Update of the 2015 Material System Analyses

Final report

In Extenso Innovation Croissance, ifeu, Ökoinstitut e.V. and Mariane Ighilahriz
August 2023

and Mariane Ighilahriz, expert consultant

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate I — Ecosystems IV: Mobility & Energy Intensive Industries
Unit I.1 — Energy Intensive Industries and Raw Materials

Contact: Constanze VEEH

E-mail: GROW-CRM@ec.europa.eu

European Commission
B-1049 Brussels

Report issued under Specific Contract No SI2.868952 implementing Framework Contract ENV.B.3/FRA/2019/0017

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Manuscript completed in August 2023

Citation as: “European Commission, Update of the 2015 Material System Analyses, 2024”

Luxembourg: Publications Office of the European Union, 2024

PDF ISBN 978-92-68-13918-9 doi:10.2873/440874 ET-05-24-214-EN-N

1. Abstract

Consistent information on raw material value chains is key for sustainable resources management, to guarantee the supply of raw materials and to strengthen the European Union's industrial competitiveness. The European Commission has launched the update of the 2015 Material System Analyses of 23 materials. The MSA studies consider the entire life cycle of a selected material, investigating the stocks and flows of materials throughout the economy. They can help identifying opportunities to source materials from urban mining or waste streams, as well as potential bottlenecks in the value chain. MSAs also support the monitoring of the circular economy and the development of the list of critical raw materials (CRM).

The list of MSAs was expanded to 11 additional materials: strontium, titanium, and additional rare earth elements for which no MSA has previously been conducted. REEs are materials with a very high supply risk, and only 6 were covered by the previous 2015 MSA. Moreover, among these additional materials, strontium and REEs were assessed as critical in the 2023 list. Titanium was assessed as non-critical in the 2023 list.

The developed MSA are comprehensive datasets that may provide crucial knowledge to help the development and monitoring of EU polices including: the EU list of Critical Raw Materials, the new EU Industrial Strategy, the Green Deal transition plan, the EU Raw Materials Initiative, the EU Circular Economy Action Plan and the Critical Raw Materials Act.

2. Contents

3. Introduction

3.1. Introduction to the MSA methodology

The economic model in the European Union (EU) is based on a high level of raw material use. In fact, raw materials are an indispensable basis in our everyday life, but also for high tech, innovations, and eco-efficient tech. The Raw Material Consumption (RMC) or material footprint of the EU-27 was evaluated at 13.7 tons per capita in 2020, corresponding to a total of approximately 6.1 billion tons[1]. This value has remained stable since 2010. The EU relies heavily on imports, often from a single third country, and recent crises have underlined strategic dependencies for the EU.

Against the background of the much-needed transition to a decarbonised society with modern, environmentally friendly technologies, securing access to strategic raw materials becomes paramount.

In 2020, the circular material use rate (CMUR) is at 12.8%[2], meaning that the vast majority of materials comes from primary material extraction. However, compared to 2019, the circularity rate increased by 0.8 % and is expected to further increase in the coming years and decades. The increased use of secondary raw materials does not only generate fewer environmental impacts but also implies that the EU can become more self-sufficient and less dependent on an extra EU raw material supply. This development can also be supported by increased raw material efficiency as a result of implementing more innovative and efficient processing and manufacturing approaches.

In 2023, the European Commission proposed a Critical Raw Materials Act to address the issue of supply security and strategic dependencies. This proposal included the results of the 2023 criticality assessment.

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1 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Material_flow_accounts_statistics_-_material_footprints#EU.27s_material_footprint_by_material_category_over_time

2 https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/ddn-20211125-1

To make evidence-based decisions, the European Commission launched the development of Material System Analysis (MSA) studies in 2015. MSA is a methodology that investigates the stocks and flows of materials throughout the economy. It supports:

the monitoring of the circular economy

the development of the list of critical raw materials (CRM)

the raw materials (RM) scoreboard.

MSA enable us to gain an in-depth understanding of the flows over the life-cycle of the individual materials, as well as of potential bottlenecks and key sectors using the materials. The level of details helps to better understand which stakeholders are involved, and to what extent the EU is autonomous or dependant on external supply (e.g. primary materials, end products, waste to be recycled in the EU). They consider hotspots and bottlenecks in the material value chain (extraction, stock accumulation and end-of-life management, e.g., through disposal or recovery). Awareness of weak points in the value chain can guide actions designed to increase the resilience of the supply chain, also in the face of disruptive events (Matos et al., 2020). In addition, dependencies that might emerge with new technologies can be identified and countermeasures can be taken. In the mid-term, MSA provides a basis for developing sound sustainable resource management strategies. The systemic view of the MSA also lends itself to develop and support scenarios and outlooks.

The first series of 28 MSAs was published in 2015 (BIO by Deloitte, 2015), then a second series covering three materials was published in 2018 (Passarini et al., 2018). A third series focused on five battery related raw materials (Matos et al., 2020) and MSAs of 9 raw materials covering those that had entered the list of critical raw materials since 2015. They were published in 2020 and 2021 respecitively,

This study is an update of the MSAs from 2015, covering 24 of the materials assessed at this point in time. Since then, however, the assessments have not been updated. In addition, the list of MSAs was expanded to 11 additional materials: strontium, titanium, and additional rare earth elements (as REEs are materials with a very high supply risk, and only 6 were covered by the previous 2015 MSAs). No MSA had previously been conducted for these materials.

This study covers the most up-to-date data for the years 2016 to 2020. The geographic coverage of the studies was the EU (without the UK). Compared to the MSA from 2015, it follows a revised MSA methodology (Torres de Matos et al, 2020) which was used for the 2020 and 2021 MSAs. It increases the resolution of the MSA system and covers the evaluation of several indicators to characterise the situation of each material in the EU.

Priority was given to official and publicly available data sources. For some materials, however, information was collected from stakeholders during the validation workshops. For each material, this report summarises the flows and stocks of the year 2020, except for the platinum group metals that reports the 2019 dataset. For PGM, the year 2020 was considered atypical due to a significant impact of the COVID crisis on the automotive industry.

The detailed calculations and the results for the full period covered (2016-2020) are stored in MSA excel files retained by the European Commission.

3.2. Presentation of the approach followed by the project team

The MSA of each individual material was performed by experts from IEIC, Oeko-Institut, ifeu and independent expert Mariane Ighilahriz. IEIC was also in charge of coordinating the work done, reviewing each MSA with the help of Mariane Ighilahriz and assembling the current report.

During their preparation, the MSA studies summarised here were presented to raw material experts in two workshops. They were organised in synergy with SCRREEN 2, to make efficient use of the experts' availability. In particular, the MSAs were developed alongside the 2023 criticality assessment study, to make sure that the data and assumptions validated at the workshop for the criticality assessment were consistent with the corresponding flows of the undergoing MSAs, labelled as Part 1 of the MSAs (extraction and processing flows).

In the **criticality validation workshop**, the first draft results of the MSA studies were presented to raw material experts during a workshop organised by the SCRREEN project together with DG GROW to support the 2023 EU criticality assessment and Part 1 of the MSAs. This workshop took place from the 20th to the 23rd of September 2022 and had the following objectives: 1) validate the data and data sources used in both studies (the criticality assessment and the material system analysis); 2) exchange data, information and knowledge (including sources for missing data) on the targeted raw materials. A dedicated section was organised for each raw material. Data and assumptions used for Part 1 flows were summarised in background documents and distributed to the participants before the workshop, including a list of questions to be discussed during the workshop session. The related results were presented at the workshop, followed by discussions. The comments received during and after the workshop were addressed, and the data collected were incorporated in the development of the complete MSA datasets.

After the preparation of complete MSA dataset drafts, IEIC organised a **second workshop** as a webinar for each raw material with the aim of discussing the results of the studies. Important stakeholders from the value chain of each raw material were invited and attended the webinars. The lists of stakeholders who participated to the workshops are provided in the Appendix. As for the first workshop, the main data and assumptions were included in a background document which was sent to the participants of the workshop prior to each session. The comments received during and after the workshops were addressed, and the data collected were used to prepare the final MSA dataset summarised here for each material.

During the review of each MSAs, IEIC ensured consistency and harmonised practices with regard to data quality and calculations.

During the preparation of the MSA, some limits and shortcomings were observed with regards to the MSA methodology. Those are described in the conclusion of the report.

4. Results of the MSA by material

The following chapters are organised as follows:

The section on the **value chain** includes a brief description of the value chain of the material, as well as the figure of the simplified value chain (incl. the main uses of the material), reflecting on steps which are either encountered within the EU or not. The description includes more precise information on the value chain of the material, e.g. identifying the sub-stages which are executed in the EU or those which are not being carried out here (e.g. distinguishing between smelters and refineries when relevant, for instance on antimony or PGMs).

The description of the **main flows and stocks** includes the explanation of the simplified Sankey diagrams for the year 2019 or 2020, depending on the material.

The section on **data sources, assumptions and reliability of results** describes the main data sources and main assumptions, and the reliability and uncertainties of the results. Furthermore, the section includes a brief evaluation of potential changes with the previous exercise (for materials on which a first MSA was conducted in 2015), to clarify whether the changes originate from a different methodological approach or can be attributed to a change in the market.

4.1. Aggregates

4.1.1. Value chain

Aggregates are granulated materials obtained from naturally occurring resources. The most common natural aggregates are land-based crushed rocks and sand and gravel, obtained from quarries and pits. Marine aggregates are obtained from seabed deposits, mostly used in damns, dikes and for beach refurbishment. Manufactured aggregates are produced by other industries, sourced from industrial processes such as blast or electric furnace slags or china clay residues. Recycled aggregated are reprocessed materials previously used in construction. Extraction of aggregates involves crushing and screening, but not chemical processing. Aggregates are used for many applications including construction products such as concrete, asphalt, or railway ballasts. They can also be used without further transformation as structural materials. These products are used in the construction sector in residential, public or commercial buildings, and in a wide range of infrastructure works.

Figure 1 below presents the value chain of aggregates with the main uses, by type of material and by end-use sector. All stages of the value chain are carried out within the EU.

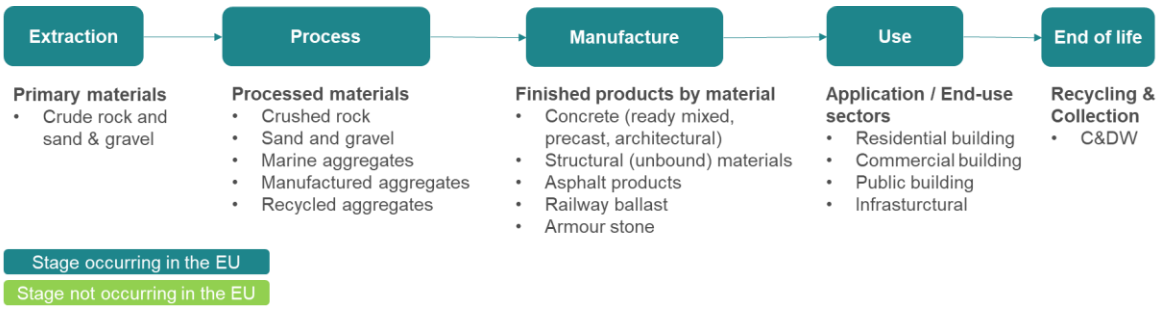


Figure 1: Value chain of aggregates, steps in dark green are carried out in the EU, steps in light green are only carried out in non-EU countries

4.1.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of aggregates and are representative of the year 2020.

Natural rock is an abundant resource and the associated reserves and resources have not been quantified. Even though natural rock is abundant, in practice there are regional constraints due to geology and access constraints to the resource. In 2020, around 41 970 Mt of aggregates was produced worldwide.

Around 2 600 Mt of natural rocks are extracted each year in the EU, corresponding to a total production of around 1 400 Mt of crushed rocks and 1 200 Mt of sand and gravel, marine aggregates, and manufactured aggregates. The residues generated during the extraction and processing steps are reused for restoration works of quarries, pits, or other extraction sites.

The extracted volume is supplemented by 220 Mt of recycled aggregates, as explained later.

The market of aggregates is mostly local and regional, with short distribution distances. There is little external trade (between the EU and the rest of the world, mostly Norway and UK) of aggregates or trade between EU Member States. The extra-EU trade of most aggregates and construction products is lower than 1% of the production sold in the EU; this applies to each step of the MSA for aggregates.

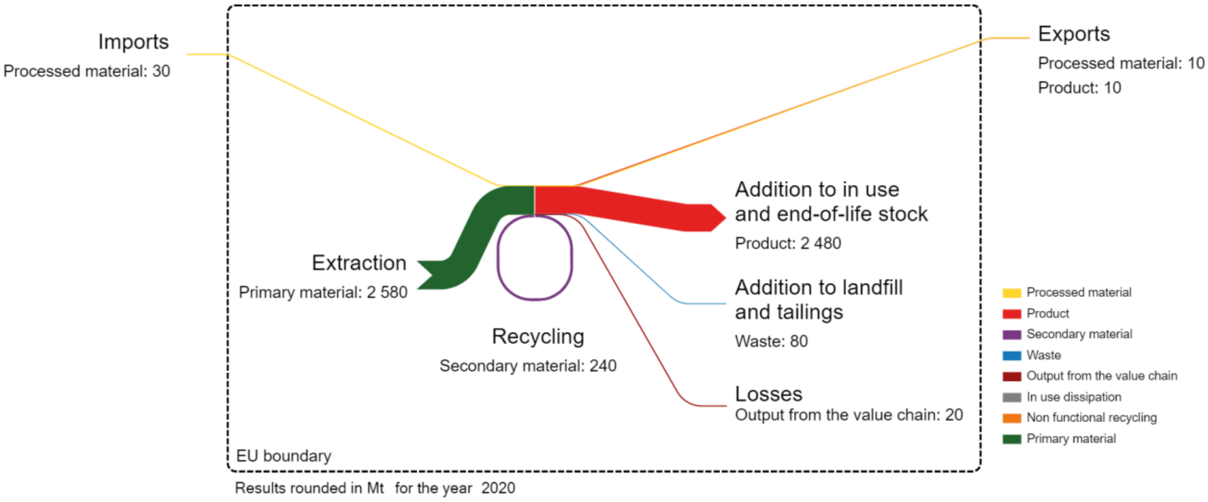
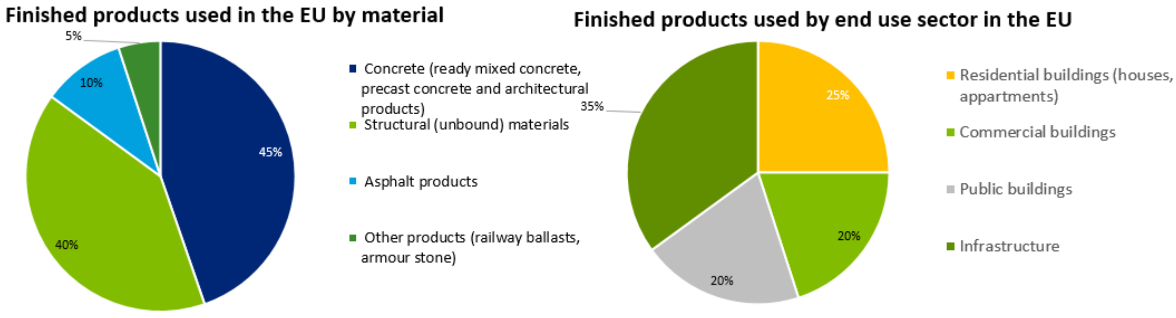


Figure 2: Simplified Sankey diagram for aggregates for the year 2020 in the EU, in Mt.

Figure 3 shows the distribution of aggregates-containing finished products used by material (pie-chart on the left-hand side) and used by end use sector (pie chart of the right-hand side) in the EU.

In the EU, aggregates are directly used in construction works as structural materials (1 120 Mt of aggregates, as presented in Figure 3 – left) or are used to manufacture concrete products (1 250 Mt), asphalt products (270 Mt), or other products such as railway ballasts or armour stone (140 Mt). The amount of waste generated during the manufacturing of products such as concrete or asphalt is negligible, as the material will directly be used again in the next mix (“reclaimed or recovered concrete”). The aggregates and construction products containing aggregates are used in infrastructure works (970 Mt), residential buildings (700 Mt), public and commercial buildings (each 555 Mt) (see distribution by end-use sector of the total consumption for the EU on Figure 3 – right).



2 795 Mt of aggregates

2 782 Mt of aggregates

Figure 3: Shares of finished products containing aggregates manufactured in the EU (left) and shares of finished products containing aggregates used in the EU (right), by application

For each of the applications, Table 1 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection, and recycling steps of all aggregates.

Application	Representative product
Concrete	Building blocks and bricks of cement, concrete or artificial stone; Tiles, flagstones and similar articles of cement, concrete or artificial stone (excluding building blocks and bricks); Pipes and other articles of cement, concrete or artificial stone, and accessories; Articles of cement, concrete or artificial stone for non-constructional purposes; Ready-mixed concrete
Structural (unbound) material	-
Asphalt products	Bituminous mixtures based on natural and artificial aggregate and bitumen or natural asphalt as a binder
Other products (railway ballast, armour stone)	Factory made mortars, Pre-coated aggregates

Table 1: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

Considering the lifespan of buildings and infrastructures and the annual growth in the construction sector, the quantity annually added to stock is around 2 500 Mt, and the stock is evaluated at 167 000 Mt of aggregates.

Construction and demolition waste is usually sent to a treatment for crushing, sorting and, if necessary, washing. From there it is sent to different construction uses. Around 300 Mt of mineral construction and demolition waste were generated in 2020, of which around 220 Mt were recovered as recycled aggregates. The rest – being sent to landfill – was considered not suitable for recycling (e.g. due to sorting).

4.1.3. Indicators

Table 2 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 72% in 2020, and the end-of-life recycling rate (EoL-RR) was 72%. According to production data published by the European Aggregates Association, the production of recycled aggregates from C&DW (including those reused on-site) is approx. 220 Mt for 2020 period; from these data the end-of-life recycling input rate (EOL-RIR) is estimated at 8%. This clearly states that the extraction of natural aggregates will continue to supply the most substantial part of market needs.

Regarding self-sufficiency, the EU is independent of imports at extraction and processing stages and is self-sufficient for manufacturing. Given the high transportation cost, it is clear that almost everything that is produced and manufactured in the EU is also extracted in the EU.

For the five years analysed, the main changes with regards to the indicators in Table 2 are related to the changes in production of recycled aggregates and fluctuation in the reported amount of collected mineral construction and demolition material.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	6%	10%	9%	8%	8%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	57%	72%	85%	72%	72%
Collection rate	F1.4/(M4.1)	57%	72%	85%	72%	72%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	100%	100%	100%	100%	100%
Self-sufficiency Processing	C1.1/M2.1	99%	99%	99%	99%	99%
Self-sufficiency Manufacturing	D1.1/M3.1	100%	101%	101%	100%	100%

Table 2: Different indicators that describe aggregates situation in the EU

4.1.4. Data sources, assumptions and reliability of results

The main sources of data used to develop the MSA are the Eurostat database COMEXT and PRODCOM as well as the European Aggregates Association (UEPG), mainly 2017-2021 data for the EU-27 and the Global Aggregates Information Network (GAIN). There is fairly reliable data on the first steps of production of aggregates, although the wide variety of uses of aggregates and construction products makes it difficult to estimate aggregate contents, efficiency of processes and fate of the different flows of aggregates.

