22 SCANDIUM

22.1 Overview

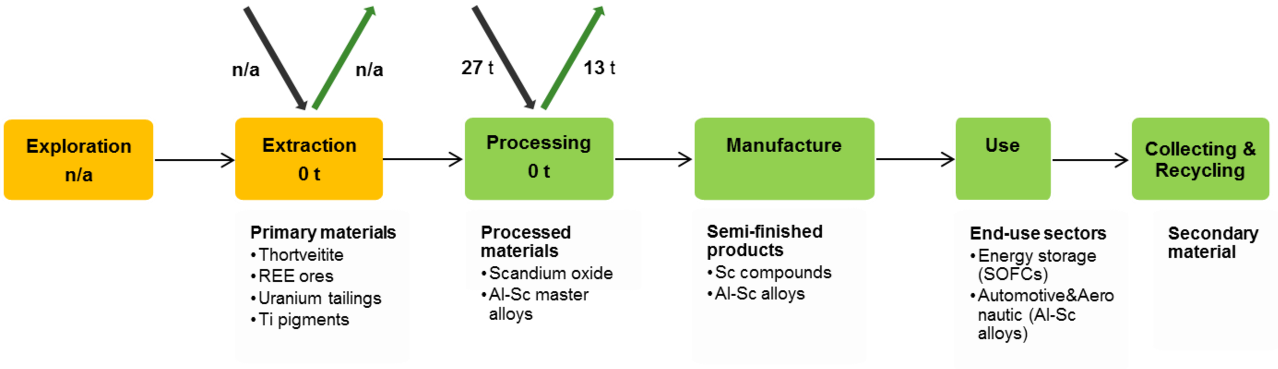

Figure 449: Simplified value chain for scandium for the EU, averaged over 2012-2016

Scandium (chemical symbol Sc, from the Latin 'Scandia' for Scandinavia where it was historically discovered) is a silvery-white light transition metal. Its main properties are its light weight (density of 2.99 g/cm^3, close to the one of aluminium), high melting point (1,541 °C) and small ionic radius. Scandium is not particularly rare; its abundance in the upper continental crust is 14 ppm[244] (Rudnick, 2003). However, due to the small size of its ions, it does not selectively combine with the common ore-forming anions, and rarely forms concentrations higher than 100 ppm in nature. Consequently,scandium deposits are rare. It shares similar characteristics with Rare Earth Elements (REEs) but has quite specific mineralogical and industrial properties, which justify a distinct classification.

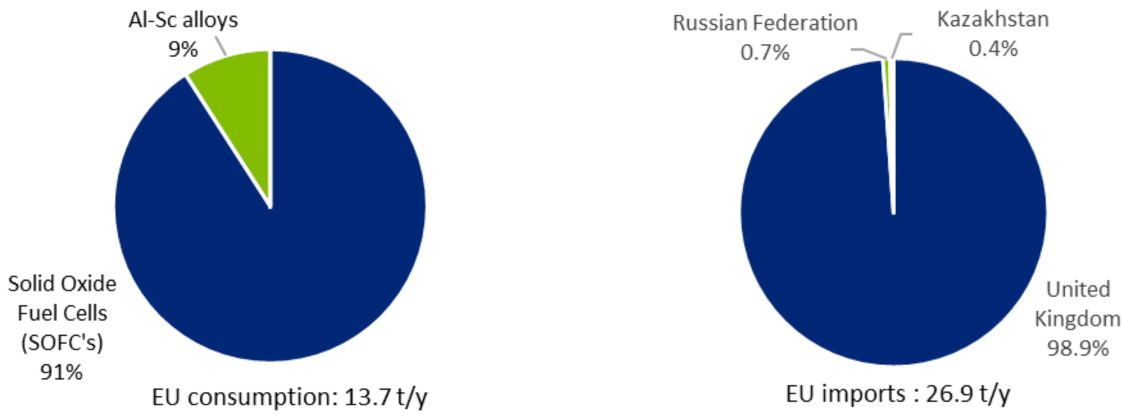

Figure 450: End uses (Duyvesteyn & Putman, 2014; Lipman, 2017; European Commission, 2014) and EU sourcing of scandium, processing stage (Eurostat, 2019), average 2012-2016

For the purpose of this assessment, scandium metal at processing stage is analysed. The product codes considering scandium at this stage are CN 2805 30 40 "Scandium, of a purity by weight

[244] parts per million

of ≥ 95% (excl. intermixtures and interalloys)" and CN 2846 90 30 "Scandium compounds, inorganic or organic" (Eurostat, 2019).

Scandium exhibits typical characteristics and challenges of a small, immature and undeveloped commodity market, meaning that lack of demand suppresses supply and non-existent supply reciprocally inhibits possible future demand. On the demand side, the main potential driver would be a growth in the use of scandium-aluminium alloys in aerospace and automotive applications, but market prices for scandium were considered by analysts too high and did not decrease as expected. On the supply side, much work is underway to study the potential for new multiple and reliable supply sources of scandium. Various players and countries have launched research on the recovery of scandium, notably from red mud caustic wastes. Several projects are currently developed to recover scandium mainly from secondary resources, but also primary resources, in Australia and the United States. As the scandium market is very small, and enough scandium is (currently) supplied, the mid-term success of the Nyngan and the other projects remains uncertain.

