, polymer catalysts 31 %, solar cells 12 %, others 10 % (Buchholz, 2019).

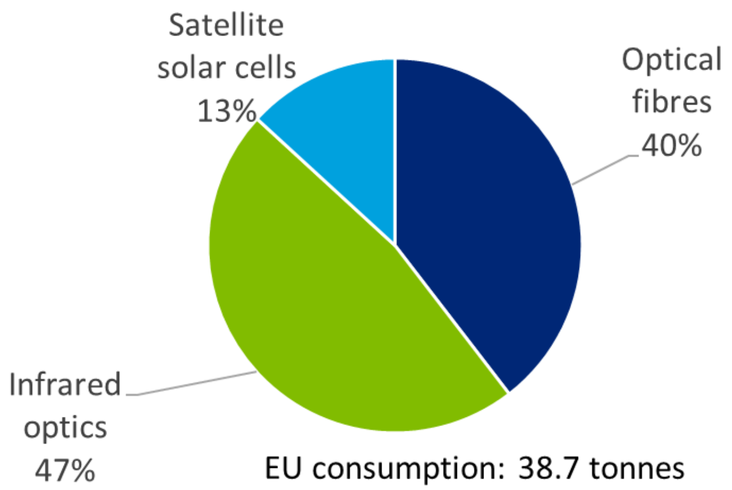


Figure 144: EU end uses of germanium (SCRREEN, 2019). Average figures for 2012-2016. (Eurostat 2019a)

The three major global uses of germanium are in fibre optics, infrared optics and polymerisation catalysts for PET plastics. Use in electronic applications and satellite solar cells also play an important role at the global scale. The other applications are mainly for phosphors, metallurgy, and chemotherapy. However, it must be noted that in the EU, Germanium is not used as PET polymerisation catalysts as well as in the electronic industry.

Figure 144 presents the main uses of germanium in the EU.

- Fibre-optics (40% of share): Germanium oxide is used as a dopant in within the core of optical fibre. Small quantities of this compound are added to the pure silica glass to increase its refractive index; this prevents light absorption and signal loss. This type of fibre is used for high-speed telecommunication. Over the past years there has been substantial growth in this sector with increasing demand for more bandwidth.
- Infrared optics (47% of share): Germanium is transparent to infrared radiation (IR) wavelengths, both as a metal and in its oxide glass form. For this reason it is used to make lenses and windows for IR radiation. These are mainly used in military applications such as night-vision devices. Uses outside of the military are in advanced firefighting equipment, satellite imagery sensors and medical diagnostics.

- Solar cells (13% of end use share): Germanium-based solar cells are principally used in space-based applications but also in terrestrial installations. Demand for satellites has increased steadily from 2007 due to commercial, military, and scientific applications. The advantage of germanium substrates over the more common silicon based solar cells are the smaller size and weight and higher efficiency (over 25%). These solar cells are not common in terrestrial applications because of the cost of their manufacture. However these are considerably more efficient at converting solar energy into electricity, so fewer cells are required in a panel to produce equivalent amounts of power. It is thought that germanium-based cells will compete for a portion of the terrestrial market in the future.
- Other uses in the EU include gamma-ray detectors and organic chemistry, phosphors, metallurgy, and chemotherapy.

Germanium is also used in the following applications outside the EU:

- Polymerisation catalysts: Germanium dioxide is used outside the EU (and particularly in Japan) as a catalyst in the production of PET for plastic bottles, sheet, film and synthetic textile fibres. There is a drive to move towards different catalysts given the increasing price of germanium.
- Electronic components: Germanium is used as a semiconductor in several electronic applications. Some examples are high brightness Light Emitting Diodes (LEDs) in devices such as cameras and smartphone display screens. Silicon germanium transistors have been replacing other silicon based components in high speed wireless telecommunications devices due to the higher switching speeds and energy efficiency.

Relevant industry sectors in the EU are described using the NACE sector codes (Eurostat, 2019b, presented in Table 60.