The data on processing of aggregates is taken from the European Aggregates Association statistics, and a number of hypotheses are taken in order to calculate the data on extraction, manufacturing and use steps. In the use step, aggregates are part of many construction works, buildings and infrastructure.

An approximation of the total accumulated stock of aggregates in the European Union’s construction sector is attempted by using the data on aggregates used by each construction sector, an average lifespan in construction works, and historic data on growth of the construction sector in Europe. The result on in-use stock of aggregates in the EU is therefore highly estimative.

Different sources report data on construction and demolition waste arising in the EU, with a range between 300-860 Mt; depending on what materials within the waste fraction is considered. Further, CDW data is reported only every two years by Eurostat, thus, for 2017 and 2019 there are data gaps. This makes it difficult to do a robust estimation of the aggregates waste generated and the fate of this waste. For the present MSA, the data on waste provided by Eurostat was preferred, after validation of experts.

The results of the MSA are comparable with the previous MSA conducted in 2015. Changes result mostly from the market evolution. With regards to construction and demolition waste, a different value was used (previously 535 Mt were assumed) explaining the higher recycling rate in the 2023 MSA.

4.2. Antimony

4.2.1. Value chain

Antimony occurs most commonly in stibnite deposits, from which antimony ores and concentrates are produced. It is also found in smaller amounts in polymetallic ores where it can be produced as a by-product of lead, copper and tin smelting. The latter is estimated to represent 10% of the worlds primary production, with 65% of Sb being extracted from antimony concentrates and ores and the rest accounted for as secondary antimony (mainly recycled form lead acid batteries).

After extraction, antimony ores & concentrates are processed into antimony metal. Antimony metal is further processed into other compounds, in particular antimony oxide, and antimonial lead alloys. Antimony oxides (most commonly diantimony trioxide) are used to manufacture flame retarded plastics and rubbers where they are often added as a synergist to enhance the function of other flame retardants as such. These can be used in plastic and rubber intermediate products then used to manufacture finished products such as textiles, electrical equipment and cable coatings. Diantimony trioxide is also used as a synergist of flame retardants for printed circuit boards in epoxy resins as well as potentially in other polymers. It is also used as a catalyst in the production of PET plastics which are used to produce PET containers such as bottles and food trays; furthermore, they are used for producing textiles. Antimonial lead is used in lead acid batteries, most of which are used as vehicle starter batteries. Antimony alloys are used in a wide variety of other finished products such as ammunition. Antimony is also used in ceramic and glass applications such as high purity and transmission flat glass used in solar applications and night vision binoculars.

At end-of-life, the recycling of lead-acid batteries results in a significant contribution to the production of antimony. For the manufacture of such batteries in the period analysed, experts said that only a few percent of primary lead were used in manufacture of new batteries, whereas in 2023 manufacture is already considered self-sufficient. The recycling of PET also enables recycling of antimony in relevant applications. In other applications, functional recycling is considered negligible. Figure 4 below depicts the value chain of antimony, its intermediates and end-uses covered by this study.

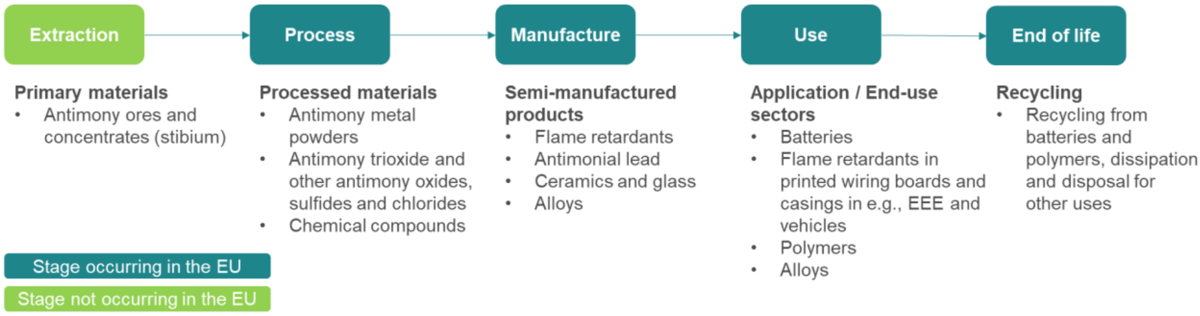


Figure 4: Value chain of antimony, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.2.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of antimony (t Sb) equivalent and are representative of the year 2020.

Global antimony reserves are reported as 2 000 kt Sb. China, Russia, Bolivia and Kyrgyzstan account together for around 70% of the total antimony reserves with similar shares. In the EU, antimony reserves are not reported. A few deposits exist (Rockliden in Sweden and Corbabado in Spain), but these are considered resources as they are not considered economical for extraction at present.

The actual global production of antimony in 2020 was 119 kt Sb, with China accounting for around 50% of the extracted volume, followed by Tajikistan who produced about 20%. In the EU, antimony is not extracted as a main product, but as a by-product of polymetallic ores. Experts have referred to such extraction carried out for example by Boliden in the extraction of lead. This is, however, not being declared as the antimony remains in the lead which is then used to produce antimonial lead. An estimation was made for 2020 that 1 482 t Sb was produced in the EU as a mass balance, in some cases not extracted from the main material as explained above. This could also explain the exports of antimony, of 11 t Sb in 2020, though some of these may also be re-exports.

The domestic input to EU antimony processing was supplemented with imports of antimony ores and concentrates and imports of secondary material (respectively 481 t Sb and 2 t Sb). It can be understood that some manufacturers use antimony metal to produce oxides, and sometimes oxides are then processed to a higher purity grade. Imports of antimony unwrought powders and antimony oxides can thus supplement the processing stage or the manufacturing stage of the value chain. In 2020, based on mass balance of other flows, it has been assumed that all such imports entered the processing stage. Thus, the domestic input was also supplemented through imports of about 19 195 t Sb semi-processed material in 2020 (Sb metal and Sb oxides). Additionally, about 467 t Sb came from manufacturing waste generated in the EU into the processing stage. Post-consumer recyclate was rather sent to directly to the manufacturing stage than the processing stage.

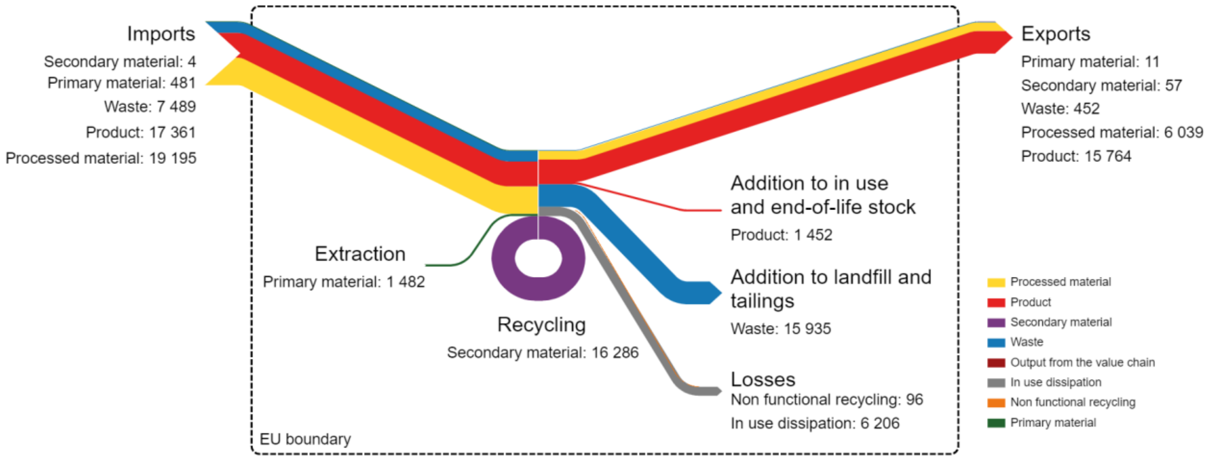


Figure 5: Simplified Sankey diagram for antimony for the year 2020 in the EU, in t

A total of 21 594 t of processed material (unwrought antimony; powders and antimony oxides) were produced in the EU in 2020. According to experts, all processing waste was recycled back to processing due to the price of this commodity, in other words there was no antimony sent to disposal at this stage. Nonetheless, 22 t Sb of scrap and slags were exported, meaning that reprocessing may also have occurred outside the EU in some cases.

Though the EU manufacturing stage was supplemented through imports of Sb metal and oxides in earlier years, this amount has been estimated to be null in 2020 (respective imports have been considered to be semi-processed materials, supplementing the processing stage, as explained above). Imports of antimony scrap and wastes also supplemented the EU manufacturing stage and were around 2 t Sb 2020. However, data varied a lot over the period investigated (<1 t to 74 t).

Additionally, about 15 818 t Sb were supplemented from post-consumer functional recycling in the EU to the manufacturing stage. The EU industry manufactures various compounds (such as diantimony trioxides, antimonial lead, etc.) which are then incorporated into finished products in the EU: flame retardants (13 221 t Sb), lead acid batteries (9 939 t Sb), PET plastics where antimony is used as a catalyst (1 844 t Sb), other metallurgical applications such as ammunition (4 348 t Sb) and other non-metallurgical uses like ceramics and glass (1 553 t Sb). Here too, due to the price of antimony, all waste generated from product manufacturing is sent for reprocessing (467 t Sb).

Figure 6 shows the distribution by end-use sector of antimony-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

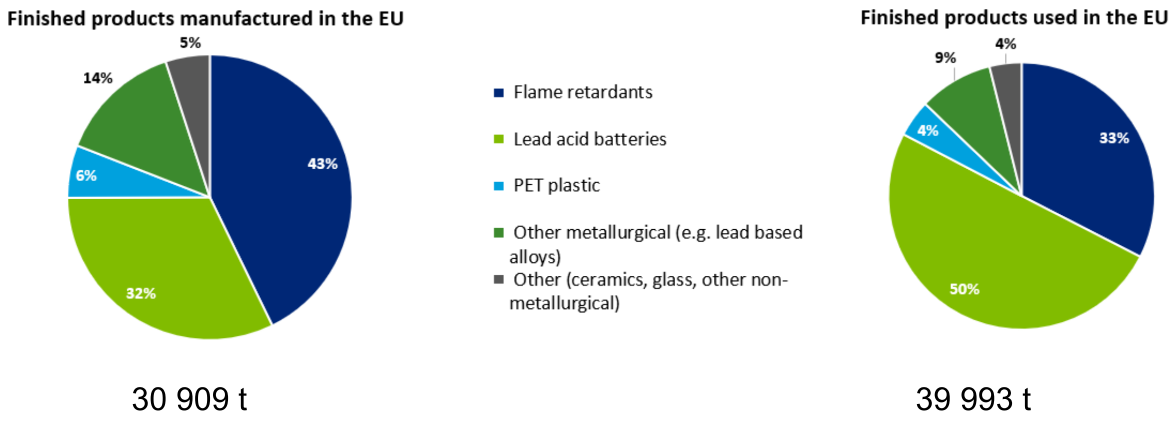


Figure 6: Shares of finished products containing antimony manufactured in the EU (left) and shares of finished products containing antimony used in the EU (right), by application

For each of the applications, Table 3 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection, and recycling steps of all antimony products.

Application	Representative product
Flame retardants	Cable sheathing
Lead acid batteries	Vehicle lead-acid batteries
PET plastic	PET bottles
Other metallurgical (e.g. lead based alloys)	Ammunition
Other (ceramics, glass, other non-metallurgical)	Frits

Table 3: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection, and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 1 374 t Sb in 2020. The total stock of products in-use is quantified at about 180 092 t Sb in 2020.

About 23 099 t Sb leaving the use phase were collected and sorted for recycling, while about 6 205 t Sb were lost due to dissipation during use, mostly due to used ammunition and batteries in vehicles that are unaccounted for at end-of-life. Despite 8 806 t Sb sent to landfill rather than collected for treatment and about 7 127 t Sb of recycling waste, a similar amount, 15 818 t Sb, of secondary antimony provided a significant input to domestic manufacturing in 2020.

4.2.3. Indicators

Table 4 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 71% in 2020, and the end-of-life recycling rate (EoL-RR) was 50%. The ratio of recycling from old scrap contributing to EU demand for antimony (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 43%. The differences between collection and EoL-RR are due to losses of Sb during recycling. In its largest application, flame retardants, antimony is often used as a synergist for other brominated flame retardants. In this case, the materials in which they are contained are sorted out and sent to incineration, and the antimony is assumed to end up in slags that will be landfilled due to hazardous classification.

Regarding self-sufficiency, the EU relies on imports at the extraction stage. In the processing stage, in the past years the EU has been self-sufficient, exporting more antimony than it imports. The EU also has a high self-sufficiency for manufacturing, importing less than quarter of the material used in this stage.

In 2020, only 7% of antimony was extracted in the EU with the rest imported. The amount of antimony consumed in the use phase (M3.1) is somewhat higher than what is manufactured in the EU (D1.1), resulting in a self-sufficiency lower than 100%. These results demonstrate that the EU manufacturing capabilities have a high sufficiency but do not yet cover the demand for all relevant products.

In the five-year period analysed, many of the flows gradually decreased, which follows the global decrease in the production of antimony in the period between 2016 and 2020. This may be related to the increasing sufficiency of lead acid battery manufacture as well as a possible shift away from brominated flame retardants with which antimony is used as a synergist.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	38%	39%	40%	40%	43%

EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	46%	46%	47%	48%	50%
Collection rate	F1.4/(M4.1)	69%	70%	70%	71%	71%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	<1%	29%	4%	<1%	7%
Self-sufficiency Processing	C1.1/M2.1	116%	125%	128%	120%	139%
Self-sufficiency Manufacturing	D1.1/M3.1	84%	83%	82%	79%	77%

Table 4: Different indicators describing the antimony situation in the EU

4.2.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the U.S. Geological Survey (USGS 2018-2022), the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other sources from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for the stages extraction and processing and for some products in manufacture and trade). The antimony content is available from discussions with various experts and references (i2a). Overall, basic extrapolation was applied to primary data to compute reliable estimates of antimony flows and stock in the EU.

Due to lack of information, some assumptions based on expert knowledge or expert judgement were made for evaluating the characteristics of antimony-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of antimony flows during use and end-of-life. The feedback from the validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results, however for some applications data was not available to allow revision.

Data provided in the MSA on antimony recycling originates from expertise gathered during personal communications with stakeholders, the validation workshops as well as from literature.

This new assessment differs from the previous one due to new information and data availability. For the reserves, USGS data is used, whereas MSA 2015 used reserves data from "Critical Metals Handbook", Ed. Guss Gunn, J. Wiley & sons, 2014. Furthermore, the reserves in Rockliden, Sweden, were disregarded, as these are considered to be currently not economically feasible for extraction. Furthermore, different conversion rates have been used to calculate the Sb content in “concentrates and ores”, in “oxides” and in “scrap metal”. Furthermore, different assumptions for end uses, in some cases stemming from difference in choice of representative product, have been made.

4.3. Beryllium

4.3.1. Value chain

Beryllium (Be) is a metal mainly found in ores such as bertrandite and pegmatites containing beryl. Beryllium extracted from these ores is mainly processed into master alloys (most of them being copper alloys), oxides or beryllium metal powders.

Beryllium master alloys enable the production of semi-manufactured products, with the alloy composition depending on the targeted applications. Beryllium used in those products can reduce the weight of the alloy, improve its mechanical stability, its resistance to wear and corrosion, or improve its electrical conductivity. They are used in electronics for consumer products, in automotive applications and telecom applications, but also in many industrial components.

Beryllium oxides are used in ceramics, for their properties as electrical insulator and to improve thermic energy dissipation of the material. Beryllium ceramics can be found in electronics and are used in the aerospace and defence industry.

Beryllium metal powders can be used to produce pure beryllium metal, which is a light-weight metal, and can be polished as a mirror. It is also has the property to reflect neutrons and is used in diverse applications in the nuclear industry for that, in particular for a significant amount in the ITER project.

Figure 7 below depicts the value chain of beryllium, its intermediates and end-uses covered by this study. There is no extraction or processing of beryllium in the EU.

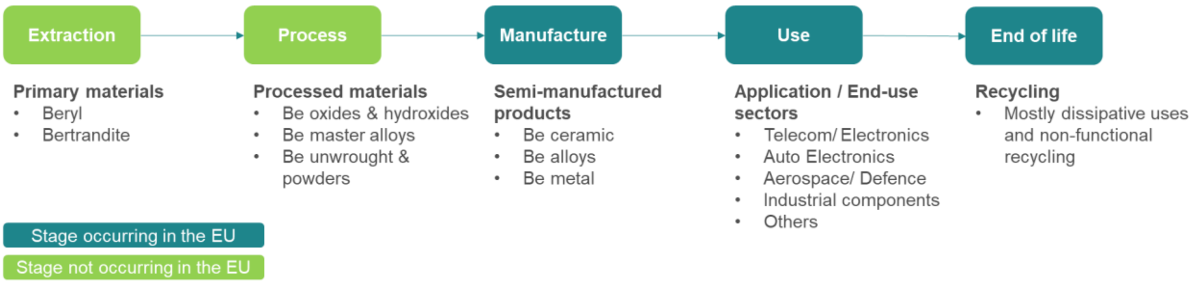


Figure 7: Value chain of beryllium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.3.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of beryllium (t Be) metallic equivalent and are representative of the year 2020.

Global beryllium reserves are estimated at about 33.3 kt Be, with 60% of the global beryllium reserves in the USA. In 2020, the world production of beryllium reached 272 t Be and the top producer country was the United States, extracting 70% of beryllium volumes.

There are no reserves of beryllium in the EU, and therefore no extraction. There is also no domestic production of processed materials of beryllium in the EU (beryllium oxides and hydroxides, beryllium powders and master alloys), and therefore no trade of beryllium ores and concentrates in the EU.

The input to EU beryllium manufacturing is entirely supplied through imports of beryllium oxides/hydroxides and master alloys (respectively 0.2 and 15 t Be) to produce intermediate products such as beryllium ceramics, alloys and metals that are further incorporated into finished products. There are no imports of secondary material to supply the manufacture of beryllium products, nor input coming from post-consumer functional recycling in the EU.