Depending on the products, prices for 2012-2018 period were of the following ranges:

- scandium oxide at 99.99% grade: US$4,600–5,400 per kilogram, when in 2010 it was US$1,620 per kilogram;
- aluminum-scandium master alloy (2% scandium): US$155-386 per kilogram.

Those prices remain too high to enable widespread commercial adoption of scandium, in alloy applications in particular. Scandium oxide prices were reported to drop by 35% in the period October 2018 to September 2019 compared to the period 2014-2018.

The total apparent consumption of scandium in the EU is around 13.7 tonnes per year. As there is no EU domestic production of scandium, this is exclusively reasoned by the excess of imports. According to the foreign trade data, United Kingdom appears by far the most important supplier of scandium to the EU, taking almost 98% (26.6 tonnes per year) of the imports to the EU. The quality of the trade data (Comext: scandium ≥95 % and scandium compounds), is estimated weak, but could not be replaced by better official data: especially the magnitude of the United Kingdom supply is very questionable. Further, minor source countries are Russia, Kazakhstan, United States and Hongkong. The world's main producers of scandium, China (around 10 tonnes per year), seems to direct its extractions and/or production to other destinations outside the EU or to use the commodity itself. This is the same for Ukraine although the production is much lower (around 1.0 tonne per year).

According to Lipmann Walton & Co (2016), the lion's share (90%) of total annual production in recent years would be absorbed by use in Solid Oxide Fuel Cells (SOFCs). There are a number of types of fuel cells, but SOFC design appears to be the current leader.

In SOFCs, yttrium and scandium can be used alternatively because they play the same role in stabilizing the zirconia-based electrolyte. The use of one or the other also depends on performance, price, or availability criteria and can evolve in time. However, In high-performance alloys, substitutes for scandium could be titanium, lithium (especially for aluminium alloys) or carbon fibre materials. They achieve comparable results in terms of resistance and low weight for aerospace and automotive structures.

In most of its applications, the use of scandium is a way to innovate and enhance performances and properties of already existing end-products. Therefore, this material could be considered as a substitute itself and alternatives exist for almost all of its uses. The choice is either driven by performance, price, or availability.

Aluminium-scandium alloys can help to minimise the weight of vehicles and thus the specific energy consumption, and SOFCs with scandium can contribute to push alternative engines. However, a drop in price would be crucial to increase the number of related vehicle units.

On a global scale, resources of scandium are abundant. There are identified scandium resources in Australia, Canada, China, Kazakhstan, Madagascar, Norway, the Philippines, Russia, Ukraine, and the United States.(Gambogi, 2017). The global reserves of scandium are not available.

Due to the lack of officially reported updated data, the assessment refers to the data of the previous one. Accordingly, it is estimated that two thirds of global production is located in China, followed by Russia with about a quarter of the global production. The Ukrainian production is from the tailing of an iron mine is estimated at 7%. However, at the validation workshop this production is said to be stopped in about 2017 (BRGM 2017).

Scandium is mostly won from secondary resources through hydrometallurgical processes, while pyrometallurgical processes are applied for recovery of scandium from primary sources (thortveitite). This latter route is energy intensive and therefore rare. Relevant secondary sources are: slags, residues, tailings and waste liquors of various metals. The processes applied there mainly involve leaching, solvent extraction, precipitation and calcination methods (Wang *et al.*, 2011). In recent years, the most single important source of secondary production comes from REE and iron ore processing in Bayan Obo (China).

Until some years ago, recycling of scandium in end-of-life products nor in 'new scrap' was known, due to its limited usage (UNEP, 2013). Over time, certain recycling routes have been developed for old scrap, namely car catalysts and as Al-Sc alloys. A bottleneck for recycling is the missing economy of scale due to the low market maturity.

22.2 Market analysis, trade and prices

22.2.1 Global market analysis and outlook

Scandium exhibits typical characteristics and challenges of a small, immature and undeveloped commodity market, meaning that lack of demand suppresses supply and non-existent supply reciprocally inhibits possible future demand. Having said that, rapid rise in supply by e.g. new mines can act the market price under pressure.

On the demand side, the main potential driver would be a growth in the use of scandium-aluminium alloys in aerospace and automotive applications. A landmark was achieved by the EU-based company Airbus which developed Scalmalloy^{TM} alloy family since 2012, with registration of the patent in 2014. In the past, analysts judged that prices for scandium had remained much too high to enable widespread commercial adoption and other materials compete directly (in particular the aluminium-lithium alloy family). The same reasoning applies for development of the SOFCs market. Until 2018, prices for scandium-aluminium alloy have not significantly increased thus the situation remained basically unchanged (Gambogi, 2019).