Table 60: germanium applications, 2-digit and associated 4-digit NACE sectors, and value added per sector (Eurostat, 2019b)

Applications	**2-digit NACE sector**	**4-digit CPA**	**Value added of NACE 2 sector (M€)**
Optical fibres	C27 - Manufacture of electrical equipment	C2630- Manufacture of communication equipment; C2731 - Manufacture of fibre optic cables	80,745
Infrared optics	C26 - Manufacture of computer, electronic and optical products	C2670- Manufacture of optical instruments and photographic equipment	65,703
Satellite solar cells	C26 - Manufacture of computer, electronic and optical products	C2611- Manufacture of electronic components	65,703

11.3.3 Substitution

Many of the substitutes for germanium result in a loss of performance and are therefore not optimal. Research on efficient germanium substitutes is currently under progress (Industrial player, 2016).

- Zinc selenide and zinc sulphide can be used as substitutes of germanium in infrared optics, but with a reduced performance (Industrial player, 2016). Tellurium is also a (partial) substitute in chalcogenide glasses for infrared optics (Industrial player, 2016).
- Substitutes of germanium in optical fibres are not really used because of performance losses, but fluorine and phosphorus can be mentioned, with a low probability of industrial use (Industrial player, 2016).
- There is actually no substitute for germanium in satellite solar cells, even if some research are ongoing on semiconductor materials based on gallium and indium such as InGaP, AlGaInP, InGaAsP, InGaAs (Industrial player, 2016).
- Silicon can be a less-expensive substitute for germanium in some electronic applications such as transistors (USGS, 2016). However, there has recently been a shift back to the use of germanium, albeit in materials with silicon, as this will allow the miniaturization of electronics (USGS, 2016). Some metallic compounds can be substituted in high-frequency electronics applications and in some light-emitting-diode applications (USGS, 2016). Antimony and titanium are substitutes for use as polymerization catalysts (USGS, 2016).

11.4 Supply

11.4.1 EU supply chain

- Extraction stage
  Resources of germanium are known to exist in the EU. In the past, there was a production of germanium in France and Austria. However, there are no known reserves of germanium in the EU. In 2012-2016, there was no germanium concentrates recovered neither from a European mine in activity, nor from coal ashes in the EU.
- Processing stage
  World Mining Data reported that the production of germanium in Finland over the period of 2012-2016 was 12.6 tonnes per year (World Mining Data, 2019). From 2012 to 2014, Finland produced some crude germanium dioxide (GeO_2) from cobalt concentrates (mined in Congo by the owner of the Finnish refinery) with 80% of the final processed materials (GeO_2, $GeCl_4$ and Ge metal) exported outside the EU (Bio Intelligence Service, 2015). The Finnish plant stopped the production of germanium in 2015 (Bio Intelligence Service, 2015). There were some very rich germanium mines in France and Austria but they all closed in the 1990's once empty (Bio Intelligence Service, 2015).
- Manufacturing stage
  The EU consumption of Ge processed materials are destined to the manufacturing of germanium processed products in the EU.
- Recycling stage
  Recyclex in France with its subsidiary PPM Pure Metals Gmbh (Germany) and Umicore in Belgium are large global recyclers and refiners of zinc, both with combined germanium production. (Melcher, F. and Buchholz, P.,2013).