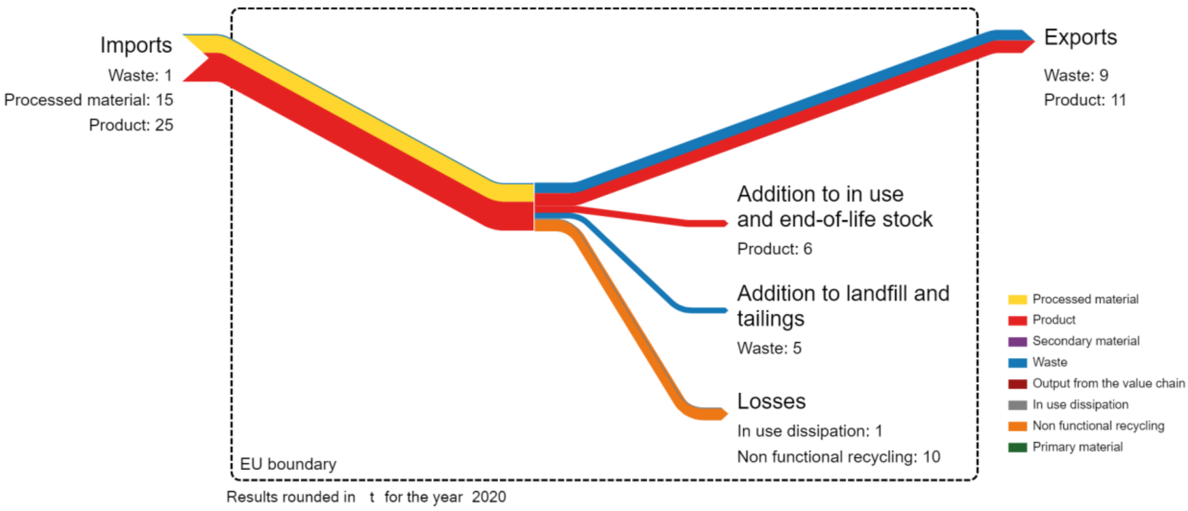


Figure 8: Simplified Sankey diagram for beryllium for the year 2020 in the EU, in t, imports of products include also 17.3 t Be of intermediate products, supplied to the manufacturing stage.

Another input to the EU manufacturing stage is the imports of 17.3 t Be in intermediate products net-imported from outside the EU (beryllium ceramics, alloys and metals). The European Union's industry consumes about 32.5 t Be to manufacture various finished products containing beryllium, such as industrial components (4.9 t Be), aerospace and defence applications (5 t Be), automotive electronics (3.6 t Be), electronics in consumer goods (2.6 t Be), telecommunication infrastructure (2.4 t Be), energy applications (1.5 t Be), and other applications (4.5 t Be), as beryllium can be used in the production of rubber, plastics and glass.

Most of the beryllium new scrap generated from product manufacturing was exported (7.7 t Be), and only 0.3 t Be considered sent to landfill.

Figure 9 shows the distribution by end-use sector of beryllium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

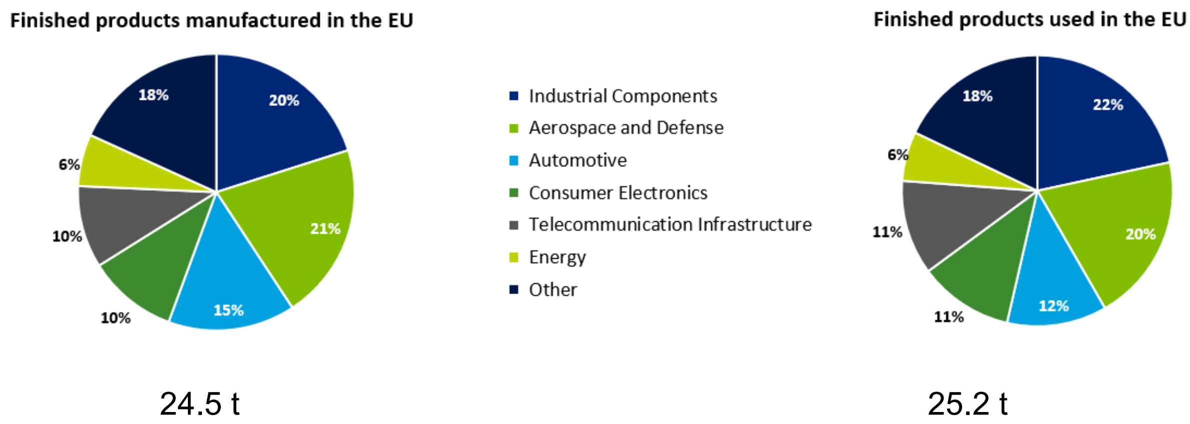


Figure 9: Shares of finished products containing beryllium manufactured in the EU (left) and shares of finished products containing beryllium used in the EU (right), by application

For each of the applications, Table 5 lists the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection, and recycling steps of all beryllium products.

Application	Representative product
Industrial Components	Drilling tools for the oil industry
Aerospace and Defence	Airplanes
Automotive	Vehicles
Electronics in consumer goods	Washing Machines
Telecommunication Infrastructure	Connectors
Energy	Nuclear Reactors
Other (including rubber, plastics and glass)	Moulds

Table 5: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 5.3 t Be in 2020. The total stock of products in-use is quantified at about 166.2 t Be in 2020.

About 15.3 t Be contained in products was collected for waste treatment, while 3.9 t Be were exported for reuse. Among products collected for waste treatment, 5.2 t Be was sent to landfill rather than recycled and about 9.8 t Be was non-functionally recycled.

4.3.3. Indicators

Table 6 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 89% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. Therefore, the ratio of recycling from old scrap contributing to EU demand for beryllium (i.e., end-of-life recycling input rate, EoL-RIR) was also null. The differences between collection and EoL-RR were due to the fact that all of the collected products are either landfilled or recycled for their copper content, regardless of the beryllium contained.

Regarding self-sufficiency, there is neither extraction of beryllium, nor is there any processing industry. Therefore, the EU relies solely on imports to supply the manufacturing stage and is self-sufficient for manufacturing, exporting more than the amount imported. In 2020, 97% of beryllium in products sent to use in the EU came from the EU manufacturing industry. The EU manufacturing capabilities are therefore nearly sufficient to cover the demand for the main application sectors.

For the five years analysed, changes are minimal for those indicators.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	90%	90%	89%	89%	89%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	N/A	N/A	N/A	N/A	N/A
Self-sufficiency Processing	C1.1/M2.1	0%	0%	0%	0%	0%
Self-sufficiency Manufacturing	D1.1/M3.1	97%	98%	97%	99%	97%

Table 6: Different indicators that describe beryllium situation in the EU

4.3.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, USGS publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for the imports of processed products and some products in manufacture). The beryllium content is available from various expertise and references such as BGS. Overall, basic extrapolation was applied to primary data to compute reliable estimates of beryllium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of beryllium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of beryllium flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on beryllium manufacturing and recycling mainly originates from expertise gathered during personal communications with BeST.

The results of the 2023 MSA differ from those of the MSA conducted in 2015 due to new information and data availability. The distribution of end uses changed in order to better reflect the market. Also, a higher rate of internal recycling is considered at the manufacturing stage, and more products are considered as collected at end-of-life due to increased resolution for the use of products.

4.4. Boron/borates

4.4.1. Value chain

Borates are inorganic salts of boron (B) with major deposits found in Turkey and California. Natural borates are extracted under the form of boron-containing minerals such as colemanite, ulexite, tincal, and kernite. Those minerals are processed into several chemical forms, including borax pentahydrate, borax decahydrate, anhydrous borax, boric acid and diboron trioxide.

A large share of natural borates and refined borates are used in the glass and ceramics industries, where borates ensure a low coefficient of thermal expansion. It improves the resistance of those materials to high temperature and prevents cracking (such as in pyrex cookware, or laboratory equipment).

Borates are also essential for agriculture and are used as such in fertilisers, as boron is a necessary element for plant growth. Boron can be found in most plants, in particular in fruits. Agricultural residues can be used as a boron containing fertiliser.

Borates are used in the chemical industry, in some metals and construction materials, for various properties: borates can be used as a wood preservative and a fungicide, they can improve the physical strength of some materials.

Finally, there are other uses with non-significant amounts, but of high economic importance, such as boron used in NdFeB magnets or semiconductor manufacturing.

Figure 10 below depicts the value chain of borates, their intermediates and end-uses covered by this study. All stages of the value chain except extraction take place within the EU.

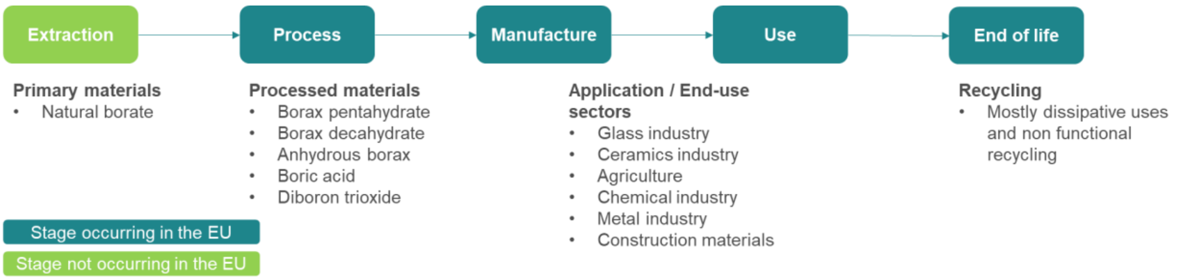


Figure 10: Value chain of borates, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.4.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of boron (kt B) atomic equivalent and are representative of the year 2020.

Global borates reserves are estimated at about 417 Mt B, with 90% of the global borates reserves in Turkey. In 2020, the world production of borates reached 1.12 Mt B and the top producer country was Turkey, with about 50% of extracted borates volumes.

There are no reserves of borates in the EU27, therefore no extraction of natural borates in the EU. Reserves exist in Serbia.

The input to EU borate processing was supplied by imports of natural borates (16.4 kt B, of which 2.2 kt B are re-exported). There was no input from secondary materials, neither imported, nor from manufacturing waste generated in the EU or from post-consumer functional recycling in the EU.

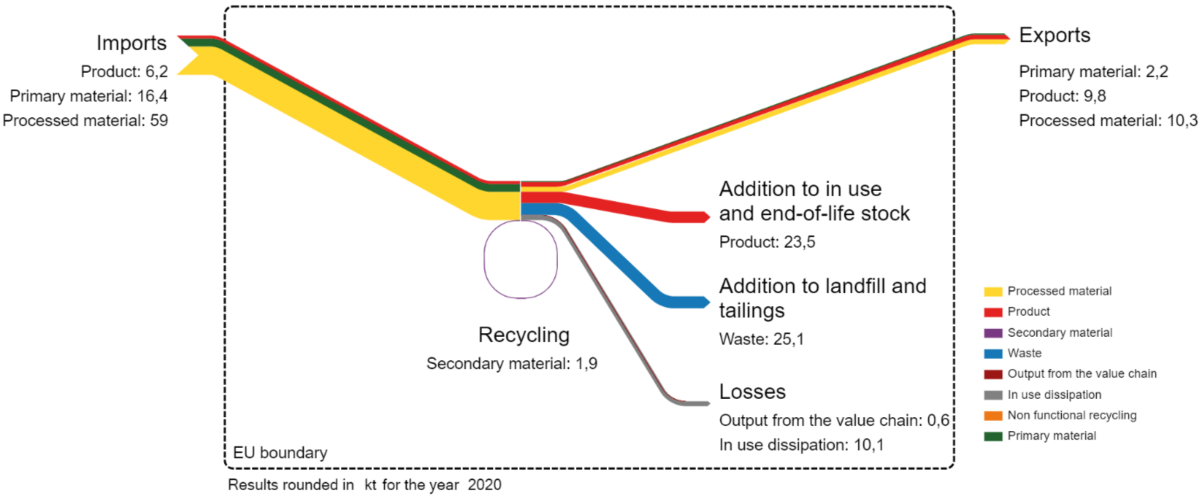


Figure 11: Simplified Sankey diagram for borates for the year 2020 in the EU, in kt.

A total of 11.2 kt B of processed material were produced in the EU. About 2.9 kt B is generated as processing waste, sent to disposal.

The input to the EU manufacturing stage was supplemented with 48.7 kt B of processed material net-imported (imports accounted 59 kt B of processed material while the exports were 10.3 kt B). Additionally, about 1.9 kt B were supplemented from post-consumer functional recycling in the EU. The EU industry manufactures various finished products containing boron: glass products (31.2 kt B), fertilizers (8.7 kt B), chemical synthesis reagents (5.3 kt B), frits and ceramics (5.6 kt B), cellulose insulation (2.5 kt B), and industrial fluids (2.6 kt B). All of the boron new scrap generated from product manufacturing was sent to landfill (5.5 kt B).

Figure 12 shows the distribution by end-use sector of boron-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

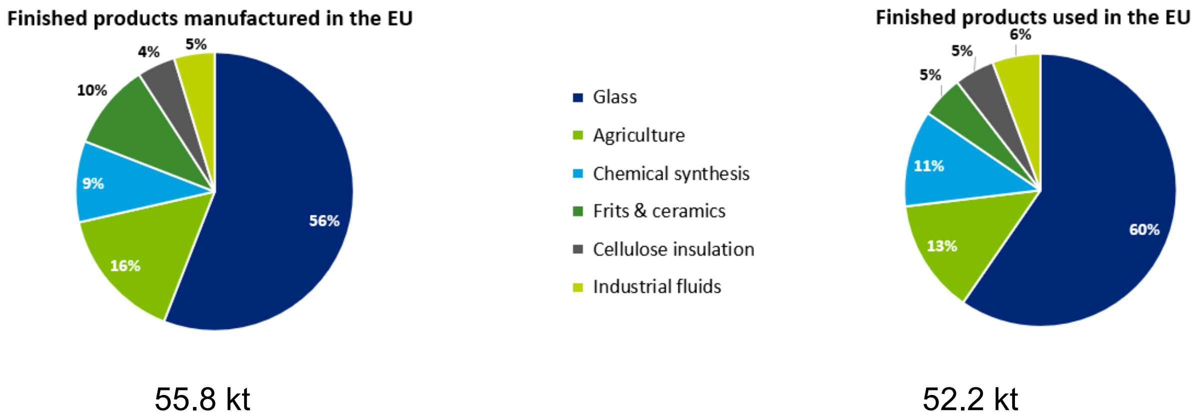


Figure 12: Shares of finished products containing boron manufactured in the EU (left) and shares of finished products containing boron used in the EU (right), by application

Table 7 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all borates.

Application	Representative product
Glass	Glass wool
Agriculture	Fertilisers
Chemical synthesis	Borates
Frits & ceramics	Frits
Cellulose insulation	Cellulose
Industrial fluids	Detergents

Table 7: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 23.5 kt B in 2020. The total stock of products in-use is quantified at about 370 kt B in 2020.

About 10 kt B were lost due to dissipation during use, mostly due to the fertilizers, industrial fluids and chemical synthesis uses. This leaves about 18.6 kt B contained in products collected for waste treatment. Among products collected for waste treatment, 16.7 kt B were sent to landfill rather than recycled and about 1.9 kt B of the volume was functionally recycled (from agriculture) to supply the manufacturing stage in the EU. It is to be noted that glass recycling is considered to concern only packaging and window frames, therefore no recycling is considered for boron-containing glass products.

4.4.3. Indicators

Table 8 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 10% in 2020, and the end-of-life recycling rate (EoL-RR) was also 10%. The ratio of recycling from old scrap contributing to EU demand for borates (i.e., end-of-life recycling input rate, EoL-RIR) was of 3%. The differences between collection and EoL-RR were due to the fact that most of the collected products are landfilled, and that the borates contained are considered non recoverable. The only exception are borates used in the agriculture, as the boron element is absorbed by plants and is recovered by the soil due to the use of manure as a fertiliser.

Regarding self-sufficiency, there is no extraction of borates, and insufficient processing industry capacities in the EU. Therefore, the EU relies solely on imports to supply the processing stage, and furthermore imports 81% of the borates required by the manufacturing industry in the EU. However, the manufacturing industry is self-sufficient for the supply to the use stage, exporting more that the amount manufactured.

For the five years analysed, changes are minimal for those indicators, except for a drop in processed volumes in 2020 which can be attributed to the COVID pandemic.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	3%	4%	4%	3%	3%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	13%	14%	14%	11%	10%
Collection rate	F1.4/(M4.1)	13%	14%	14%	11%	10%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	23%	20%	22%	25%	19%
Self-sufficiency Manufacturing	D1.1/M3.1	106%	103%	105%	107%	107%

Table 8: Different indicators that describe borates situation in the EU

4.4.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, Etimine publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for the imports of processed products and some products in manufacture). The boron content is available from various expertise and references such as IMA and CNRS. Overall, basic extrapolation was applied to primary data to compute reliable estimates of borates flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of borates-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of borates flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on borates manufacturing and recycling mainly originates from expertise gathered during personal communications with IMA Europe.

The results of the 2023 MSA differ from those of the MSA conducted in 2015 due to new information and data availability. Data for the processing stage now relies on extractions from Eurostat databases, and the distribution of end uses is increased in resolution. Also, manufacturing waste is now calculated on higher quality hypothesis, and the representative product for the main application, in the glass industry, is now considered to be glass wool. This has a significant impact on flows at the use stage and collection flows, and therefore on recycling flows.

4.5. Chromium

4.5.1. Value chain

Chromium ore is extracted, beneficiated and separated into distinct grades. The main primary material is metallurgical-grade chromium ore, which is processed into ferrochromium. Ferrochromium is used, along with scrap, to produce stainless steel and alloy steel. The finished products can be found in all end-use sectors with a dominance in consumer goods for households (cutlery, kitchen surfaces, cookware, appliances, sinks, etc.).

Refractory-grade chromium ores are processed into refractory chromite and are used to manufacture refractory bricks and mortars, whereas foundry-grade chromium ores are processed in foundry sands and used for the production of casting molds. Most of the final applications are in the heavy industry (iron and steelmaking, foundries).

The main processed materials from chemical-grade ore are hexavalent sodium dichromate and chromium trioxide (both toxic and carcinogenic). These chemicals are manufactured into other chromium compounds (such as chromium (III) oxide) with various final applications (leather tanning, chrome plating, pigments). In particular, chromium (III) oxide is used to manufacture chrome metal, necessary for super alloys in the aviation and energy sector (e.g. gas turbine).

Figure 13 below depicts the value chain of chromium, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

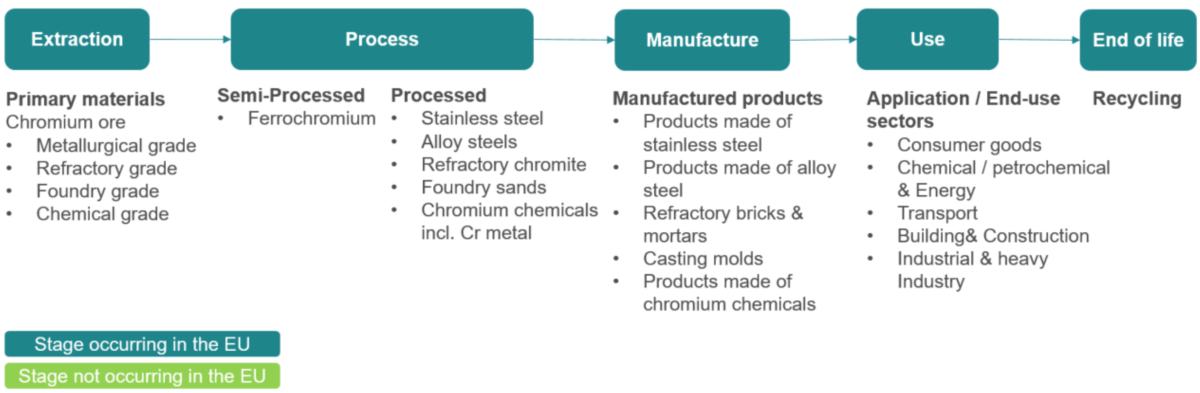


Figure 13: Value chain of chromium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.5.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of chromium (t Cr) metallic equivalent and are representative of the year 2020.