On the supply side, much work is underway to study the potential for new multiple and reliable supply sources of scandium. Various players and countries have launched research on the recovery of scandium, notably from red mud caustic wastes (notably in Russia, with the support of the major aluminium producer UC Rusal, as well as in Quebec, Canada). Other research projects are active in Japan, the Philippines, Kazakhstan, or Ukraine on scandium recovery from uranium tailings, sulphate titanium wastes, or nickel-laterites (Gambogi, 2016). The development and outcomes of these projects should be closely followed.

In terms of scandium exploration, as main or by-product, various projects are worth mentioning, among them four projects in Australia:

- Nyngan project, New South Wales;
- Clean TeQ, Syerston scandium project near Condoblin, central New South Wales;
- Sconi project, in northern Queensland.

In spite of efforts, so far no mine production of scandium has been reported in Australia.
The feasibility and economic assessment of the Nyngan scandium project was completed, and a mining lease was already granted.The reserves were estimated to contain about 590 tonnes of scandium (1.4 Mtonnes ore, cut-off grade 155 ppm scandium). The developer expected the beginning of the production in 2019, however, this was still subject to financing. The production volume expected is 38.5 tonnes per year of scandium oxide. An expert stated at the validation workshop that this new Australian mine claims that Airbus will be their main customer. The Syesterton project is also under development, but less close to opening with a cut-off grade of 300 ppm scandium.(Gambogi, 2019)[245]

In the United States, developers of multimetallic deposits, including the Round Top project in Texas and the Elk Creek project in Nebraska, were examining the incorporation of scandium recovery into project plans (Gambogi, 2016).

As the scandium market is very small, and enough scandium was supplied in …, the mid-term success of the Nyngan and the other projects remains uncertain.

Table 184: Qualitative forecast of supply and demand of scandium

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
Scandium	x		?	?	?	?	?	?

22.2.2EU trade

Only since 2016, scandium specific trade codes are applied at Eurostat Comext by the introduction of codes on pure scandium (CN 2805 30 40) and scandium compounds (CN 2846 90 30)[246]. Previous estimates by Lipman for Russia (200 kilogram per year) and Kazakhstan (100 kilogram per year), mainly in the form of scandium oxide, were maintained aiming to complete the uncertain data set. According to this joint dataset, the United Kingdom is by far the most important supplier of scandium to the EU, taking almost 99% (26.6 tonnes per year) of the imports to the EU, averaged over 2012-2016 (see Figure 451) (Eurostat, 2019). Minor source countries are Russia, Kazakhstan, United States and Hongkong. As the United Kingdom does not have own scandium production, the supply are considered re-exports. The world's main producers of scandium, China, seems to direct its extractions to other destination outside the EU or use the commodity themselves.

In terms of trade restrictions, Chinese export quotas on REEs also applied to scandium. These were lifted in 2015, replaced by resources taxes based on sales value (Metal Pages, 2015). At the moment, there are no export quotas or prohibition in place between the EU and its suppliers (OECD, 2016). From the EU's suppliers, only China has an export tax (≤ 25%) (OECD, 2016).

245 https://www.usgs.gov/centers/nmic/scandium-statistics-and-information?qt-science_support_page_related_con=0#qt-science_support_page_related_con

246 EU trade is analysed using product group codes. It is possible that materials are part of product groups also containing other materials and/or being subject to re-export, the "Rotterdam-effect". This effect means that materials can originate from a country that is merely trading instead of producing the particular material.

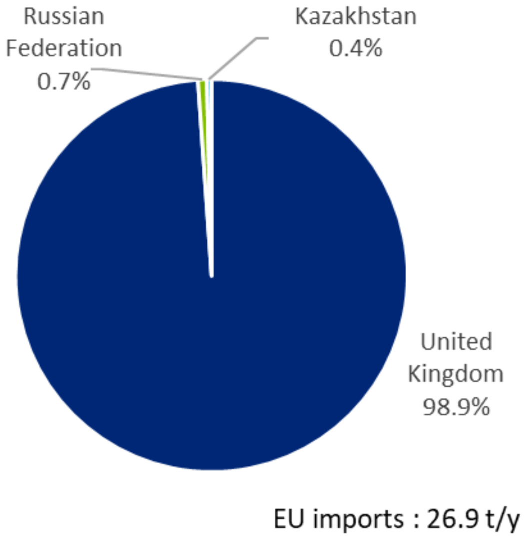

Figure 451: EU imports of scandium oxides, average 2012-2016 (Eurostat, 2019)[247]

22.2.3Prices and price volatility

Scandium is not traded on any metals exchange, and there are no terminal or futures markets where buyers and sellers can fix an official price. Scandium products are sold between private parties at undisclosed prices.