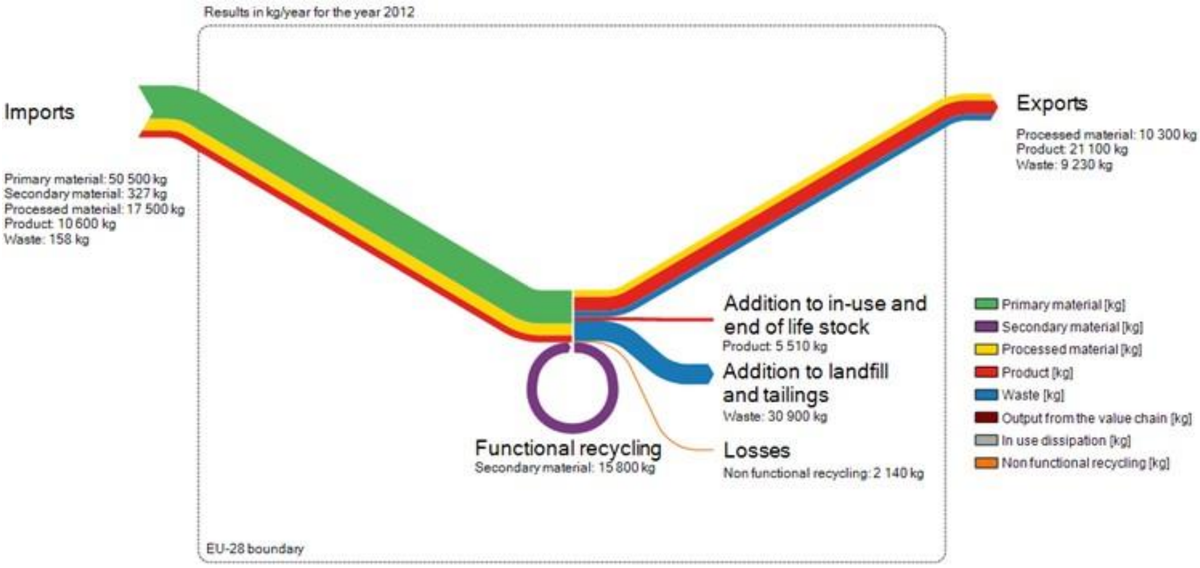


Figure 145: Simplified diagram of germanium material system analysis for 2012 (Bio Intelligence Service, 2015)

11.4.2Supply from primary materials

Germanium recovered from the leaching of zinc residues or coal fly ash and is precipitated into germanium concentrates and crude germanium dioxide (GeO_2). Crude GeO_2 is then converted into germanium tetrachloride ($GeCl_4$) and hydrolysed to produce high grade GeO_2. $GeCl_4$ is also partly used to produce high grade GeO_2. A fraction of high grade GeO_2 is then reduced and refined into germanium metal (Bio Intelligence Service, 2015).

Today, germanium is extracted as a by-product of zinc production and from coal fly ash. It is estimated that 60% of worldwide production of germanium is sourced from zinc ores, mainly the zinc sulphide mineral sphalerite, and 40% from coal. China and Russia are the only countries to recover germanium from coal fly ash.

11.4.2.1 Geology, resources and reserves of germanium

Geological occurrence: Germanium is a rare metal, with an average concentration in the Earth's crust of 1.6-2 ppm, and 1.4 ppm in the upper crust (Rudnick, 2003).

As is the case for many minor metals, germanium does not occur in its elemental state in nature, but is found as a trace metal in a variety of minerals and ores. Only a few minerals of germanium have been identified, the major one being germanite ($Cu_{13}Fe_2Ge_2S_{16}$). This was the principal source of germanium in the past. However, no ore bodies with commercially viable contents of germanite are known at present.

Global resources and reserves[102]*:*

[102] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of germanium in different geographic areas of the EU or globally (comment: see Melcher and Buchholz, 2014, probably most comprehensive overview; the resource numbers in that paper are still valid). 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.[102], which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource

Global resources and reserve data for germanium are difficult to obtain, because details related to trace-metal concentrations in many sulphide and coal deposits are not readily available, or are of poor quality (Melcher, F. and Buchholz, P.,2013). The available resources of germanium are associated with certain zinc and lead-zinc-copper sulfide ores (USGS, 2016a), as well as coal ashes. The amount of germanium potentially recoverable from coal ash is unlimited, but the commercial recovery is currently not viable except for germanium-rish coals from Russia and China (Melcher, F. and Buchholz, P.,2013).

Global known resources of germanium are estimated at 11,000 tonnes in zinc ores and 24,600 tonnes in coal in 2013 (European Commission, 2014). Approximately half of total known resources are located in Russia (17,500 tonnes, all from coal ashes) and one quarter is located in China (10,860 tonnes, including 4,200 tonnes in zinc ores and slag, the remaining in coal ashes) (European Commission, 2014). The USA and Congo also have significant resources of germanium in zinc ores (respectively 2,300 and 3,750 tonnes), while Canada, Mexico, Namibia, Ukraine and Uzbekistan account for the rest of germanium resources (European Commission, 2014).

World known reserves for germanium are estimated at 8,600 tonnes in 2012, including 3,500 tonnes of proven reserves of germanium in China (Bio Intelligence Service, 2015).

Another source estimated 13,000 tonnes of germanium reserves and resources from sulphide deposits and 25,000 tonnes from germanium-rich coal (Melcher, F. and Buchholz, P.,2013).

EU resources and reserves [103]*:*

Some resources of germanium in zinc mines exist in the EU but they are not quantified. They have been estimated at less than 1,000 tonnes using the low germanium content (0-10 ppm) in EU zinc resources (Bio Intelligence Service, 2015).