Significant reserves of chromium in the EU are located in Finland only, with about 8 900 kt in chromium content. In comparison, reserves in the rest of the world are estimated as 167 000 kt in chromium content with vast reserves in South Africa and Kazakhstan. The first stages of the value chain mainly take place outside the EU. The EU production of chromium ore is of 330 kt in chromium content and comes from the mine of Tornio in Finland (the only mine located in the EU). In comparison, the world annual production is around 11 900 kt, mainly in South Africa (45%), Kazakhstan (17%) and India (11%).

Around 97% of the Chromium ore extracted in the EU is sold on the EU market. The domestic input to EU chromium processing was supplemented with imports of chromium ores of different ore grades (metallurgical, refractory and foundry) and imports of secondary material (respectively 66 kt Cr and 71 kt Cr). Additionally, about 140 kt Cr were supplemented from manufacturing waste generated in the EU, and 533 kt Cr from post-consumer functional recycling in the EU. Further, 415 kt of ferrochromium is imported and sent to processing in the EU.

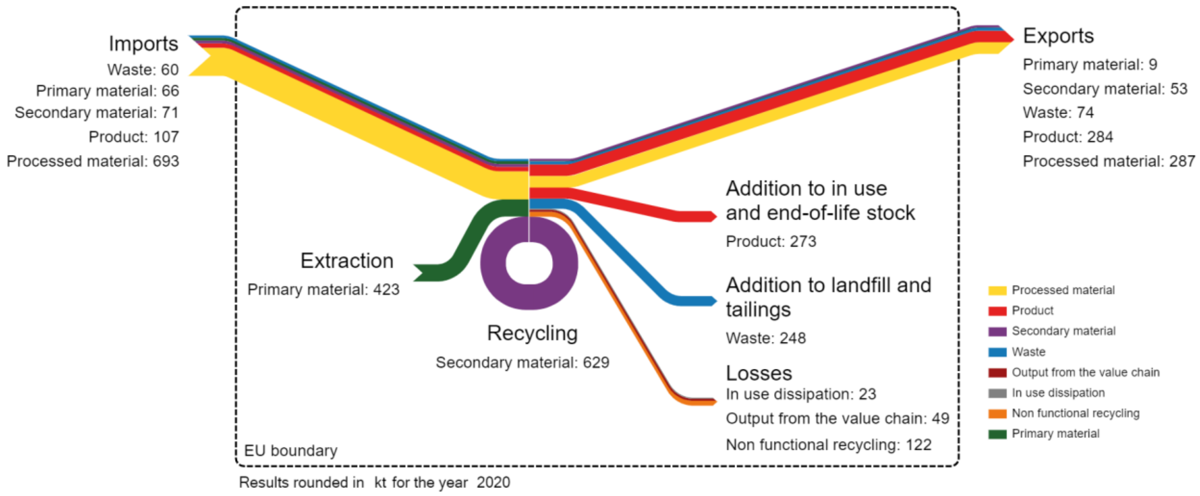


Figure 14: Simplified Sankey diagram for chromium for the year 2020 in the EU, in kt, imports of products include also 6.3 kt Cr of intermediate products, supplied to the manufacturing stage.

Regarding the semi-processed material ferrochromium (used to process crude stainless steel and alloy steel), the majority of the 345 kt produced from metallurgical chromium ore in the EU is sold for further processing in the EU (213 kt). Around 49 kt of chromium leave the value chain in form of slag that arises in the ferrochrome production and is reused non-functionally (e.g. in the construction sector).

A total of 1 370 kt Cr of processed material were produced in the EU: 970 kt Cr in stainless steel in primary forms and alloy steel in primary forms (360 kt Cr), 29 kt Cr in foundry sands and 14 kt Cr in refractory chromite. About 13 kt Cr is generated as processing waste and is sent to disposal.

The total EU production of stainless steel and alloy steel is supplemented with an input of 860 kt of chromium as scrap (560 kt as old scrap from recycling in the EU and imports of secondary material; 300 kt as new scrap from manufacturing and from processing of alloys in primary forms).

The availability of stainless steel scrap is the limiting factor to a higher use of scrap in this sector. About 160 kt of chromium in scrap are generated from the processing of steel in primary forms (“home” scrap), and directly remelted into new steel; 140 kt are generated as “new” scrap from the manufacturing of finished products. Around 490 kt of chromium originate from recycling in the EU as old scrap from end-of life products; the remaining scrap input is coming from imports of secondary material (70 kt in chromium content).

As input to the EU manufacturing stage, chromium was supplemented with: 400 kt Cr of processed material net-imported (imports accounted 690 kt Cr of processed material while the exports were 290 kt Cr), 6 kt Cr in intermediate products net-imported from outside the EU.

The EU industry uses semi-finished products (mainly) made of stainless steel and alloy steel to manufacture various finished products which are either sold in the EU market (1 100 kt Cr) or exported (220 kt Cr). During this manufacture step, about 10% of the input in chromium content is generated as scrap, which is sent back to the steel making process (processing step).

13 kt in chromium content are used for the manufacturing of refractory bricks and mortars and 28 kt in chromium content go into the production of molds for casting.

Products made of chromium chemicals represent a minor volume of all chromium contained in finished products; the EU industry entirely relies on imports of chromium chemicals (26 kt in chromium content) and semi-finished products from chromium chemicals (23 kt). However, these are key products for the EU industry for economic and technological reasons.

Imports of finished products amount to 110 kt Cr, i.e. 10% of the domestic consumption in the EU.

The figure below shows the distribution by end-use sector of chromium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

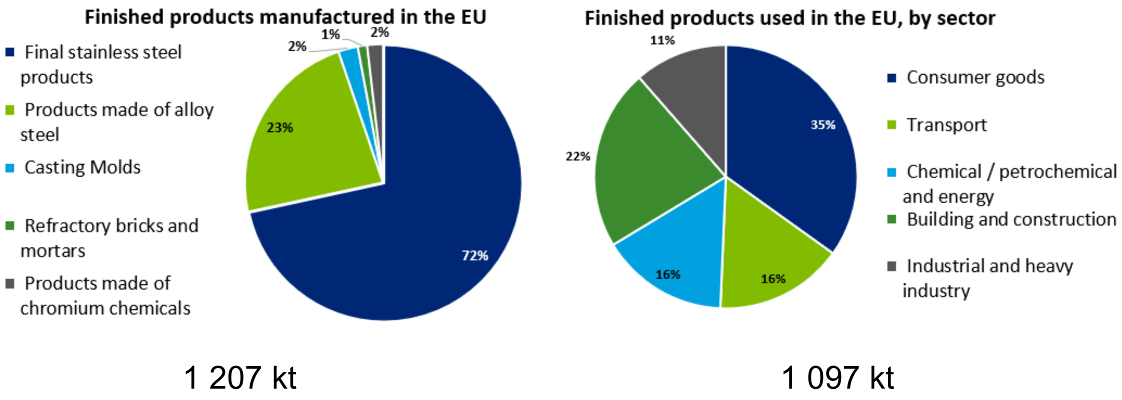


Figure 15: Shares of finished products containing chromium manufactured in the EU (left) and shares of finished products containing chromium used in the EU (right), by sector

Table 9 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all chromium products.

Application	Representative product
Consumer products	Sinks and washbasins, of stainless steel; Table, kitchen or other household articles, and parts thereof, of stainless steel; Spoons, forks, ladles, skimmers, cake-servers, fish-knives, butter-knives, sugar tongs and similar kitchen or tableware of stainless steel, not plated with precious metal; Sets consisting of one or more knives [...]
Transport	A long list of diverse non-consumer related STS products was used to model trade flows, see table in appendix (including e.g. Line pipe of a kind used for oil or gas pipelines, seamless, of stainless steel; Tubes, pipes and hollow profiles, seamless, of circular cross-section, of stainless steel, cold-drawn or cold-rolled)
Chemical / petrochemical and energy	
Building and construction	
Industrial and heavy industry	

Table 9: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

Considering the lifespan of the finished products containing chromium and the annual growth of the stainless steel market in Europe, about 25% of the chromium put on the EU market is annually added to the in-use stock of chromium (270 kt in chromium content) and almost 67% is collected in products at end-of-life (800 kt). The stock of products in-use is about 23 700 kt in chromium content.

The chromium contained in the waste stream is either landfilled (18% of the collected flow) or recycled. The post-consumer functional recycling of stainless steel is well established and reaches recycling rates between 70% and 95%, depending on the product. However, the detection and sorting of alloy steel products is more difficult, thus the majority of these products ends up in carbon steel (i.e. as non-functional recycling). The stock accumulated in landfill over the last 20 years is calculated in the MSA at around 2 900 kt in chromium content.

4.5.3. Indicators

Table 10 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 83% in 2020, and the end-of-life recycling rate (EoL-RR) was 68%. The ratio of recycling from old scrap contributing to EU demand for chromium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 30%.

Regarding self-sufficiency, the EU relies on imports at extraction stage and is self-sufficient for processing and manufacturing, exporting more that the amount imported. In 2020, only 38% of the chromium consumed was extracted in the EU, the rest was imported (imports include also secondary materials). The amount of chromium consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the main changes are related to imports of semi-processed ferrochromium that decreased by 40% from 2016-2020. This decrease - mostly in 2020 due to the pandemic – was only partly compensated by an increased domestic production of ferrochromium. Shares for end use applications were considered constant for 2016-2019. Changes occurring in 2020 were considered with a noticeable decrease of chromium used in transport sector towards a slight increase in consumer products, respectively.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	32%	31%	32%	30%	30%

EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	69%	69%	69%	69%	68%
Collection rate	F1.4/(M4.1)	84%	83%	83%	84%	83%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	26%	24%	26%	35%	38%
Self-sufficiency Processing	C1.1/M2.1	100%	99%	98%	96%	101%
Self-sufficiency Manufacturing	D1.1/M3.1	110%	111%	110%	110%	110%

Table 10: Different indicators that describe chromium situation in the EU

4.5.4. Data sources, assumptions and reliability of results

The main sources of data for the elaboration of this MSA are Eurostat, ICDA, World stainless SMR and EUROALLIAGE. Hence, the results can be considered as quite robust for all steps: exploration, extraction, processing, and manufacture.

The most important data source for import and export of materials containing chromium is Eurostat Comext. Data for import and export of chromium ores, concentrates and ferrochrome were supplemented by ICDA statistics that provide e.g. country specific information on chromium contents in ores and processed material (such as FeCr) that increased accuracy. Eurostat PRODCOM is a relevant data source for production volumes produced in EU. But its level of detail and the coverage often is not sufficient for this MSA.

From the manufacture to the recycling steps, only few statistical data and information from literature are available. The calculation of the associated parameters requires a number of other data sources to characterise each of the different end-use sectors (e.g. data on lifespan, annual growth, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and treatment of waste streams in the EU. Where qualified literature data is not available for these aspects, expert information are used, in particular selected data from SMR for end-uses, collection and recycling of stainless and alloy steel products. In order to fill remaining data gaps, other hypotheses were made, particularly in terms of quantity of waste generated during the manufacture step and quantity of end-of-life products kept by users. For these reasons, the reliability of results from the use step to the recycling step is lower than for the other steps.

The results of the 2023 MSA are comparable with results of the MSA conducted in 2015. A few changes can be observed, with an overall increase in imports of secondary material, and lower non-functional recycling flows due to changes in hypothesis suggested by experts. Further, given the update of the methodology in the 2023 MSA, trade flows of chromium in ferrochrome are considered as semi-processed material, thus considered as imports of processed material, in the 2015 MSA this flow was considered as primary material.

Overall, the discussions with experts at the two workshops helped to validate and ensure the accuracy of the MSA.

A study conducted by Team Stainless group on stainless steel stocks and flows (commissioned and financed by International Chromium Development Association, Worldstainless, Nickel Institute and International Molybdenum Association) was unfortunately not delivered in time before finalizing the MSA (beginning of April 2023) and could thus not be considered for validation.

4.6. Coking coal

4.6.1. Value chain

Coking coal is a low-ash, low-sulphur bituminous coal. Once extracted, it is usually processed on-site. Processing includes crushing, screening, cleaning, and dewatering. Coking coal is then sent to coke oven plants where the coal is heated with the exclusion from air. This process removes the condensable hydrocarbons (pitch, tar, and oil), and coke-oven gas, leaving behind a solid residue named coke.

The side products are sent to further processing steps which are not covered by this study. Coke can either be used directly in blast furnaces for steel making or in other applications (foundries, base metals and ferroalloy production, and in the production of non-metallic minerals). Coke can be used as backfilling material to produce carbon electrodes as well.

Figure 16 below depicts the value chain of coking coal, its intermediates and end-uses covered by this study.

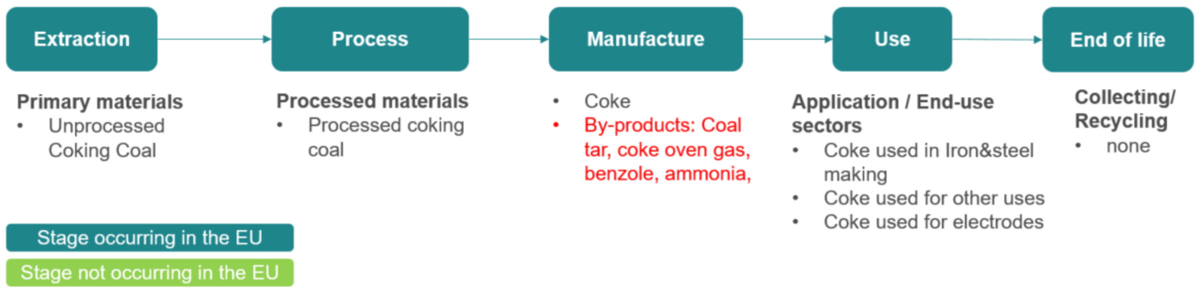


Figure 16: Value chain of Coking Coal, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.6.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (Mt C) equivalent and are representative of the year 2020.

Global reserves of coking coal are estimated at about 139 000 Mt of C content, whereas the reserves in the EU are assumed to be around 4 700 Mt of C content.

World annual production is around 1 029 Mt of C content, mainly in China (60%), Australia (16%), Russia (9%), USA (4%), and India (1%). The EU production of metallurgical coal is about 12 Mt in C content in 2020. The EU production of coking coal has decreased over the last years due to the commitment of the EU to phase out coal-fired power generation and thus the closure of mines in Germany and Czech Republic [3]. In 2020, mining only took place in Poland (92%) and the Czech Republic (8%), after mines had been closed down in Germany in 2018.

Most of the coal mined and processed in the EU is sent to manufacture in the EU; only around 1 % of coking coal is exported. Around 29 Mt of C content in processed coking coal are imported to the EU, mostly from the USA, Australia, Russia, and Canada.

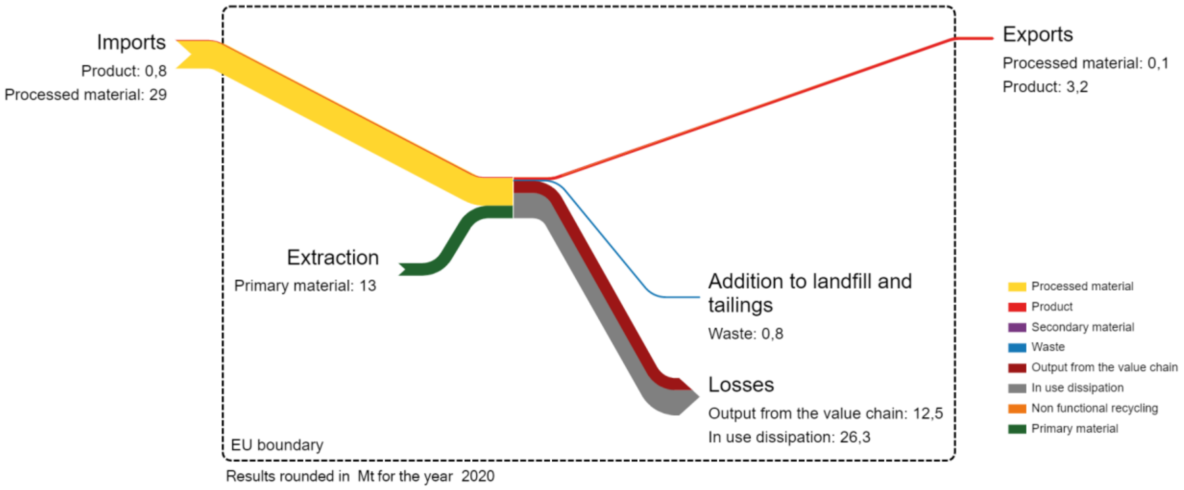


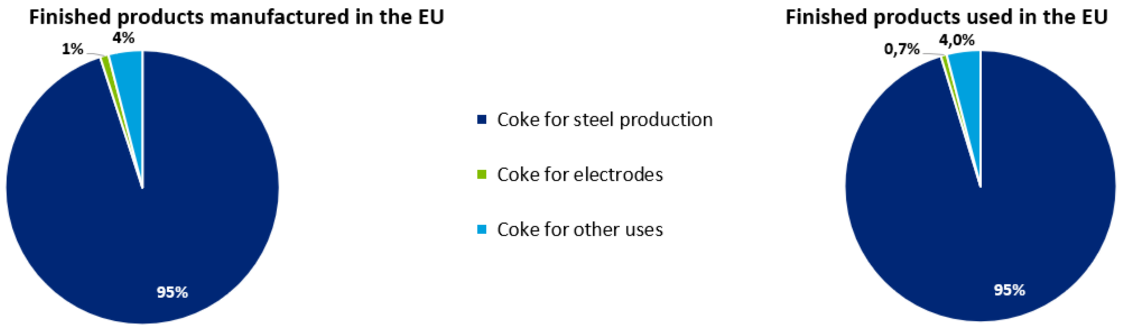
Figure 17: Simplified Sankey diagram for coking coal for the year 2020 in the EU, in Mt.

In total 41.2 Mt of metallurgical coal was sent to manufacturing to transform coking coal into coke. In 2020 28.6 Mt of C in coke were manufactured in the EU, mostly for steel production (see Figure 18 – left). Most of the coke manufactured in the EU is sold for use in the EU rather than exported (exports of finished products represent 2.9 Mt of C content). Imports of coke in manufactured products are about 0.7 Mt in C content to be used in the EU. Thus, around 26.2 Mt of coke (C content) are sent to use in the EU.

In the coke-making process, about 12.5 Mt of C inside products (pitch, tar, oil, and coke-oven gas) are produced and fed to the chemical industry for further processing.

[3] https://rmis.jrc.ec.europa.eu/uploads/2200629_JRC129975_briefing_coking_coal.pdf
https://iea.blob.core.windows.net/assets/f1d724d4-a753-4336-9f6e-64679fa23bbf/Coal2021.pdf

These C-containing by-products are considered as output from the value chain as the MSA focuses on the use of coke (for further explanation see chapter 1.1.4).



28.6 Mt 26.3 Mt

Figure 18: Shares of finished products containing 28.6 Mt C manufactured in the EU (left) and shares of finished products containing 26.3 Mt C used in the EU (right), by application

For each of the applications, Table 11 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all coking coal products.