A way to estimate scandium metal or oxide prices is to simulate a purchase to specialized suppliers. In this way USGS determines some prices and publishes also for scandium products, based on consultation of a specialist supplier (Stanford Materials Corp.). Depending on the products, prices for 2011-2018 period were of the following ranges (Gambogi, 2016; Gambogi, 2019):

- scandium oxide at 99.99% grade (4N): US$4,600–5,400 per kilogram, when in 2010 it was US$1,620 per kilogram;
- aluminum-scandium master alloy (2% scandium): US$155-386 per kilogram.

Those prices remain too high to enable widespread commercial adoption of scandium, in alloy applications in particular. Scandium oxide prices were reported to drop (Asian Metal) strongly, i.e. by 35% in the period October 2018 to September 2019 compared to the period 2014-2018.

[247] in combination with a hypothesis on consumption and EU imports, based on expert communication (Lipmann Walton & Co)

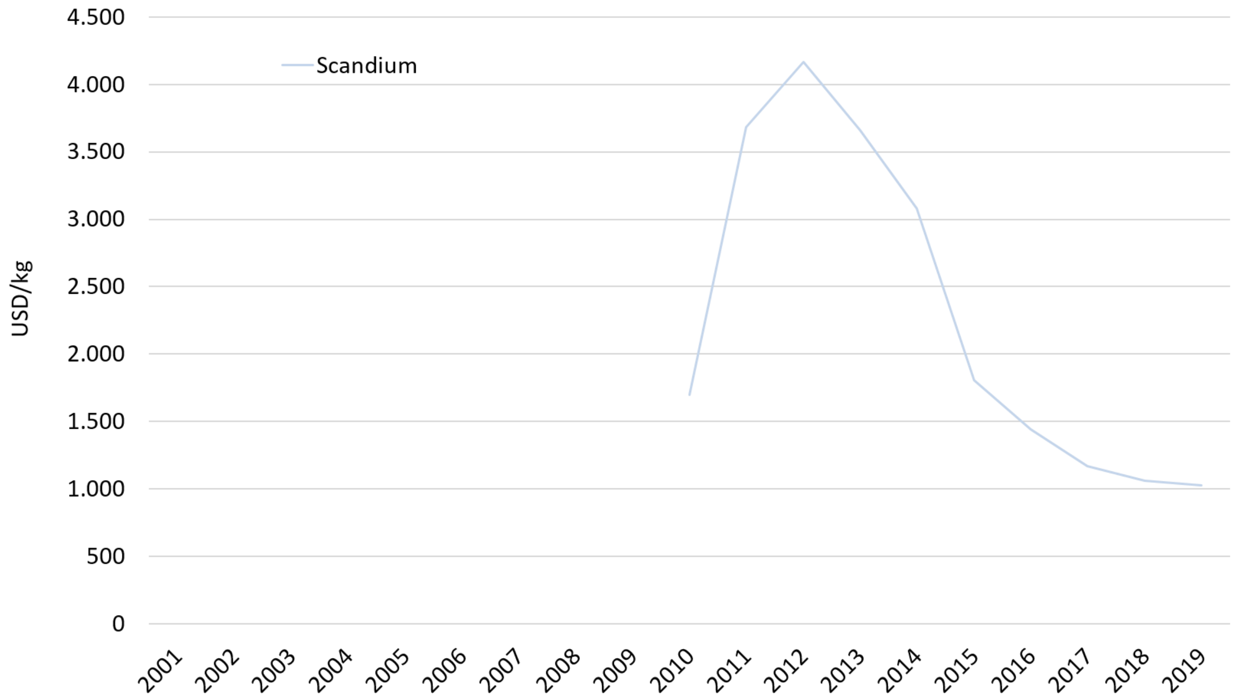

Figure 452: Annual average prices of 99% scandium oxide in US$ per kilogram from 2010 to 2019 (FOB China) (DERA, 2019)

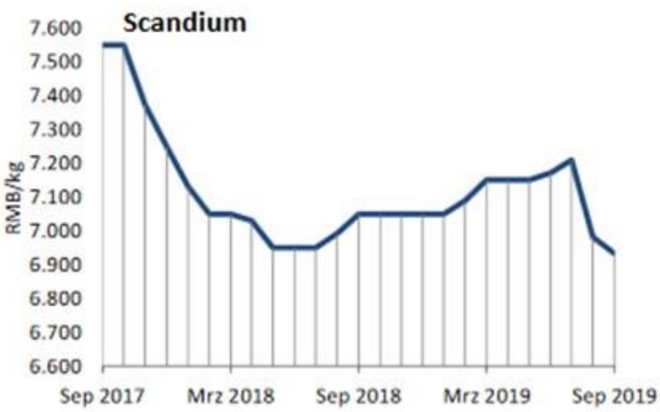

Figure 453: Price development of Scandium (oxides), min. 99.5%, China (Asian Metal).(after BGR, 2019)

22.3 EU demand

22.3.1 EU demand and consumption

Most of the imported quantities (a few hundred tonnes) are currently used either in R&D projects or in small markets (scandium-aluminium alloys, SOFCs) or minor other applications, such as high-quality sports equipment.