In the EU, high germanium concentrations were reported in Bleiberg, Austria (on average 300ppm; 126 tonnes germanium produced) and Cave del Predil, Italy (250-450 ppm) (Melcher, F. and Buchholz, P.,2013).

In the past, there were deposits of germanium in Noailhac-Saint Salvy, France, that contributed significantly to the global germanium production until its closure in 1993 (Melcher, F. and Buchholz, P.,2013). There were reportedly germanium-bearing deposits in Freiberg district, Germany, Sardinia (Italy), and Kirki (Greece), and Czechia, all of which with limited economic potential or known to be drained (Bio Intelligence Service, 2015). Minerals4EU (2019)reported an estimated quantity of 473 tonnes with 0.01% of germanium content in Czechia, categorized as potentially economic. To-date, there has not been any new information on Minerals4EU.

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data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

[103] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for germanium. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for germanium, 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 germanium 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.

Polish Geological Institute (2017) reports an estimated resource of 30 tonnes of germanium in the Zawiercie deposit, according to the Polish classification. In Portugal, the Iberian Pyrite Belt, that has deposits such as Neves Corvo and Barrigão, is potential for germanium, which is present in the latter with average whole-rock contents of 61 ppm (Reiser et al. 2010). Until 2020, germanium is not recovered from these deposits. Germanium was also known to exist in some deposits in Romania and Slovenia, but no resource data is available.

There was no information on the reserves of germanium in the EU.

Some exploration activities were undertaken within the EU for germanium, in particular in Portugal and Slovakia according to the Minerals4EU (2019). At Bleiberg (Austria) exploration was carried out by Tacsa Resources, but the project was cancelled in January 2018.

11.4.2.2 World and EU mine production

As with data for reserves and resources, the data for global germanium mine production are not readily available or are of poor quality (Melcher, F. and Buchholz, P.,2013). In 2010, the global germanium production was estimated to be double the reported refined germanium (300 tonnes in residues), suggesting that major amounts of germanium were not being extracted from residues. There was only one zinc mine very rich in germanium (400 g/t) within the world (located in Tennessee, USA), but it has been closed temporarily in the last years (Bio Intelligence Service, 2015). Several zinc mines with medium germanium content (50-100 g/t) are located in Alaska, Mexico and Australia, and there are also plenty of zinc mines with low germanium content (0-10 ppm) located in China, Congo, India, Bolivia, etc. (Bio Intelligence Service, 2015).

Most of germanium is extracted from zinc ores as a by-product, mainly in China, the United States, Australia and India (Bio Intelligence Service, 2015). Only a small fraction of the germanium contained in the zinc ore extracted worldwide is effectively recovered and further used in the value chain of germanium. The main fraction is not valued and is considered as lost (in tailings, as impurities in zinc products, etc.). About 760 tonnes of Germanium were present in 2012 in zinc ores mined worldwide, but only a small proportion is effectively recovered.

11.4.2.3 World refinery production

The data for global germanium mine and refinery production are not readily available or are of poor quality. Germanium is produced as a by-product of zinc mining and also extracted from coal ash.

- As by-product of zinc mining: after mining, the germanium-containing ores are processed to increase their base metal and germanium contents using conventional mechanical and flotation methods (Melcher, F. and Buchholz, P.,2013).

  On a global scale, as little as 3% of the germanium contained in zinc concentrates is recovered. There are several reasons why such a low percentage of germanium is refined from zinc concentrates:

  1. Germanium recovery can have a negative impact on zinc recovery, detracting from the core business for these refineries (European Commission, 2014). As a consequence, except the Chinese refineries, only two zinc refineries (located in the USA and Canada) reportedly in 2011 extract germanium as part of their operations.

2. High germanium zinc concentrates must be sourced in order to make recovery of germanium economic. This may increase the cost of sourcing the concentrate, making it prohibitive. This is of particular importance given that germanium production only accounts for a low percentage of the business's turnover. For example, in the Canadian zinc refinery, germanium accounts for at most 2% of total revenues. Therefore, the investment may not be profitable unless germanium prices are sufficiently high.