Application	Representative product
Coke for steel production	Coke and semi-coke of coal
Coke for electrodes	Carbon electrodes Carbon electrodes for furnaces; Carbon electrodes (except for furnaces)
Coke for other uses	Coke and semi-coke of coal

Table 11: List of the applications and of the corresponding representative product used for the assumptions made to model trade and use for each application.

As displayed on Figure 18 – right, the majority of coke (95%) is used in blast furnaces both for heating and as a reduction medium for the production of pig iron from iron ores. A small share (~1%) of the produced coke is sent to another processing step as backfilling material in electrodes production, e.g. for aluminium production and for steel making. The rest is used in different niche applications like foundries, base metals and ferroalloy production, and in the production of non-metallic minerals or as a household fuel.

In all these applications, it is considered that coke is entirely dissipated as it is oxidised to CO_2. A very small amount of carbon is introduced into the steel (~0.4%).

Coke is an intermediate product and used directly after production. It is considered that there are no stocks in the EU. Therefore, no flows of coke were taken into account for collection and recycling.

4.6.3. Indicators

Table 12 summarises recycling and EU self-sufficiency indicators.

Given the dissipative nature of coke in use the collection rate at end-of-life; the end-of-life recycling rate (EoL-RR) and the end-of-life recycling input rate, EoL-RIR) resulted in 0%.

Regarding self-sufficiency, the EU relies on imports at processing stage and is self-sufficient for extraction and manufacturing. In 2020, only 30% of coking coal was processed in the EU, the rest was imported. The amount of coke consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the main changes are related to EU extraction, which decreased from 2016 to 2020 by 30% given the EU policy of phasing out coal-fired power generation.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2 - B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	Not applicable				
Collection rate	F1.4/(M4.1)	Not applicable				
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	100%	100%	100%	100%	100%
Self-sufficiency Processing	C1.1/M2.1	32%	30%	28%	27%	30%

Self-sufficiency Manufacturing	D1.1/M3.1	104%	107%	104%	104%	109%

Table 12: Different indicators that describe coking coal situation in the EU

4.6.4. Data sources, assumptions and reliability of results

The choice of perimeter for this MSA was limited to coke. However, there are significant amounts of side produces resulting from coke production, which are used in different chemical applications. From the side product coal tar (e.g. 33 kg coal tar come from 1 ton coal input into coking battery), for example, needle coke and pitch coke can be produced. Needle coke is used as primary material for electrodes used in an electric steel furnace that melts and refines steel scrap. It can thus replace natural graphite, which is a critical raw material in 2023[4]. Pitch coke is an essential material for building production equipment for semiconductor or solar array panels. Furthermore, coal tar-based carbon fibre can be processed from the side product. Potentially, alumina fibre and lithium-ion battery material are further products that can be derived.[5] However, this is not yet the case in the EU27.

For the next MSA, it may be recommended to include the C containing by-products, given that the potential strategical applications are more established in the EU and sufficient data is available.

For the steps of exploration, extraction, and processing literature data from IEA, BGR and the WMD, was considered. Concerning the steps of manufacturing and use, the main data sources for total production amounts and traded flows of raw materials and products were the Eurostat databases (Energy balance, PRODCOM and COMEXT) and statistics from the Verein der Kohleimporteure. Details on the manufacturing processes and of side products were obtained from JRC, BAT reference documents as well as from experts and publications from industry, industry associations and academia (e.g. JSW S.A., EURACOAL, Silesian University, ITPE). The results can be considered as a quite robust for the steps exploration, extraction, and processing.

For the manufacturing and use steps, several assumptions were necessary to fill data gaps leading to a lower level of reliability of the results, especially regarding results concerning the single products while the overall flows are still considered to

[4] https://op.europa.eu/en/publication-detail/-/publication/c0d5292a-ee54-11ea-991b-01aa75ed71a1/language-en

[5] https://www.m-chemical.co.jp/en/products/departments/mcc/coke/product/__icsFiles/afieldfile/2013/11/05/miracles_of_fossils_en_1.pdf

be of good quality. Hypotheses were made on the carbon content of wastes from coking, on the share of carbon in electrodes coming from coking coal, and on the share of coke being dissipated during use.

The results of the 2023 MSA are comparable with results of the MSA conducted in 2015. In total, the volume of coking coal flows has decreased in the last years which is due to the natural evolution of the market given the decarbonisation policy and the closing of mining activities in the EU.

4.7. Fluorspar

4.7.1. Value chain

Fluorspar is the commercial name for the mineral fluorite (calcium fluoride, CaF2). Fluorite is a colourful mineral that occurs globally with significant deposits in over 9 000 areas.

After extraction, fluorspar ore is directly transformed into fluorspar acid grade (AG), or metallurgical grade (MG), ceramic grade or cement grade. The fluorspar acid grade, the purest one, is then processed either into hydrogen fluoride (HF), or cryolite and aluminium fluoride (AlF_3). Fluorspar MG is used in iron and steel making, but it is not incorporated in the iron and steel products. The lowest grades of fluorspar are used to directly process ceramics or cement.

The processed material HF is converted into semi-finished products such as fluorocarbons, fluoropolymers, fluoroaromatics, inorganic fluorine and uranium hexafluoride (UF6, used in nuclear energy production). Fluorocarbons, fluoropolymers and fluoroaromatics are used in finished products in various applications such as cable insulation, fire protection, refrigerants, pharmaceuticals, etc.

HF is also directly used for etching and pickling of metals and for alkylation process in oil refining but for those two applications there is no F element in the final product. In the same way, cryolite and aluminium fluoride are used for aluminium processing but are not incorporated in aluminium alloys.

Figure 19 below depicts the value chain of fluorspar, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

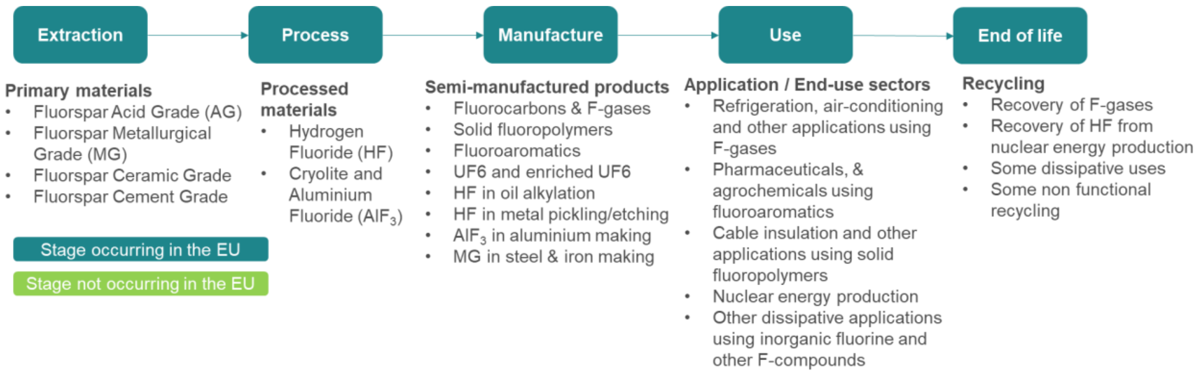


Figure 19: Value chain of fluorspar, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.7.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of fluorine (t F) metallic equivalent and are representative of the year 2020.

Global fluorspar reserves are estimated at about 155.7 Mt F, widespread all over the world. The reserves of fluorspar in the EU27 are mainly located in Spain, but also exist in Germany, Sardinia and Bulgaria. Although consolidated numbers for EU reserves do not exist, they have been estimated at, at least, 5.7 Mt F.

In 2020, the world production of fluorspar reached 3.7 Mt F and the top producer countries were China and Mexico, accounting for respectively 58% and 20% of extracted fluorspar volumes. The EU production of fluorspar is mainly acid grade, accounting for 72 kt F (in Germany and Spain, Bulgaria ceased the production in 2016); and also, metallurgical grade at 7.3 kt F, produced in Spain. Cement grade production is also reported for Spain and Italy, with no official figures, and has been estimated at 10.3 kt F. There is no ceramic grade production in the EU.

While metallurgical grade and cement grade are directly used in the manufacturing stage, the fluorspar acid grade is sent to the processing stage to be transformed into HF or cryolite and aluminium fluoride.

In addition to the domestic input to EU fluorspar processing, 164 kt F of AG fluorspar was imported. Secondary supply came from recovered HF, 9.6 kt F of manufacturing waste generated in the EU (from depleted uranium deconversion) and 0.2 kt F from post-consumer functional recycling in the EU (from enriched uranium use, and also F-gases recycling).

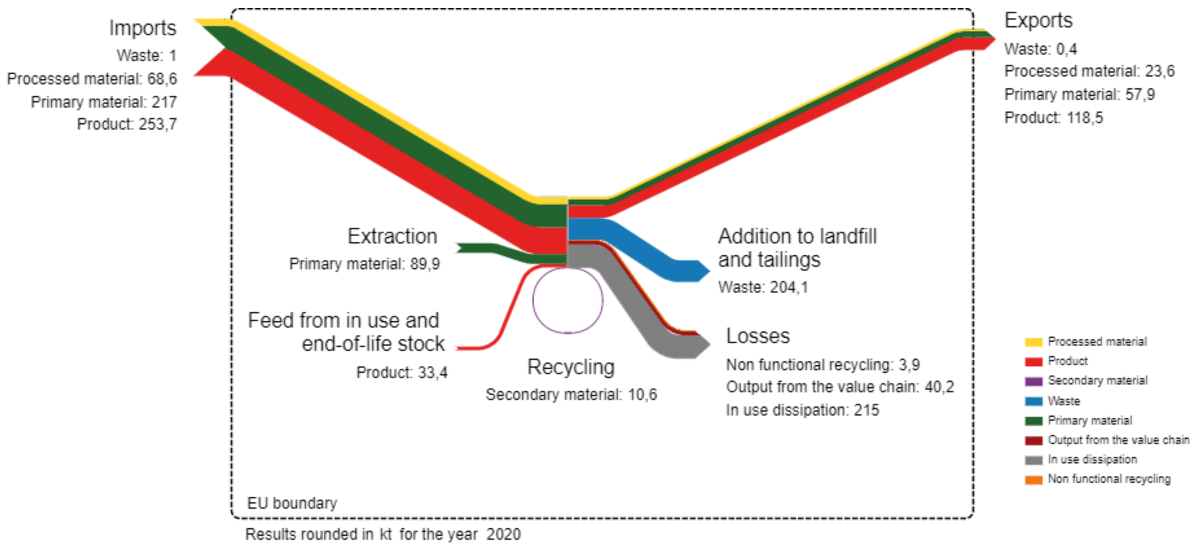


Figure 20: Simplified Sankey diagram for fluorspar for the year 2020 in the EU, in kt.

A total of 271.7 kt F of processed material were produced in the EU, respectively 237.7 kt F in HF and 34 kt F in aluminium fluoride. Almost no processing waste is sent to disposal or exported, but about 20.4 kt F are generated as a by-product used in other value chains.

The input to the EU manufacturing stage was supplemented with 7.2 kt of imports of processed materials. Additionally, about 157 kt F were supplemented from imports of semi-processed materials and 0.8 t F from post-consumer functional recycling in the EU (recovered F-gases). The EU industry manufactures various finished containing fluorspar: refrigeration and air-conditioning (27.7 kt F), pharmaceuticals and agrochemicals (28.7 kt F), insulated cables and membranes (80.7 kt F), enriched uranium (1.7 kt F), cement (10.3 kt F) and other various applications (186 kt F). The EU industry also consumes a lot of fluorspar as a reagent that ends up in waste, mainly for the manufacturing of metal, such as aluminium (that consumes 22.4 kt F), iron & steel (17.7 kt F) or stainless steel (19 kt F); or for oil refining (11.4 kt F). All the fluorspar new scrap generated from product manufacturing was sent to landfill (5.5 kt F).

Figure 21 shows the distribution by end-use sector of fluorspar-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

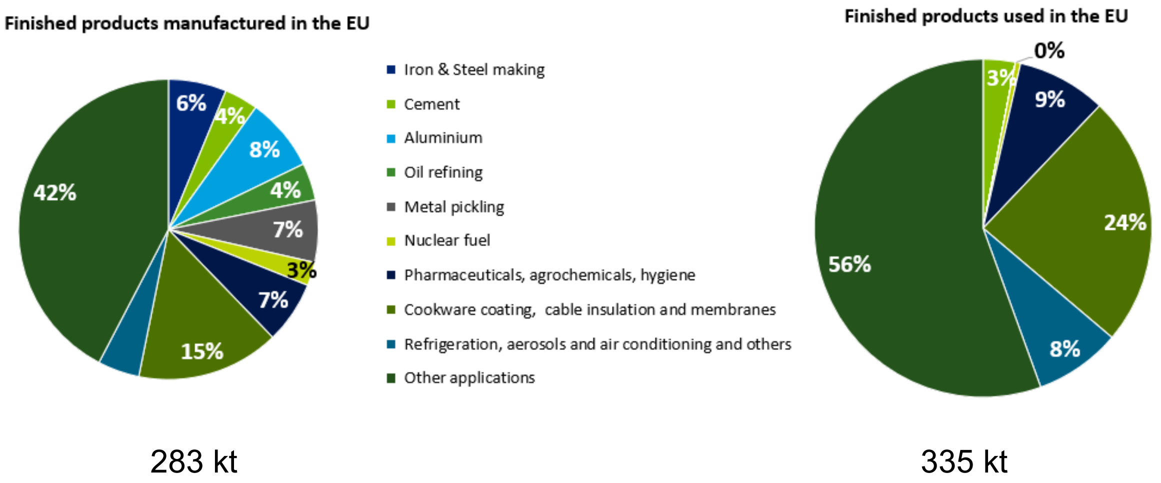


Figure 21: Shares of fluorspar used to manufacture finished products in the EU (left) and shares of finished products containing fluorspar used in the EU (right), by application

Table 13 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all fluorspar products.

Application	Representative product
Cement applications	Buildings & infrastructure
UF6 nuclear fuel	Enriched UF6

Pharmaceuticals, agrochemicals, and hygiene products using fluoroaromatics	Pharmaceuticals
Cable insulation, cookware coating, membranes in electronic appliances, telco, aeronautics, lighting industry and other applications using solid fluoropolymers	Insulated electric cables
Refrigeration, air conditioning, aerosols and electronic applications using gaseous fluorocarbons and fluoroaliphatics	Refrigeration, air-conditioning and heating devices
Other applications using inorganic fluorine and other fluorinated compounds (glass industry, electronics, batteries and others)	Dissipative uses

Table 13: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about -33.3 kt F in 2020. The total stock of products in-use is quantified at about 1 600 kt F in 2020.

About 215 kt F were lost due to dissipation during use. This leaves about 153.8 kt F contained in products collected for waste treatment. Among products collected for waste treatment, 150 kt F were sent to landfill rather than recycled, 3.9 kt F was downcycled, and only few tonnes were functionally recycled to supply respectively the processing (236 t F) and the manufacturing stage (782 t F) in the EU, mainly from recycling or recovery of F-gases and recovery of HF in nuclear energy production.

4.7.3. Indicators

Table 14 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 28% in 2020, and the end-of-life recycling rate (EoL-RR) was 0.7%. The ratio of recycling from old scrap contributing to EU demand for fluorspar (i.e., end-of-life recycling input rate, EoL-RIR) was 0.3%. The differences between collection and EoL-RR were due to the fact that most of the collected products are landfilled, and that the fluorspar contained is considered non-recoverable.

Regarding self-sufficiency, despite domestic extraction of fluorspar, the EU still relies greatly on imports to supply the processing stage. However, the processing industry manages to supply 66% of the fluorspar needed for the manufacturing stage, and the manufacturing industry is self-sufficient for the supply to the use stage, exporting more that the amount manufactured.

For the five years analysed, changes are minimal for those indicators.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0.4%	0.4%	0.4%	0.3%	0.3%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0.9%	1.0%	0.8%	0.7%	0.7%
Collection rate	F1.4/(M4.1)	31%	31%	29%	28%	28%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	31%	27%	33%	33%	29%
Self-sufficiency Processing	C1.1/M2.1	69%	75%	69%	70%	66%
Self-sufficiency Manufacturing	D1.1/M3.1	112%	116%	109%	108%	106%

Table 14: Different indicators that describe fluorspar situation in the EU

4.7.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for the imports of processed products and some products in manufacture). The fluorspar content is available from various expertise and references or through molecular mass calculations. Overall, basic extrapolation was applied to primary data to compute reliable estimates of fluorspar flows and stock in the EU. Especially, no official and consolidated data exist for fluorspar consumption or demand in the EU industry.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of fluorspar-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of fluorspar flows at use and end-of-life. The feedback from validation workshops helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on fluorspar processing and manufacturing mainly originates from expertise gathered during personal communications with experts.

The results of the 2023 MSA differ from those of the MSA conducted in 2015 due to updated assumptions for missing information.

4.8. Gallium

4.8.1. Value chain

Gallium is produced exclusively as a by-product during the processing of the ores of other metals. Bauxite ores are the main source of gallium (Ga), accounting for more than 95% of worldwide production of primary gallium, which is then further processed into refined gallium.

Gallium is predominantly used in electronics for its semiconducting and optoelectronic capacities. Gallium arsenide, the primary chemical compound of gallium in electronics, is used in microwave circuits, high-speed switching circuits, and infrared circuits. Semiconducting gallium nitride and indium gallium nitride produce blue and violet light-emitting diodes and diode lasers. GaN is also used in high-capacity chargers.

The main semi-finished products are wafers of GaAs and GaN, as well as some other gallium compounds (GaIn, GaO, etc.). GaAs wafers are mainly used to produce integrated circuits, that are incorporated in electronic devices, or can also be used in civil and military applications, for semiconductor or sensor uses. GaN wafers are mostly used in optoelectronic applications, such as LEDs. Other applications include photovoltaic cells, permanent magnets and finished products based on various gallium compounds.

Figure 22 below depicts the value chain of gallium, its intermediates and end-uses covered by this study. The first steps of the value chain (extraction and production of 3N/4N gallium) have not taken place within the EU since 2016. However, the remaining of the value chain (from production of 6N/7N gallium) takes place within the EU until 2020, even if there is a strong gap in terms of capacities to manufacture integrated circuits and applications using it.

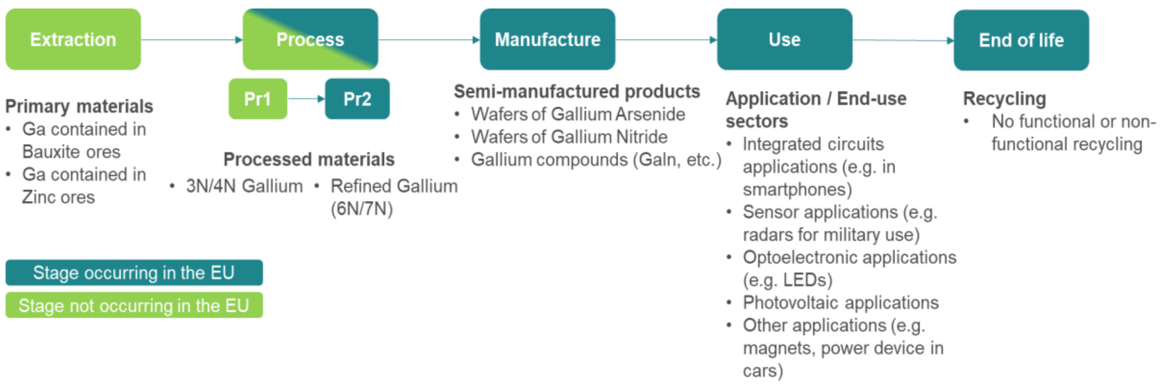


Figure 22: Value chain of gallium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.8.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of gallium (t Ga) equivalent and are representative of the year 2020.