Due to the very high import values from United Kingdom, apparent consumption is determined as around 14 tonnes per year, averaged over 2012-2016. In spite of missing plausibility, there were in 2019 no better data available on EU consumption.

22.3.2Uses and end-uses of Scandium in the EU

According to Lipmann Walton & Co (2016), the lion's share (90%) of total annual production in recent years would be absorbed by use in Solid Oxide Fuel Cells (SOFCs) as shown in the Figure 454. The apparent EU consumption of scandium is 13.7 tonnes per year between 2012 and 2016.

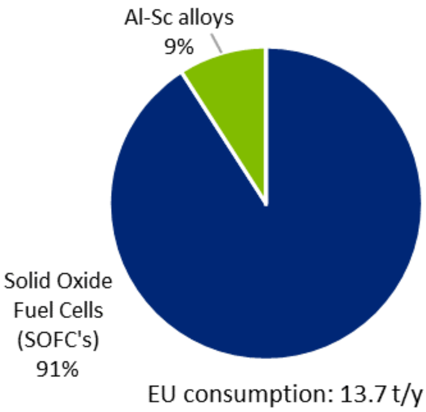

Figure 454: Global end uses of scandium. Average figures for 2012-2016 (Data from Duyvesteyn & Putman, 2014, Lipman Walton & Co., 2017, and , EC, 2014)[248]

Fuel cells, in particular SOFCs, are seen as a promising alternative electrical power supply, notably for automotive transportation. There are a number of types of fuel cells, but SOFC design appears to be the current leader.

In general terms, a fuel cell is an electrochemical cell that converts a fuel source and an oxygen source into an electrical current, plus water, CO_2 and heat. It does this by promoting reactions between the fuel and oxidant (reactants), which are triggered by a very high temperature environment (1,000 °C). The central part of a SOFC is a solid electrolyte generally composed of zirconia. However, zirconia would never withstand high operating temperatures without being stabilized with a metal. The stabilizing and conducting metal of choice for the electrolyte has traditionally been yttrium. Its advantages are its relative abundance (global production of around 8,000-10,000 tonnes per year) and low price (at around US$40-60 per kg, 100 times lower than scandium oxide). But, since the price spike on REEs and yttrium in 2011, scandium was given more attention to be the stabilizing agent for zirconia. Although playing the same role, it lowers the operating temperature of the cell and increases its lifespan and efficiency by improving the power density. Scandium proved to be a considerably better ionic electrical conductor than yttrium and more importantly, scandium allows the electrolyte to conduct at significantly lower temperatures (750-800 °C) so that the cost, efficiency and lifespan of materials for thermal shielding can be reduced (Duyvesteyn, 2014). Barriers for expansion of scandium in this market remain price and availability of this element.

There are more than hundred companies designing SOFCs today. The technical leader in commercial SOFC technology is Bloom Energy, a private company headquartered in Sunnyvale, California (Bloom Energy, 2016).

The second most important use application is as alloying element combined with aluminium. Aluminium-scandium (and magnesium) alloys are amongst the lightest metal resourcesknown

[248] At the validation workshop, the data was estimated by an expert as "outdated", but no better data was provided or promised. Therefore, the data is kept as "best available" estimate also for the period 2012-2016.

and could help increasing fuel efficiency in aerospace and automotive transportation. Small additions of scandium have the most promising effect on aluminum alloys, as this allows obtaining materials with a significantly improved set of properties. Scandium refines the crystal structure of aluminium to the point where the alloyed metal can be welded without loss in strength. It also increases plasticity in the moulding of complex shapes, improves corrosion resistance, and increases thermal conductivity. An extension in use to structural materials for aerospace engineering could develop in the future. In 2014, Airbus patented and developed Scalmalloy™, a specific scandium-magnesium-aluminium alloy family for use in aerospace (Airbus, 2016). However, aluminium-scandium alloys' are still extremely expensive, and the main market at present is mostly high-quality sports equipment (bikes, baseball bats, etc.).

The calculation of economic importance is based on the use of the NACE 2-digit codes and the value added at factor cost for the identified sectors (Table 185).

Table 185: Scandium applications, 2-digit NACE sectors, associated 4-digit NACE sectors, and value added per sector

Applications	2-digit NACE sector	4-digit NACE sector	Value added of sector (M€)
Solid Oxide Fuel Cells (SOFCs)	C27 - Manufacture of electrical equipment	27.90 - Manufacture of other electrical equipment	80,745
Al-Sc alloys	C25 - Manufacture of fabricated metal products, except machinery and equipment	25.11 - Manufacture of metal structures and parts of structures	148,351

Other minor useapplications of scandium in the form of metal or metal oxide include titanium-scandium carbides, GSGG lasers, mercury vapor high-intensity light, tracing agents in oil refining, or dopants in special glasses, glazes, and ceramic products (Gambogi, 2016). Scandium is also used for the manufacture of ferrites with low induction for computer memory elements (Intermix Met, 2016).