- Extraction from coal ash: High concentrations of germanium in coal ashes from coal and lignite deposits were first found in 1930 while the process to recover it was first developed and used between 1950 and 1974, both took place in the UK (Melcher, F. and Buchholz, P.,2013). Approximately 30-50% of primary germanium production is from lignite deposits in China, Russia, and Uzbekistan. The recovery of germanium from coal includes burning the coal at 1200°C, filtering the ashes, pyrometallurgical treatment, followed by sulfuric acid leaching (Melcher, F. and Buchholz, P.,2013). Significant amounts of germanium are contained in ash and flue dust generated in the combustion of certain coals for power generation (USGS, 2019). The amount of germanium potentially recoverable from coal ash is unlimited, but the commercial recovery is currently not viable except for germanium-rich coals from Russia and China (Melcher, F. and Buchholz, P.,2013).

Figure 146 presents the average share of world refinery production of germanium over the period 2012-2016 (WMD, 2019). China was the largest producer of refined germanium, accounting for 80% of global supply. The EU refining activity of germanium from cobalt ores took place in Finland, until 2015 (Bio Intelligence Service, 2015).

In 2015, total production of refined germanium was estimated to be around 122.6 tonnes This comprised germanium recovered from zinc concentrates, fly ash from burning coal, and recycled material.

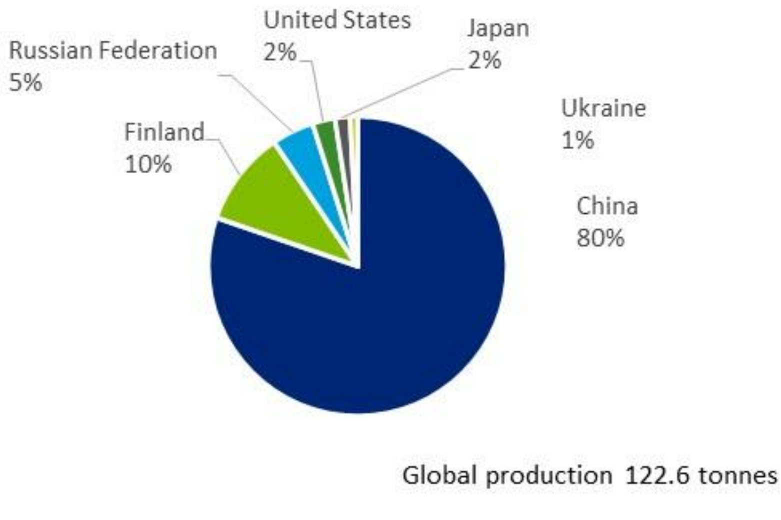

Figure 146: Global refinery production of germanium, 2012-2016. (World Mining Data, 2019)

11.4.3 Supply from secondary materials/recycling

It is estimated that around 30% of global germanium production is supplied by recycling, mostly from scrap generated during the manufacture of fibre-optic cables and infrared optics (new scrap). Due to the value of refined germanium, this scrap is reclaimed and fed back into the production process (European Commission, 2014). On the other hand, due to its high dispersion in most products and application in very low quantities, only a little quantity of germanium is recovered from post-consumer scrap (old scrap) (Melcher, F. and Buchholz, P.,2013).

11.4.3.1 Industrial recycling (new scrap)

As germanium products usually need to be of a very high purity, a lot of production scrap is generated all along the manufacturing chain. The high price of refined germanium encourages recycling. The majority of the new scrap generated during the manufacture of germanium processed materials and products is recycled by being fed back into the manufacturing process (Sundqvist Oeqvist, Pr. Lena et al. ,2018).

All the waste generated during the conversion of germanium dioxide (GeO_2) and the production of germanium tetrachloride ($GeCl_4$) and germanium metal is internally recycled (Bio Intelligence Service, 2015).

The manufacture of optical fibres generates about 75% of waste, and about 80% of this new scrap is reprocessed (Bio Intelligence Service, 2015). The effluents from optic fiber manufacturing process should be processed on site due to economic and environmental reasons (Ge recovery, chlorine gas disposal). The specialists from Bell Technologies invented and then implemented to industrial practice the effective method for germanium recovery from optic fiber production effluents, with Ge recovery rate over 95% (Sundqvist Oeqvist, Pr. Lena et al. ,2018).