Global gallium reserves are estimated at about 75,000 t of Ga. Gallium is extracted as a by-product from bauxite ores. In 2020, the world production of gallium reached 304 t of Ga and the top producer country was China, with 94% of extracted gallium volumes. Since 2020, Chinese production of Ga has significantly increased.

In the EU, gallium reserves (contained in Bauxite ores) are estimated to be around 19,800 t of Ga. Hungary was the only EU producer of gallium as a by-product from domestic bauxite ores, but stopped its activity in 2015. Since 2016, gallium is no more extracted in the EU27 from European bauxite ores for use in the Ga industry. Germany was also a producer or gallium from imported bauxite ores, but also stopped this activity in 2016. Since 2017, gallium is no more extracted in the EU27 from imported bauxite ores for use in the Ga industry.

In the absence of domestic production, the EU market of 3N/4N gallium is supplemented with imports of 3N/4N gallium (with a strong decreasing trend from 2016 to 2020, leading to the absence of 3N/4N gallium imports in 2020 in the EU27), as well as – and only for the year 2016 – a small production of 3N/4N gallium in Germany from imported bauxite (equivalent to 4t Ga). In 2020, there is no input of 3N/4N gallium in the EU neither from domestic production nor imports.

The domestic input to EU gallium processing was therefore mainly supplied from manufacturing waste generated in the EU (about 30 t Ga), but not from post-consumer functional recycling in the EU (as there is no functional recycling of gallium in the EU). Additionally, about 4-to-0 t Ga were supplemented with imports of 3N/4N gallium (strongly decreasing from 2016 to 2020) and about 5 t Ga was imported in secondary material.

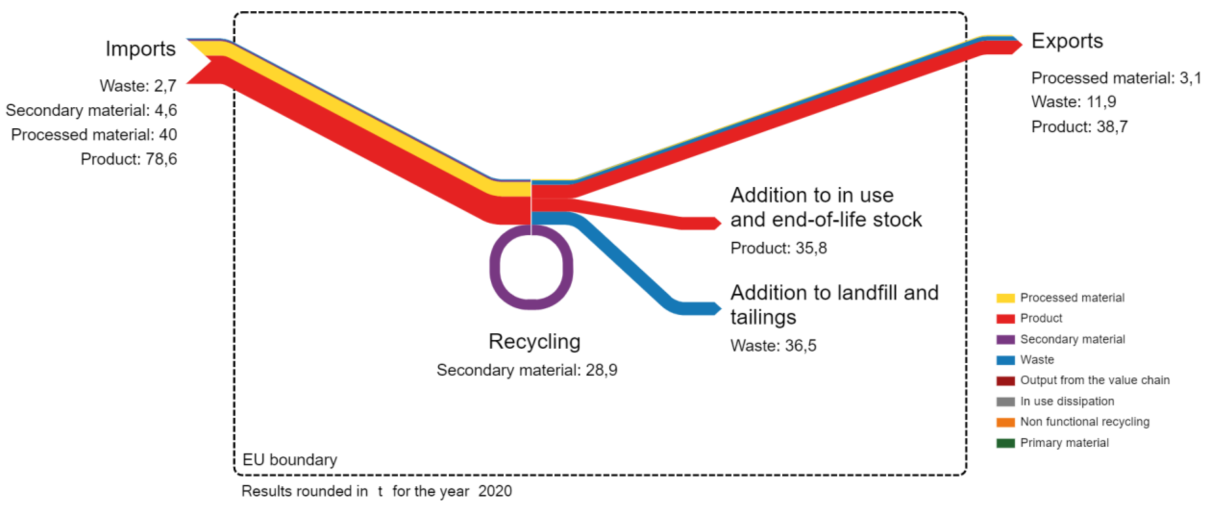


Figure 23: Simplified Sankey diagram for gallium for the year 2020 in the EU, in t.

Processed materials are 6N/7N gallium. A total of 31 t Ga of 6N/7N gallium were produced in the EU. About 2.5 t Ga is generated as processing waste, sent to disposal.

A total of 68 t Ga was used in the EU manufacturing stage, of which 37 t Ga of processed material were net imports (imports accounted for 40 t of 6N/7N Ga while the exports were 3 t Ga). No gallium was supplemented for the manufacturing step from post-consumer functional recycling in the EU.

The EU industry transforms 6N/7N gallium mainly into GaAs and GaN wafers (34 t Ga, 90% in GaAs wafers and 10% in GaN wafers). The new scrap generated during the production of the wafers is sent to reprocessing in the EU (29 t Ga).

The majority of semi-finished products (i.e. wafers) produced in the EU are exported (29 t Ga), because there is no production of Ga-based integrated circuits for electronic devices nor CIGS cells in the EU; while some stays in the EU for the manufacture of LEDs (1.8 t Ga) and wireless or military applications using Ga-based sensors (3.3 t Ga).

Gallium consumption in the EU at the Use step is estimated at about 84 t Ga; Figure 24 shows the distribution by end-use sector of gallium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

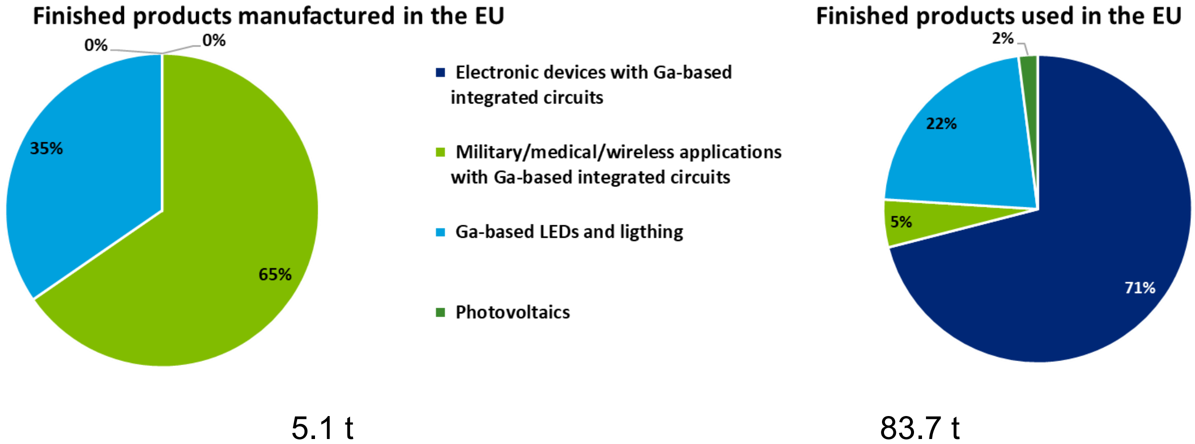


Figure 24: Shares of finished products containing gallium manufactured in the EU (left) and shares of finished products containing gallium used in the EU (right), by application

Table 15 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all gallium products.

Application	Representative product
Electronic devices with Ga-based integrated circuits	Smartphones
Military/medical/wireless applications with Ga-based integrated circuits	Military radars & sensors
Ga-based LEDs and ligthing	Flat panel displays
Photovoltaics	CIGS PV panels

Table 15 : List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 32 t Ga in 2020. The total stock of products in-use is quantified at about 373 t Ga in 2020.

About 38 t Ga leaving the use phase were collected and sorted as end-of-life products for waste treatment. Even if some end-of-life products containing gallium were sent to recycling processes, gallium contained in those products was not recovered and recycled in the EU. This flow is considered to be sent to landfill in the MSA.

4.8.3. Indicators

Table 16 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 69% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. The ratio of recycling from old scrap contributing to EU demand for gallium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 0%.

Regarding self-sufficiency, the EU relies on imports at extraction, processing and manufacturing stages. In 2020, 46% of the gallium was refined in the EU, the rest was imported (imports include also secondary materials). For the manufacturing phase, the EU also relies on imports, as only 41% of the consumed gallium comes from EU production and the remaining volumes are imported.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	69%	69%	69%	69%	69%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	65%	45%	52%	60%	46%
Self-sufficiency Manufacturing	D1.1/M3.1	42%	54%	42%	33%	41%

Table 16: Different indicators that describe gallium situation in the EU

4.8.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, USGS publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The gallium content is available from various expertise and references (Indium Corporation, industrial players, etc.). Overall, basic extrapolation was applied to primary data to compute reliable estimates of gallium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of gallium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimation of gallium flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimations made, which adds more robustness to the results.

Data provided in the MSA on gallium recycling mainly originates from expertise gathered during personal communications with stakeholders.

Regarding the comparability to the previous MSA, some market evolutions have impacted the results, mainly for the extraction stage, as no more gallium is extracted from bauxite ores in the EU27 since 2016. Accordingly, imports of bauxite for Ga extraction or imports of 3N/4N gallium have also strongly decreased in comparison to the previous MSA. Another difference with the previous MSA is the fact that it has been considered in this exercise that EU produce only sensors applications (for wireless or military applications) and LEDs, whereas in the previous exercise it was sensors applications (for wireless or military applications) and applications using permanent magnets that had been considered. However, experts during the workshop confirmed the fact that for the 2016-2020 time period, magnet applications are negligible.

4.9. Germanium

4.9.1. Value chain

Germanium (Ge) is a rare metal which is mainly found in zinc ores, and in some types of coals, such as vitrain and some lignites. It is mainly extracted as a by-product due to processing from zinc tailings. Furthermore, it is extracted as a main product from coal in China and in Russia.

The germanium concentrate obtained is first chlorinated to obtain crude $GeCl_4$. It is then further purified and hydrolysed to produce germanium oxide, which can be reduced to produce germanium metal. Those two processed forms are then traded to be used in several industries.

Germanium metal is used to produce crystals, which enable the production of Ge lenses and Ge wafers. Germanium is used in wafer for its semi-conductor properties; now replaced by silicon metal wafers in most applications, it is still used in satellite solar cells (higher performance and resistance to cosmic radiations) and in high brightness LEDs. Germanium lenses are widely used in infrared optics, as they are transparent in the infrared wavelengths.

One of the main applications for germanium oxide is the production of high purity GeCl4 for fibre optics cables to increase the refraction angle. Germane (GeH4) is another component produced from germanium oxide which is used for microelectronic applications. Finally, germanium oxide at a high level of purity can be used as a catalyst for PET production.

Figure 25 below depicts the value chain of germanium, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

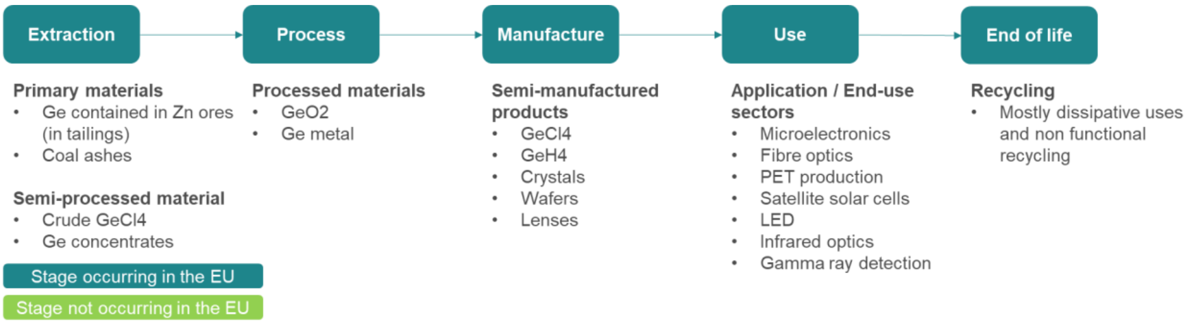


Figure 25: Value chain of germanium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.9.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of germanium (t Ge) metallic equivalent and are representative of the year 2020.

Global germanium reserves are estimated at about 5.5 kt Ge, mainly in China and in the USA. In the EU, no germanium reserves have been evaluated, although traces of Ge are present in several zinc mines.

In 2020, the world production of germanium reached 140 t Ge and the top producer country was China, with more than 68% of extracted germanium volumes, from vitrain and lignites, and from zinc tailings. Another significant flow for primary germanium production comes from a refinery in Canada which processes germanium zinc tailings imported from the USA. Since 2020, Chinese production of Ge has significantly increased.

Some production of germanium concentrates may happen from extraction residues in the EU, if economically viable. This flow is highly dependent on germanium market prices and is estimated at about 3 t Ge in 2020, and goes from 0.2 t Ge to 3.4 t Ge depending on the corresponding year.

Most of the EU germanium processing was supplied by imports of germanium secondary material and by manufacturing waste generated in the EU (respectively 5 t Ge and 15.6 t Ge). Imports of primary material are extremely low and can be considered negligeable.

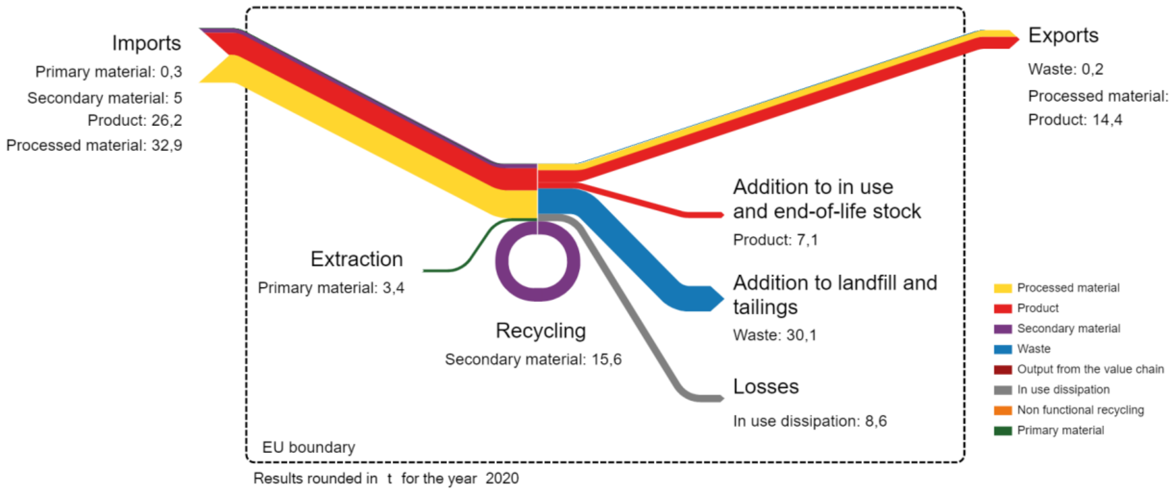


Figure 26: Simplified Sankey diagram for germanium for the year 2020 in the EU, imports of products include also 11 t Ge of intermediate products, supplied to the manufacturing stage.

A total of 23 t Ge of processed material were produced in the EU. About 1.2 t Ge becomes processing waste and is considered non-recoverable.

As input to the EU manufacturing stage, the germanium was supplemented with 25 t Ge of processed material net-imported, and 11 t Ge in intermediate products net-imported from outside the EU. The EU industry manufactures various semi-finished products (such as crystals, wafers, lenses, etc.) which are then incorporated into finished products in the EU: infrared optics (16 t Ge), fibre optics (7 t Ge), satellite solar cells (6.2 t Ge), LEDs (2.4 t Ge), gamma ray detection (2.9 t Ge), and other applications (8.7 t Ge). High rates of germanium scraps are generated from product manufacturing, mostly from the fibre optics industry. About 15.6 t Ge of manufacturing waste is sent for reprocessing, with only 0.3 t Ge of unavoidable losses considered sent to landfill.

Figure 27 shows the distribution by end-use sector of germanium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

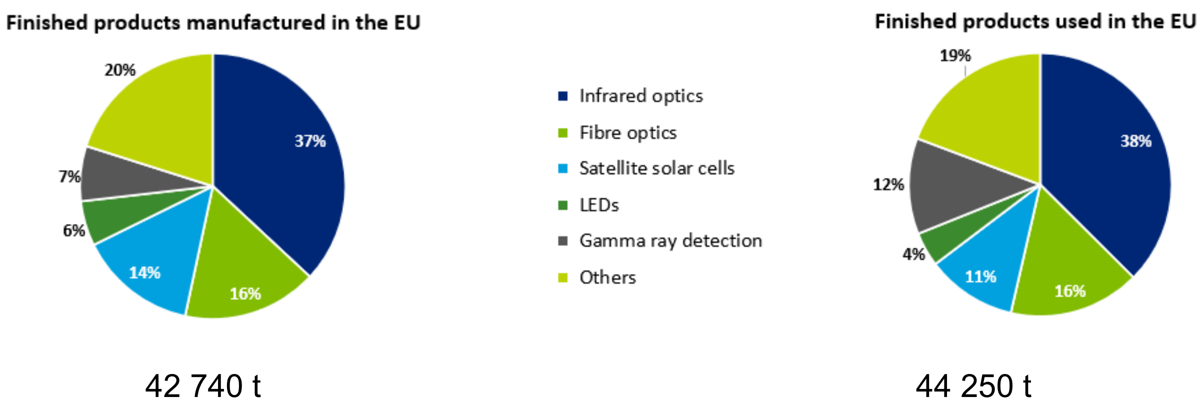


Figure 27: Shares of finished products containing germanium manufactured in the EU (left) and shares of finished products containing germanium used in the EU (right), by application

Table 17 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all germanium products.

Application	Representative product
Infrared optics	Infrared cameras
Fibre optics	Fibre optic cable
Solar cells	Wafers
LED	LED
Gamma ray detection	Gamma ray detector

Others, covering PET production and microelectronics	Transistors

Table 17: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 7.1 t Ge in 2020. The total stock of products in-use is quantified at about 1 018 t Ge in 2020.

About 8.6 t Ge were lost due to dissipation during use, mostly due to unrecoverable use of the products (satellites sent in space, and fibre optics installed below ground or even sea level). This leaves about 28.8 t Ge contained in products collected for waste treatment. Among those products, most were sent to disposal, which represents about 27 t Ge contained in this fraction. However, most of LEDs at end-of-life were sent for recycling, which represents about 1.4 t Ge. Nonetheless, Ge contained in those products was not recovered during the recycling process, and ends up in slag. It is to be noted that some fractions of Ge may be found in other recovered materials, such as PGMs, but this flow of non-functional recycling is considered negligible. This is considered to be sent to landfill in the MSA.

4.9.3. Indicators

Table 18 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 5% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. Therefore, the ratio of recycling from old scrap contributing to EU demand for germanium (i.e., end-of-life recycling input rate, EoL-RIR) was also null. The differences between collection and EoL-RR were due to the fact that all of the collected products are either landfilled or recycled for other metallic content, regardless of the germanium contained.