22.3.3Substitution

As the use of scandium is new and still a "niche market", the use of scandium is in most of its applications a way to innovate and enhance performances and properties of already existing end-products. Therefore, scandium is rather considered as a substitute itself, and alternatives exist for almost all of its uses. The decision for scandium at the choice of material is mainly driven by performance, price, or availability.

In high-performance alloys, substitutes for scandium can be titanium, lithium (especially for aluminium alloys) or carbon fibre materials. They achieve comparable results in terms of resistance and low weight for aerospace and automotive structures. Titanium and aluminum high-strength alloys, as well as carbon-fiber materials, may substitute in high performance scandium-alloy applications (Gambogi, 2019).

In SOFCs, yttrium and scandium can be used alternatively because they play the same role in stabilizing the zirconia-based electrolyte. The use of one or the other also depends on performance, price, or availability criteria and can evolve in time.

In some applications, however, that rely on scandium's unique properties, substitution is not possible (Gambogi, 2019).

22.4 Supply

22.4.1 EU supply chain

There is no mining of scandium and no production in the EU. The import reliance of EU-27 for scandium is 100%.

Scandium specific trade codes are applied at Eurostat Comext by the introduction of codes on pure scandium (CN 2805 30 40) and scandium compounds (CN 2846 90 30). Previous estimates for Russia (200 kilogram per year) and Kazakhstan (100 kilogram per year), mainly in the form of scandium oxide, based on expert consultation were maintained aiming to complete the uncertain data set on imports (Lipmann, 2016). According to this joint dataset, the United Kingdom is by far the most important supplier of scandium to the EU, taking almost 98% (26.6 tonnes per year) of the imports to the EU[249], which is almost double the reported global production. The quality of the trade data is estimated weak, but no better official data was available; especially the magnitude of the United Kingdom supply is very questionable. Further, minor source countries are Russia (0.2 tonne per year), Kazakhstan, United States and Hongkong (each 0.1 tonne per year).

Not much is known about scandium transformation in the EU. At present, it is still commercialized at a very modest level, focusing more attention at the R&D level, both for uses in alloys and Solid Oxide Fuel Cells (SOFCs). The EU-based company Airbus developed the Scalmalloy™ alloy family since 2012, with registration of the patent in 2014 (Airbus, 2016). But only one company is known to offer patented Scalmalloy™ alloys for sale, namely RSP Technology[250] in the Netherlands.

SCALE is an EU funded project that aims for efficient exploitation of a selection of high concentration scandium containing resources including bauxite residues from alumina production and acid wastes from TiO_2 pigment production. Based on a number of innovative extraction, separation, refining and alloying processes, the project investigates options for improvements along the overall supply chain with the ultimate goal to develop a stable and secure EU scandium supply chain to serve the needs of EU aerospace and high tech industry. This requires also the establishment of the foundation for a European scandium industry.

In terms of trade restrictions, Chinese export quotas on REEs also applied to scandium. These were lifted in 2015, replaced by resources taxes based on sales value (Metal Pages, 2015). At the moment, there are no export quotas or prohibition in place between the EU and its suppliers (OECD, 2016). From the EU's suppliers, only China has an export tax (≤ 25%) (OECD, 2016).

22.4.2 Supply from primary materials

22.4.2.1 Geology, resources and reserves of scandium

Geological occurrence: In the continental crust, scandium is essentially a trace constituent of igneous rocks ferromagnesian minerals. Scandium concentrations in these minerals (amphibole-hornblende, pyroxene, and biotite) are typically in the range of 5-100 ppm equivalent Sc_2O_3.

[249] Experts estimated the car catalyst recyclers as potential source.

[250] Website: www.rsp-technology.com

Genetic types of scandium deposits are difficult to classify (Borisenko, 1989) because this element is widely dispersed in the lithosphere and forms solid solutions in over hundred minerals such as rare-earth minerals, wolframite-columbite, cassiterite, beryl, garnet, muscovite, and the aluminum phosphate minerals. Scandium is also often associated with the elements fluorine and titanium in magmatic and sedimentary processes and can be found in numerous types of deposits (Hocquard, 2003). In the past, some scandium production has been generated from the scandium-yttrium silicate mineral, thortveitite (Crystal Mountain, United States). Some current exploration projects notably in Australia focus on nickel and cobalt lateritic deposits with high scandium concentrations (Duyvesteyn, 2014).

Scandium is also concentrated during the processing of various ores, specifically uranium, thorium, aluminium, tungsten, tin, tantalum, titanium and REE's, which are the main sources of supply.