The waste produced during the manufacture of Infra Red optics amounts about 30% of the germanium input, of which 100% is internally recycled. The sawing (from large high purity mono-crystals) and grinding of germanium wafers during wafer manufacturing produces a lot of production scrap (e.g. germanium dust from sawing the wafers) - almost 50% if the germanium input - which is fully recycled internally (Bio Intelligence Service, 2015). Downstream producers of solar cells or infrared optics also generate a lot of production scrap on the way to the final product. About 50% of waste from this process is recycled (Melcher, F. and Buchholz, P.,2013).

11.4.3.2 Post-consumer recycling (old scrap)

Due to its high dispersion in most products and application in very low quantities, only a little quantity of germanium is recovered from post-consumer scrap (old scrap) (Melcher, F. and Buchholz, P.,2013). Recycling of old scrap has increased over the past decade but is still low. The functional recycling rate has been estimated at about 12% (Bio Intelligence Service, 2015) and the end-of-life recycling input rate is assessed at 2% only. Very few used end-products are collected separately to be recycled: all used optical fibres go into non-functional recycling in C&D waste, solar cells for satellites are not recovered and only some germanium is recycled from old scrap of IR optics. According to experts, this situation will not improve in future due to dissipation and low grade uses, as well as extra-terrestrial applications (solar cells for satellites) that cannot be collected, etc. (Industrial player, 2016) Moreover, in most of the products and devices containing germanium the metal is present in trace amounts, making it technically and economically difficult to recover secondary germanium.

Table 61: Material flows relevant to the EOL-RIR of germanium[104], reference year 2012

MSA Flow	Value (kg)	Year
B.1.1 Production of primary material as main product in EU sent to processing in EU	0	2012
B.1.2 Production of primary material as by product in EU sent to processing in EU	0	2012
C.1.3 Imports to EU of primary material	50,494	2012
C.1.4 Imports to EU of secondary material	327	2012
D.1.3 Imports to EU of processed material	17,472	2012
E.1.6 Products at end of life in EU collected for treatment	9,874	2012
F.1.1 Exports from EU of manufactured products at end-of-life	79	2012
F.1.2 Imports to EU of manufactured products at end-of-life	158	2012
G.1.1 Production of secondary material from post consumer functional recycling in EU sent to processing in EU	0	2012
G.1.2 Production of secondary material from post consumer functional recycling in EU sent to manufacture in EU	1,211	2012

11.5 Other considerations

11.5.1 Environmental and health and safety issues

Germanium is a non-toxic element, except for a few compounds. Germanium in the ppm range, when dissolved in drinking water may cause chronic disease (Melcher, F. and Buchholz, P.,2013).

With environmental regulations becoming more stringent, the ecological footprint of Ge recovery from coal starts to get more attention. An LCA study has demonstrated the ecological benefit of other sources, such as recycling or Ge from Zn-based ores (Robertz, Benedicte, Jensen Verhelle, and Maarten Schurmans, 2015)

11.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk was analysed at processing stage, the stage considered to be the bottleneck of the supply in the EU. Constructing a reliable estimation of EU consumption and EU supply risk of germanium was confronted by the lack of up-to-date and publicly available data for the EU for the trade of germanium products such as germanium oxides and germanium tetrachloride. Therefore, compared to the assessment of supply risk in 2017, only global supply of germanium was taken into consideration for the calculation of supply risk The change of approach can be seen in the increase of supply risk of germanium, reflecting a high production concentration in China. The results of criticality assessment 2020 and of the earlier assessments are shown in Table 62.

Table 62: Economic importance and supply risk results for germanium in the assessments of 2011, 2014, 2017, 2020 (European Commission, 2011; European Commission, 2014; European Commission, 2017)

Assessment	2011		2014		2017		2020	
Indicator	EI	SR	EI	SR	EI	SR	EI	SR
Germanium	6.28	2.73	5.54	1.94	3.5	1.9	3.45	3.89

[104] EOL-RIR=(G.1.1+G.1.2)/(B.1.1+B.1.2+C.1.3+D.1.3+C.1.4+G.1.1+G.1.2)

The economic importance of germanium has slightly decreased between 2012 and 2016 while the end-use application sector remained the same in comparison to the results in 2017's criticality assessment. The change was caused by the change in the value added of the sectors.

11.7 Data sources

In this assessment, the only information available on the trade of germanium was for unwrought germanium. The lack of publicly available data for the EU for the trade of germanium products such as germanium oxides and germanium tetrachloride was identified. Estimation for the EU import of germanium oxides and tetrachloride was taken from the "Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials – Final Report", published in 2015.

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