Regarding self-sufficiency, there is little germanium concentrates production in the EU due to the lack of extraction capacities, and the processing industry is also small, considering that germanium is mostly extracted close to extraction sites. Therefore, the EU relies mainly on imports to supply 61% of the demand for the processing stage and 61% of the demand for the manufacturing stage. The EU is nearly self-sufficient at the manufacturing stage, and on some years produced more than the demand at the use stage. In 2020, 97% of germanium in products sent to use in the EU came from the EU manufacturing industry. The EU manufacturing capabilities are therefore nearly sufficient to cover the demand for the main application sectors.

For the five years analysed, changes are minimal for most indicators, except for the self-sufficiency at the manufacturing stage due to reduced imports of gamma ray detection material in year 2016.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	5%	5%	5%	5%	5%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	25%	39%	4%	35%	39%
Self-sufficiency Processing	C1.1/M2.1	35%	38%	32%	37%	39%
Self-sufficiency Manufacturing	D1.1/M3.1	104%	97%	96%	97%	97%

Table 18: Different indicators that describe germanium situation in the EU

4.9.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are a commercial report, the Eurostat PRODCOM database, and other elements from the literature. Eurostat database is used for some products in manufacture only, due to lack of data availability and information on metal content for flows at the extraction and processing stages. The germanium content is estimated by experts. Overall, basic extrapolation was applied to primary data to compute reliable estimates of germanium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of germanium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of germanium flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on germanium recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA differ significantly from those of the MSA conducted in 2015 due to new information and data availability. Previously recorded flows of germanium processed from cobalt ores in Finland have stopped since 2015. Most of the hypothesis on manufacturing and use have been updated, in particular the distribution of end uses, in order to better reflect the market based on feedback from experts. Also, data from a commercial report was used to improve coverage of germanium market flows.

4.10. Indium

4.10.1. Value chain

Indium occurs mainly in low concentrations in zinc ores, and to a lesser amount also in copper, lead and tin ores. It is mainly produced as a by-product of zinc smelting, but though there are many zinc refineries globally, only about 25% are capable of extracting indium. When indium is not recovered from zinc ores, it is lost as waste and as an impurity in zinc metal. Less than half of the material processed in the EU is sourced in the EU, with most indium extracted from zinc concentrates in France and small amounts extracted from lead concentrates in Belgium. The rest of processed material is sourced by importing primary and secondary indium. At the processing stage, there are several EU refineries that recover small amounts of indium from secondary materials. Though there is a small amount of recycling from end-use products, most secondary indium is recycled from post-industrial waste.

Zinc refineries produce indium metal as a by-product in the form of unwrought indium powder. Indium is then processed into a variety of compounds (chlorides, hydroxides, oxides, sulfamates, and others) for use in the manufacture of various applications. The most significant of these globally is the manufacture of indium tin oxide (ITO), which is used to manufacture displays, mainly in Asia. The ITO sputtering process, applied in the manufacturing of thin films for displays, has a relatively low efficiency (30%) with most of the ITO losses being sent to reprocessing.

Indium metal is used in the EU to make alkaline batteries, architectural and automotive glass with ITO coatings, thin-film photovoltaics (e.g., Copper indium gallium diselenide solar cells (CIGS)), solders, other alloys, semi-conductors as well as for research. Most uses of indium are in electrical and electronic equipment (EEE) such as displays and semiconductors (e.g., light emitting diodes) and in solders often replacing lead solders. The latter uses are also relevant for vehicles, i.e., in vehicle electric and electronic components. Though the waste management and recycling of EEE, vehicles and batteries at end-of-life is quite developed, indium is usually not targeted during the recycling and ends up in slags (possibly non-functionally recycled) or is disposed of in the EU. Only a single facility in the EU is known to recycle indium from end-of-life products, accounting for relatively negligible amounts. Figure 28 below depicts the value chain of indium, its intermediates and end-uses covered by this study.

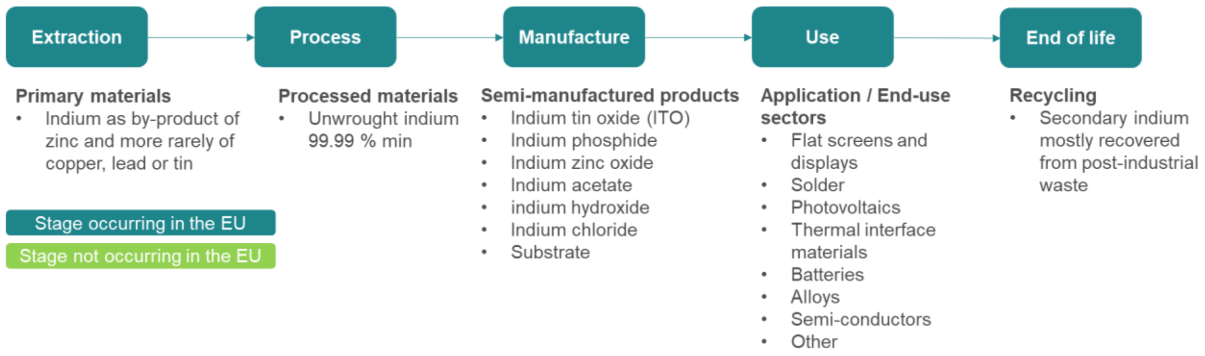


Figure 28: Value chain of indium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.10.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of indium (t In) equivalent and are representative of the year 2020.

Global indium reserves are not reported but estimated based on the average concentration of indium in zinc and copper reserves at about 21.2 kt In. China accounts for around a third of the zinc related indium reserves and Chile for around a quarter of the copper related indium reserves. The actual global production of indium in 2020 is unknown, as it is produced as a by-product. Hence, all data use rough estimations. Based on WMD data, in 2020, the global production of processed material was 944 t of indium.

In the EU, indium reserves are not reported. A few deposits exist (Pöhla in Saxony, Germany, Neves-Corvo in Portugal) but are considered resources. There are also deposits in Finland and Sweden, however their classification is unknown.

There is little data available on the production of indium in the EU. France and Belgium produced about 60 t of processed indium in 2020. The division between production in the EU and import is estimated through mass balance. Following this approach, 23 t In of the EU were extracted as by-product of mainly zinc and, to a lesser degree, from lead. The EU imported an additional 26 t In in as indium metal and 7 t In as secondary material serving as input to in processing. An additional 10 t In came from EU manufacturing waste, while about 7 t of the 67 t In are lost as processing waste, to be sent to disposal. There is some recycling from displays in Belgium, the amount of recycled post-consumer waste sent to processing, however, is considered to be negligible.

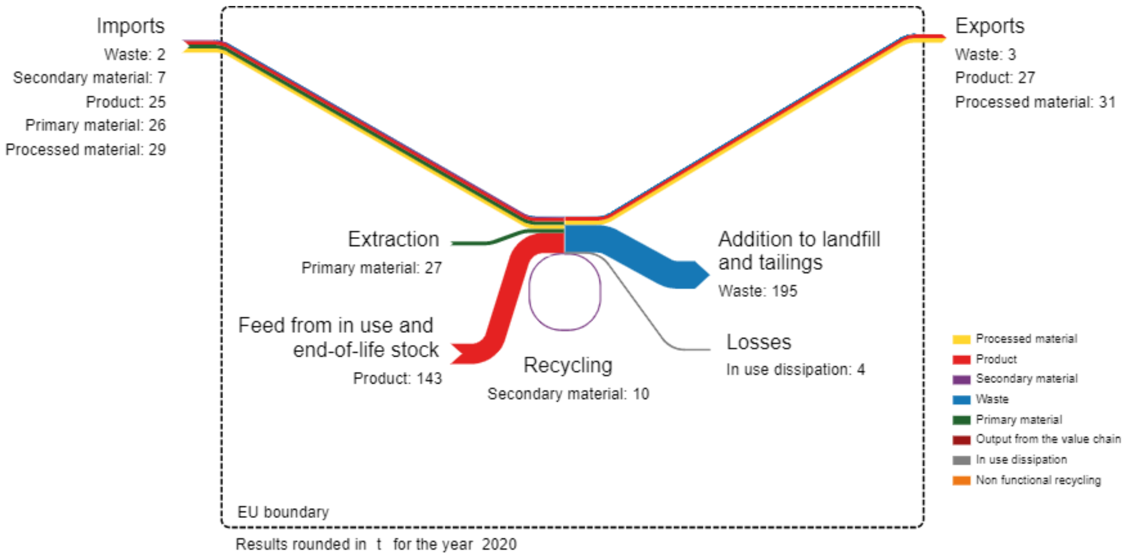


Figure 29: Simplified Sankey diagram for indium for the year 2020 in the EU, in t.

Though in earlier years (2016-2017) there were net-imports of processed material going to the EU manufacturing stage, in the last years the EU is a net-exporter with 2 t In net-exported in 2020 (imports of 29 t In processed material, and exports of 31 t In). This results in around 58 t In that were sent to manufacturing in the EU in 2020.

The EU industry manufactures various compounds which are then incorporated into finished products in the EU: solders and thermal interface materials (25 t In), alkaline batteries (8 t In) and other alloys, compounds and semiconductors (12 t In). Though globally the largest use of indium (ITO) is in the manufacture of flat panel displays, these are not manufactured in the EU[6]. Similarly, for CIGS photovoltaics, there was no direct manufacture in the EU in 2020.

Most of the indium new scrap generated from product manufacturing was sent for reprocessing, with around 1 t In of unavoidable losses considered sent to landfill.

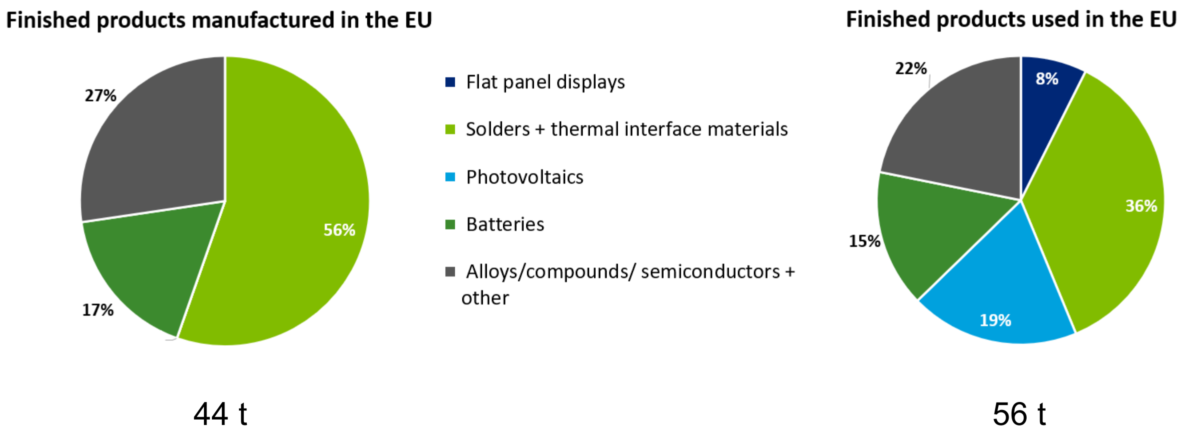


Figure 30: Shares of finished products containing indium manufactured in the EU (left) and shares of finished products containing indium used in the EU (right), by application

Table 19 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all indium products.

Application	Representative product
Flat panel displays	Indicator panels incorporating liquid crystal display (LCD)
Solders + thermal interface materials	Car windshield solders
Photovoltaics	Copper indium gallium diselenide solar cells (CIGS)
Batteries	Primary button cells

[6] Though displays (e.g., flat panel and liquid crystal) may be assembled in the EU, it is considered that the ITO relevant display components are imported and not manufactured in the EU.

Alloys/compounds/ semiconductors + other	Glass lenses

Table 19: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about -33 t In in 2020 (net removal from the stock in 2020). The total stock of products in-use is quantified at about 765 t In in 2020.

About 181 t In left the use phase in 2020. Of these, about 92 t In were collected and sorted for recycling, and about 4 t In were lost beforehand due to dissipation during use, mostly due to vehicles that are unaccounted for at EoL and dissipation from EEE. The remaining 91 t In were sent to landfill rather than recycled.

There is currently little functional recycling of In, rendering the total amount of secondary indium input to domestic processing and manufacturing in 2020 negligible. The indium contained in waste collected and sorted for recycling is expected to be in slags. Though in principal slags may be used as filling materials in construction (non-functional recycling), it is assumed that most will be landfilled due to content of other compounds considered to be hazardous.

4.10.3. Indicators

Table 20 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 50% in 2020, and the end-of-life recycling rate (EoL-RR) was <1%. The ratio of recycling from old scrap contributing to EU demand for indium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in <1%. The differences between the high collection rate on the one hand and the low recovery rates represented by EoL-RR and EoL-RIR on the other hand are due to the fact that most of the indium in collected products is sent to disposal rather than being recycled, such as for solders and thermal interface materials and batteries. For photovoltaics it could be that panels collected are sent for recycling outside of the EU, however the indium content is considered not to be recycled (though this is being researched and could change, also as end-of-life panels increase in volume). This is due to indium not being targeted in most recycling processes.

Regarding self-sufficiency, the EU relies on imports at the extraction stage. In 2020, only 41% of the indium sent to processing originated in the EU with the rest being imported.

In the processing stage, though the EU relied on imports in 2016 and 2017, in the past years it has been self-sufficient, exporting more indium than it imports. In 2020, the volume of indium processed in the EU exceeded somewhat the EU demand for manufacturing (103%), with processed indium exports exceeding its imports.

The EU is also self-sufficient for manufacturing, importing only small amounts (though all indium used in flat panel displays and possibly In used in CIGS sold in the EU is imported). The amount of indium consumed in the use phase (M3.1) exceeds the volume manufactured in the EU (D1.1), resulting in a self-sufficiency at the manufacturing stage lower than 100%. This sounds contradictory to the high self-sufficiency in the processing stage but is related to the fact that flat panel displays used in the EU rely on the import of indium containing components, i.e., indium not used in the manufacturing stage for this application. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for most of the application sectors.

For the five years analysed the main changes are related to EU processing. According to data, France started processing in 2017 and increased its production in 2018. In parallel, a German facility that was active in recycling of post-industrial waste ceased activity after 2017.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	<1%	<1%	<1%	<1%	<1%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	<1%	<1%	<1%	<1%	<1%
Collection rate	F1.4/(M4.1)	50%	50%	50%	50%	50%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	29%	35%	38%	40%	41%
Self-sufficiency Processing	C1.1/M2.1	51%	65%	147%	134%	103%
Self-sufficiency Manufacturing	D1.1/M3.1	79%	81%	71%	73%	80%

Table 20: Different indicators that describe indium situation in the EU

4.10.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the U.S. Geological Survey (USGS 2017-2021), the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other sources from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for the stages extraction and processing and for some products in manufacture and trade). The indium content is available from various experts and references (Schwarz-Schampera). Overall, basic extrapolation was applied to primary data to compute reliable estimates of indium flows and stock in the EU.

Due to lack of information, some assumptions based on expert knowledge or expert judgement were made for evaluating the characteristics of indium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of indium flows during use and end-of-life. The feedback from the validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on indium recycling mainly originates from expertise gathered during personal communications with stakeholders and through the validation workshops.

This assessment applies a different approach than the one used in the 2015 MSA to estimate indium extraction and processing. It is based on mass balancing and the amounts needed for production in the EU. Though the amount of functional recycling remains at the same order of magnitude, in the current assessment it has been assumed that slags are not used due to hazardous content, meaning a significant decrease in the indium previously assumed to be sent to non-functional recycling.

4.11. Magnesite/magnesia

4.11.1. Value chain

Magnesia (MgO) appears in natural form as magnesium carbonate ($MgCO_3$) and in synthetic form as in seawater and brines.. Magnesite is also extracted as a side product of talc ores. Nevertheless, natural magnesium carbonate is the largest feedstock for magnesia. Natural magnesium carbonate is mainly processed into magnesia including fused magnesia (FM), dead burned magnesia (DBM), caustic calcined magnesia (CCM). Synthetic magnesia is mainly processed into dead burned magnesia (DBM), caustic calcined magnesia (CCM) and magnesium chloride.

These processed materials are manufactured into various products such as refractory bricks for steel industry, cements, ceramics, and glass industries, and as monolithic bricksfor the steel scrap industry. For these applications, magnesite is used for its high resistance to extreme temperatures, as it increases the melting point of refractories and monolithics. Magnesite is also used in fertilisers and in livestock feed as Mg is an important nutrient for plants and cattle growth. Finally, magnesite is found in chemicals in various stages of the paper industry: pulping, bleaching and at the oxygen stage.

Figure 31 below depicts the value chain of magnesite/magnesia, its intermediates and end-uses covered by this study.

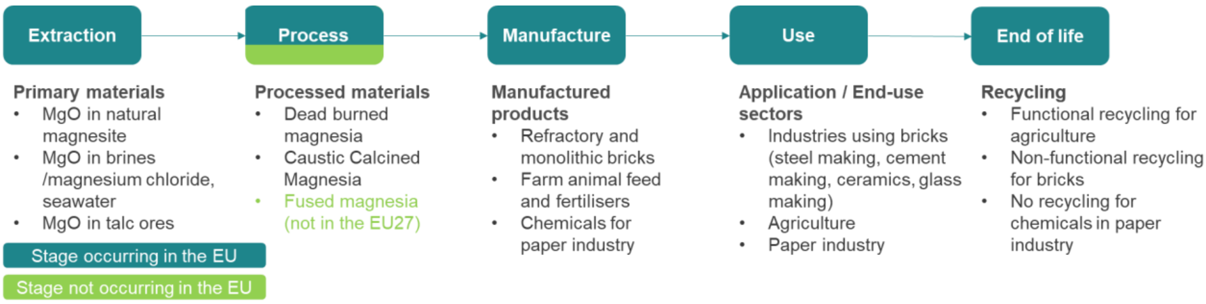


Figure 31: Value chain of magnesite/magnesia, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.11.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of magnesia (t MgO) equivalent and are representative of the year 2020.

Global magnesite ores reserves are estimated at about 3 096 Mt MgO (i.e. 7 200 Mt $MgCO_3$), with Russia and China accounting for about 23% of the global magnesite/magnesia reserves. In the EU, natural magnesite reserves are estimated at about 734 000 kt MgO, accounting for reserves in Spain, Austria, Greece and Slovakia, which are the main extracting countries of natural magnesite. Smaller reserves exist in other EU countries (Poland, Bulgaria) but no data is reported. In addition, reserves of about 26 000 kt MgO in talc are identified in Finland and reserves of about 150 kt MgO are reported in brines in the Netherlands.

In 2020, the world production of magnesite ores reached 10 058 kt MgO and the top producer country was China, accounting for 70% of extracted magnesite/magnesia volumes. In the EU, about 1 380 kt MgO were extracted as main product in 2020, i.e. in Slovakia (33% of magnesite extraction in EU), in Austria (25%) and in Spain (25%). Among these 1 380 kt MgO, 240 kt MgO were extracted from brines/magnesium chloride in the Netherlands.

In 2020, about 60 kt MgO were extracted as a by-product in the EU, extraction waste is not considered in this case.

Around 14% of the EU extracted magnesite is sold on the EU market including exports of magnesium chloride estimated at 130 kt MgO, from the Netherlands.

The domestic input to EU magnesite processing was supplemented with imports of natural magnesium carbonate (20 kt MgO). No brines are imported in the EU. There are no imports to the EU of secondary material used in the processing of magnesite/magnesia.