Global resources and reserves[251]: The world resources of scandium are abundant. There are identified scandium resources in Australia, Canada, China, Kazakhstan, Madagascar, Norway, the Philippines, Russia, Ukraine, and the United States. The global reserves of scandium are not available. (Gambogi , 2019)

EU resources and reserves[252]*:* The Minerals4EU website does not display data about resources and reserves of scandium for Europe. In Finland, a resource of 13.4 Mtonnes is reported for the Kiviniemi deposit with a grade of 0.01627% scandium (Hokka et al. 2016).

Table 186: Resource data for the EU on Scandium

Country	Reporting code	Quantity	Unit	Grade	Code Resource Type
Finland	non-compliant code	13.4	Mtonnes	0.01627%	inferred

22.4.2.2 World and EU mine production

There are no scandium mines known globally, but all scandium is won as by-product (BRGM 2017). Various independent authors quote global market volumes of 2-10 tonnes per year. The

[251] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of vanadium 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.[251], 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.

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

estimate number of 15 tonnes (Lipmann, 2016) was confirmed by EMC Metals Corporation (Duyvesteyn, 2014) based on discussions with their potential customers, the level of metals trader activity and interest, and the fact that certain scandium consumers are believed to be sourcing their own scandium through small controlled recovery operations.

Chinese production would amount to 10 tonnes per year of Sc_2O_3 (66%), mainly as a by-product of REEs extraction (Bayan Obo mine). Also from recovery of sulphate wastes from the manufacture of titanium pigments, or from residues of iron ore, zirconium, tungsten or bauxite production (BRGM 2017, Gambogi 2019). Russia produces 3-5 tonnes per year (33%), mainly from uranium mill tailings (Intermix Met, 2016) and apatite (Gambogi 2019). Kazakhstan is estimated to produce 100-200 kg scandium oxide annually (1%), also from uranium mill tailings (Lipmann, 2016, Gambogi 2019). Scandium is also extracted as by-product of uranium mining in Ukraine (Gambogi 2019). Small stockpiles of this material may exist in Russia, Ukraine and Kazakhstan. At the validation workshop, an expert mentioned that in Norway some scandium had been produced as by-product of uranium, for usage in lasers. Mine production data for 2018 were not available (Gambogi 2019).

22.4.3Supply from secondary materials/recycling

Until some years ago, recycling of scandium in end-of-life products nor in ‘new scrap’ was known, due to its limited usage (UNEP, 2013). Over time, certain recycling routes have been developed for old scrap.

22.4.3.1 Post-consumer recycling (old scrap)

Scandium was considered widely as not recyclable, accordingly scandium contained in waste ends up predominantly in landfill (European Commission, 2014).

Scandium can be potentially recycled from certain end-of-life products, namely from car catalysts, fuel cells and aluminium-scandium alloys. However, scandium recovery from Sc-Al alloys and Sc_2O_3 is a complex issue as: (a) there is lack of information on the amount of Sc-containing electronic wastes and whether this materials are collected and processed by the recycling companies, (b) the number of specific cutting-edge devices containing scandium is small and therefore the potential recovery amounts are limited. Scandium in fuel cells is not recycled due to missing economy of scale.

We conclude that this recycling is still a niche activity, and neglectable or non-existent (Gambogi, 2019). Figures on recycling volumes are not available[253].

22.4.3.2 Industrial recycling (new scrap)

It is very difficult to recover scandium contained in intermediates, mixed scrap etc., i.e. scraps that are processed by specialty chemicals companies (e.g. Johnson Matthey)(Fontboté 2019).

22.4.4Processing of Scandium

Pyrometallurgical processes are suitable for recovery of scandium from primary sources (thortveitite). This route is energy intensive and rare.

Hydrometallurgical processes are more widely used for scandium recovery from secondary sources (slags, residues, tailings and waste liquors of various metals). They mainly involve leaching, solvent extraction, precipitation and calcination methods (Wang et al., 2011). Most of

[253] The Material System Analysis (MSA-Sc2019) is still work in progress and was, at the time of the criticality assessment, not able to provide more insightful information.

the time, the first step is the precipitation of insoluble scandium compounds from scandium-containing solutions. The complexities of flowsheets to recover scandium depend on the amounts and types of impurities that can co-precipitate at this stage. Scandium oxide (Sc_2O_3) is then obtained by thermal decomposition of the precipitate. After purification, Sc_2O_3 is fluorinated to obtain an intermediate compound ScF_3 (scandium fluoride). Scandium metal is produced by reducing ScF_3 with calcium metal or by aluminothermic reduction. Aluminothermic reduction has the advantage of obtaining the aluminium-scandium alloy directly (Blazy, 2013).

In recent years, the most single important source of secondary production comes from REE and iron ore processing in Bayan Obo (China). In this case, REEs and scandium are extracted into solutions by roasting the ore in concentrated sulphuric acid at 250–300 °C and then leaching with water (Li et al., 2004).

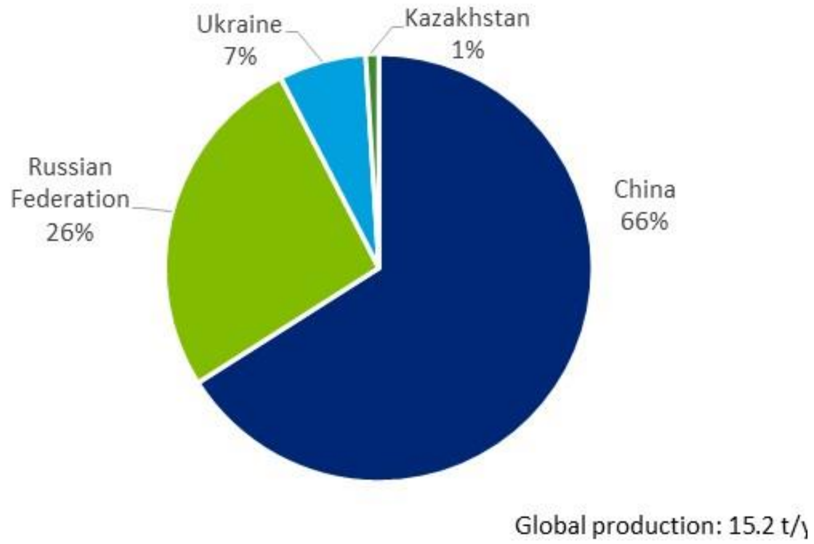

Figure 455: Estimation of global production capacity of processed scandium products. (Comtrade, 2019), average of year 2012-2016

Figure 455 shows the estimation of global production capacity of processed scandium products. Due to lack of officially reported updated data, the assessment refers to the data of the previous one. Accordingly, two thirds of global production between 2012 and 2016 was located in China, followed by Russia with about a quarter of the global production. The Ukrainian production was from the tailing of an iron mine. For the period 2012-2016 it is estimated to 7%, however, at the validation workshop this production is said to be stopped in about 2017 (BRGM 2017).

22.5 Other considerations

22.5.1 Environmental and health and safety issues

Scandium is considered non-toxic, and it is not subject to restrictions by the REACH regulation (ECHA 2019). The median lethal dose (LD_{50}) levels for scandium chloride for rats have been determined as 4 milligramme per kilogram for intraperitoneal and 755 milligramme per kilogram for oral administration (Haley *et al.*, 1962).

EU occupational safety and health (OSH) requirements exist to protect workers' health and safety. Employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[254].

22.5.2 Socio-economic issues

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

22.6 Comparison with previous EU assessments

The assessment has been conducted using the same methodology as for the 2017 list. Supply risk has been analysed at processing stage.

The results of this and earlier assessments are shown in Table 187.

Table 187: Economic importance and supply risk results for Scandium 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
Scandium	5.8	4.9	3.8	1.1	3.7	2.9	4.4	3.1

After decrease of the Economic Importance (EI) score for scandium between 2011 and 2017, the 2020 assessment shows a trend reversal. Supply Risk (SR) score, after a minimum in 2014, continued to increase modestly. The abrupt rise in SR after 2014 can partly be explained by a revised methodology that took into account new parameters such as the concentration of global production, the diversity of EU supply sources, and geopolitical risks. Thus it reflects, among others, the dominance of China on global production.

22.7 Data sources

Criticality assessment was performed at the stage of processing due to the better data availability than for the stage of extraction (no global information available) and the fact that it was judged as the main bottleneck for EU, as in the 2017 CRM assessment. Market shares and production data were in great part based on expert consultation (Lipmann, 2016).

Trade data is based on the Eurostat Comext dataset, which was significiantly improved regarding scandium trade. At the 2017 CRM assessment, the Comext dataset did not allow evaluating imports quantities, as CN8 customs codes referring to scandium (CN 2805 30 10, 2805 30 90, 2846 90 00[255]) mixed various products with scandium being the least. Therefore, scandium imports to the EU were estimated based on expert consultation (Lipmann, 2016). However, new scandium trade codes on pure scandium (CN 2805 30 40 "scandium, of a purity by weight of ≥ 95% (excl. intermixtures and interalloys)") and scandium compounds (CN 2846 9030 "scandium compounds, inorganic or organic") were introduced, providing data more specific on scandium since 2016. Aiming for comprehensive data coverage, both new Comext data and hitherto used expert data (Lipmann, 2016) were combined. Information on export restrictions

[254] https://ec.europa.eu/social/main.jsp?catId=148

[255] CN 2805 30 10 "Intermixtures or interalloys of Rare Earth Metals, Scandium and Yttrium", CN 2805 30 90 "Rare Earth metals, Scandium and Yttrium (excl. intermixtures and interalloys", CN 2846 90 00 "Compounds, inorganic or organic, of Rare Earth metals, of Yttrium or of Scandium or of mixtures of these metals (excl. Cerium)"

are derived from the OECD Export restrictions on the Industrial Raw Materials database (OECD, 2016). Data on trade agreements are taken from the DG Trade webpages, which include information on trade agreements between the EU and other countries (European Commission, 2016).

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