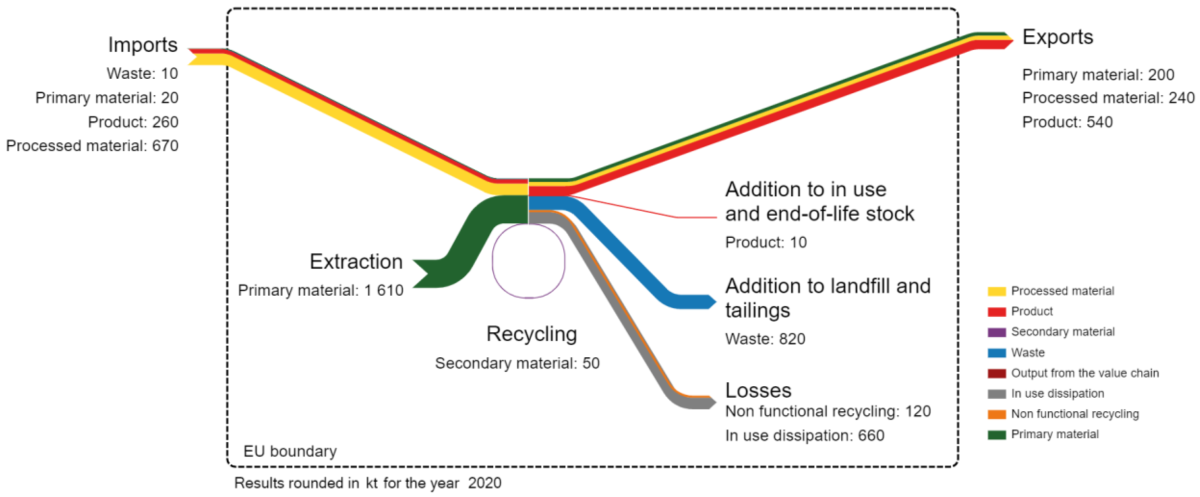


Figure 32: Simplified Sankey diagram for magnesite for the year 2020 in the EU, in kt.

A total of 1 070 kt MgO of processed material were produced. About 190 kt MgO is generated as processing waste, sent to disposal. MgCl2 is mainly processed into DBM (84% of total volumes of MgO production), hydroxide and caustic calcined magnesia. In the EU, there are two producers of synthetic MgO, both produce CCM and DBM. Ireland produces MgO out of seawater, and the Netherlands out of brine. Fused magnesia is not produced in the EU anymore.

Further input to the EU manufacturing stage was:

430 kt MgO of processed material net-imported (670 kt MgO of processed material imported while the exports were 235 kt MgO)

50 kt MgO from post-consumer functional recycling in the EU

The EU industry manufactures various finished products in the EU: MgO containing bricks for industrial use (1 140 kt MgO), fertilizers for the agriculture (220 kt MgO) and chemicals used in the paper industry (180 kt MgO). All of the waste generated at that stage (i.e. 20 kt MgO) was sent to landfill.

Figure 33 shows the distribution by end-use sector of MgO-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

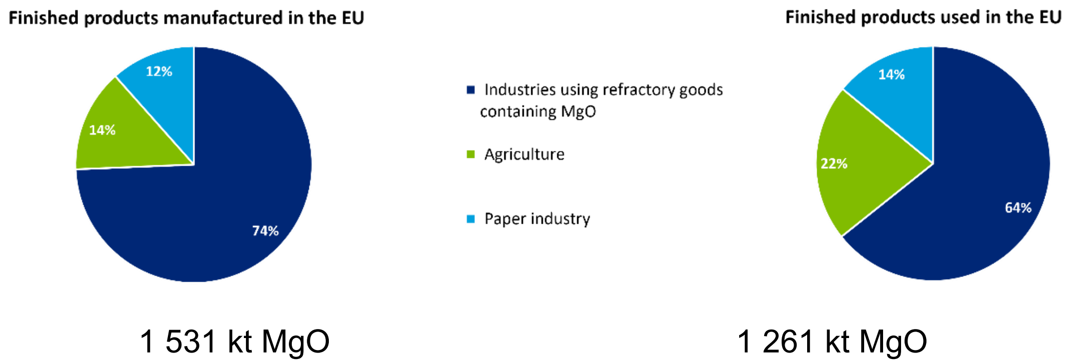


Figure 33: Shares of finished products containing magnesite manufactured in the EU (left) and shares of finished products containing magnesite used in the EU (right), by application

Table 21 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all magnesite products.

Application	Representative product
Industries using bricks containing MgO	Refractories and monolithics
Agriculture	Fertilisers Preparations for farm animals
Paper industry	Chemicals used in pulping, oxygen stage and bleaching processes

Table 21: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 10 kt MgO in 2020. The total stock of products in-use is evaluated at about 600 kt MgO in 2020.

About 660 kt MgO were lost due to dissipation of MgO during use of the manufactured products containing magnesite mentioned above, mostly due to the dissolution of magnesia in refractory and monolithic bricks.

About 590 kt MgO leaving the use phase were collected at end-of-life for treatment in the EU. Among this flow, 180 kt MgO were sent to recycling, mostly bricks, crop residue and livestock manure. Regarding crop residue and manure, recycling corresponds to reuse as fertilisers for crop growing, which is evaluated as 80 kt MgO directly sent to manufacturing stage for use as a fertilizer.

4.11.3. Indicators

Table 22 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 30% in 2020, and the end-of-life recycling rate (EoL-RR) was 8%. The ratio of recycling from old scrap contributing to EU demand for magnesite (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 2%. The differences between collection, EoL-RR and EoL-RIR were due to the fact that most of the collected products are landfilled rather than recycled, such as monolithic bricks and chemicals used in the paper industry.

Regarding self-sufficiency, the EU relies on imports at processing stage and is self-sufficient for extraction and manufacturing stages, exporting more that the amount imported. In 2020, 114% of magnesite required at the processing stage was extracted in the EU, the rest being exported. Only 71% of the demand for manufacturing was supplemented by magnesite refined in the EU, the rest was imported from outside the EU. The amount of magnesite consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed those indicators may be considered as stable.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	2%	2%	2%	2%	2%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	8%	8%	8%	9%	8%

Indicator	Formula	2016	2017	2018	2019	2020
Collection rate	F1.4/(M4.1)	29%	29%	30%	29%	30%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	118%	111%	112%	108%	114%
Self-sufficiency Processing	C1.1/M2.1	65%	70%	69%	71%	71%
Self-sufficiency Manufacturing	D1.1/M3.1	124%	130%	124%	130%	121%

Table 22: Different indicators that describe magnesite situation in the EU

4.11.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, BGS, Euromines publication and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The magnesite content is available from various expertise and references (IMA, Nedmag B.V, experts); it is also calculated on molar masses.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of magnesite-containing products (lifetime, in use dissipation rate, market share, etc.). For this reason, higher uncertainty likely affects the estimate of magnesite flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on magnesite recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA are comparable with results of the MSA conducted in 2015. In the 2023 MSA, a higher level of detail is available in the model for the use and end-of-life stages: industries using magnesite application was disaggregated into 2 sub-categories (monolithics and refractories).

4.12. Magnesium

4.12.1. Value chain

Magnesium is currently produced through two main processes: thermic reduction and electrolysis. The global main producer of magnesium – China – uses almost exclusively thermic reduction with dolomite as input raw material. Other producing countries use the electrolysis process with magnesium-rich salts (e.g. carnallite), magnesium-rich brines and seawater as input raw materials.

Primary raw magnesium is processed into aluminium alloys and magnesium alloy for die-casting, the latter being finally processed into magnesium die-casting parts. Raw magnesium is also processed into chips or powder forms.

Aluminium alloys containing magnesium are used in a wide range of applications such as packaging (mostly beverage cans), transport (automotive and aerospace) and construction (in roofing, windows, balconies, doors, internal fittings such as sinks and door handles as well as fencing and facades) and other versatile products (e.g. in marine and rail applications, consumer durables, equipment and machinery). Magnesium alloy die-casting parts are chiefly used in the automobile industry (as well as in aerospace components) because of the need for lightweight materials and premium corrosion performance. Magnesium in powder or granulated form is also used as an efficient desulphurization agent in the production of crude steel to remove sulphur from pig iron.

In addition, granulated magnesium has a range of other metallurgical, chemical and electrochemical uses (e.g. Grignard reagents, in pyrotechnics, nodular cast iron or as in refractory materials), although these all remain relatively minor sources of consumption.

Figure 34 below depicts the value chain of magnesium, its intermediates and end-uses covered by this study.

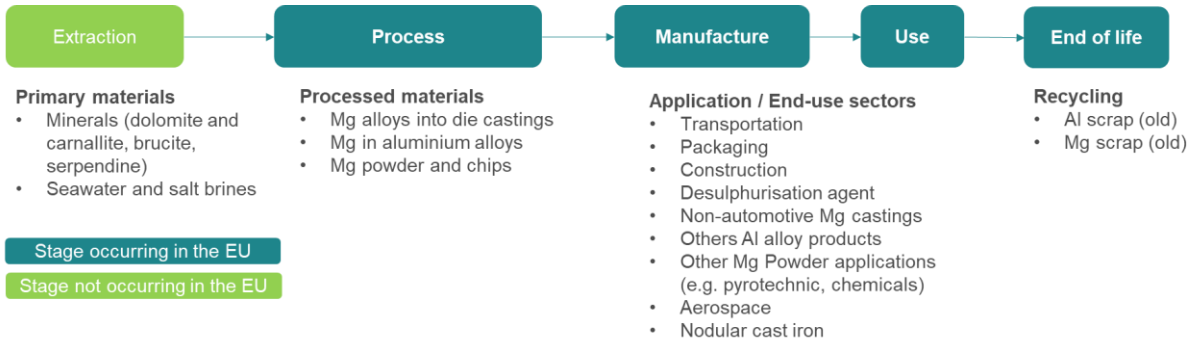


Figure 34: Value chain of magnesium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.12.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (kt Mg) equivalent and are representative of the year 2020.

The global reserves of magnesium have not been quantified, yet magnesium constitutes about 2% of the Earth's crust, and is the third most plentiful element dissolved in seawater Thus, primary material used for production of magnesium is considered sufficient to supply current and future requirements. Worldwide production of primary material (magnesium metal) is around 945 kt Mg. The major producer of magnesium is China, which is responsible for about 91% of worldwide magnesium production. The USA, Brazil, Israel and Russia produce around 1-3% each.

There is no primary production of magnesium in the EU, which results in a dependency on imports of semi-processed materials: 70 kt Mg of pure magnesium metal was imported in 2020 according to Eurostat[7]. This input is used to process aluminium alloys and magnesium alloy die-casting parts, which are sold on the EU market as well as magnesium powder and chips. Around 5 kt Mg in Mg scrap is imported and sent to processing. Around 11.5 kt Mg of new manufacturing scrap is sent to reprocessing. Mainly Al alloys (73 kt Mg), magnesium powder and chips (8 kt Mg) and Mg alloys for die casting parts (6 kt Mg) are produced.

As input to the EU manufacturing stage, the EU further imports processed magnesium in form of magnesium alloys for die-casting parts (51 kt Mg) and Mg in

[7] Experts in the MSA workshop conducted in February 2023 suggested that imports of pure magnesium is higher (around 120 kt Mg) yet for the analysis, the official Eurostat trade data were used.

aluminium alloys (25 kt Mg). The Mg export volume of processed material is 17 kt Mg.

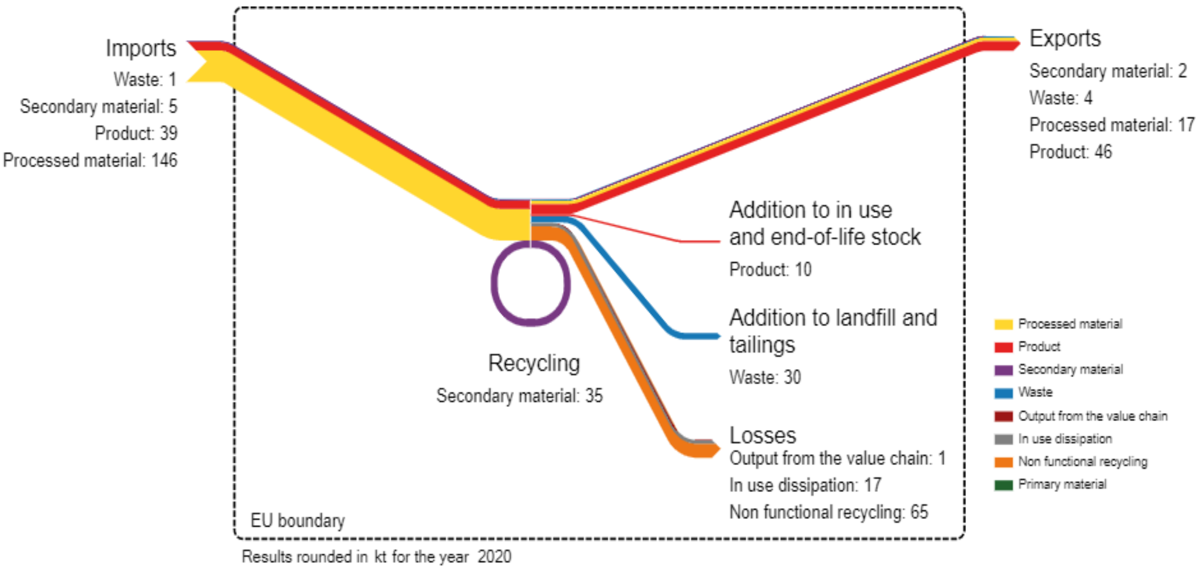


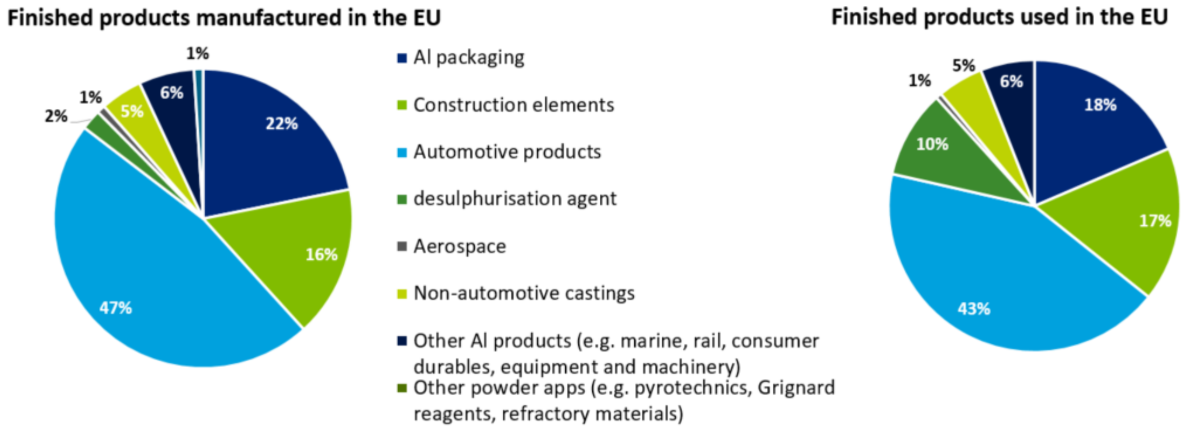
Figure 35: Simplified Sankey diagram for magnesium for the year 2020 in the EU, in kt.

About 154 kt of finished magnesium products are manufactured in the EU. The highest shares go to manufacturing of magnesium in automotive parts and in aluminium packaging (see Figure 36 – left). Most of the magnesium new scrap generated from product manufacturing was sent for reprocessing (11.5 kt).

In 2020, a total of 163 kt Mg of manufactured magnesium products are sent to use in the EU (see Figure 36 – right). In order to cover its requirements, the EU further imports around 39 kt of Mg in finished products at the use step: including 11 kt of automotive parts, 13 kt of Mg in magnesium powders for steel-desulphurization, and 9 kt of magnesium for other powder applications.

The main application is the manufacturing of cars and other vehicles (66 kt Mg in manufactured products sent to use in EU, 18 kt Mg in exports). The second biggest application is magnesium in Aluminium packaging (29 kt are sent to use in 2020, 6 kt are exported). The third most common use of magnesium is the production of aluminium construction elements (26 kt of Mg sent to use in the EU, 2 kt of Mg exported).

Further applications are the use as desulphurisation agents (15 kt), in aerospace products (1 kt), other alloy products (9 kt), other powder applications (8 kt), non-automotive castings (8 kt), and as nodular cast iron (1.5 kt).



154 kt 163 kt

Figure 36: Shares of finished products containing 154 kt Mg manufactured in the EU (left) and shares of finished products containing 163 kt Mg used in the EU (right), by application

For each of the applications, Table 23 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all magnesium products.

Application	Representative product
Al packaging	Aluminium reservoirs, tanks, vats, and similar containers for any material (other than compressed or liquefied gas), of a capacity > 300 litres (excluding fitted with mechanical or thermal equipment)
Construction elements	Aluminium alloy bars, rods, profiles, and hollow profiles (excluding rods and profiles prepared for use in structures)
Automotive products	Several codes for vehicle cars; light commercial vehicle, busses; heavy trucks (see appendix table 4)
Desulphurisation agent	Magnesium raspings, turnings and granules, graded according to size; magnesium powders
Aerospace	Powered aircraft, "e.g. helicopters and aeroplanes"; spacecraft, incl. satellites, and suborbital and spacecraft launch vehicles
Non-automotive castings	Mowers for lawns, parks or sports grounds, powered, with the cutting device rotating in a horizontal plane; Chainsaws for working in the hand, with self-contained non-electric motor
Other Al products	-

Other powder apps	Magnesium raspings, turnings and granules, graded according to size; magnesium powders
Nodular cast iron	-

Table 23: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection, and recycling steps for each application.

Considering the lifespan of the finished products containing magnesium and the annual growth of the magnesium containing applications in Europe, about 6% of the magnesium put on the EU market (163 kt Mg) is annually added to the in-use stock (9.5 kt in magnesium content). The total stock of products in-use is estimated at about 2,000 kt in magnesium content.

The largest stock of magnesium is related to vehicles (1,050 kt) followed by aluminium construction elements (700 kt). Relatively small amount of magnesium is stored in packaging stock – about 29 kt.

The amount of magnesium in end-of-life products collected and sent for treatment is about 121 kt, mostly in vehicles (40 kt), construction elements (19 kt) and packaging (29 kt).

The major part of these end-of-life products is sent to recycling (100 kt of Mg), while the rest is either exported (approx. 1.6 kt) or considered sent to disposal (19 kt). Production of secondary material from functional recycling is around 23 kt of Mg, and is sent for manufacturing. Around 65 kt of Mg are considered as going through non-functional recycling, as the alloys in which the magnesium is contained are recycled without knowledge of the content in magnesium. A negligible part of magnesium in secondary materials is exported (1.5 kt).

4.12.3. Indicators

Table 24 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 83% in 2020, and the end-of-life recycling rate (EoL-RR) was 21%. The ratio of recycling from old scrap contributing to EU demand for magnesium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 13%.

Regarding self-sufficiency, the EU relies 100% on imports at extraction stage. At the processing stage the EU covers up to 60% of the demand for the manufacturing, the rest being supplemented by imports. At the manufacturing stage the self-sufficiency rate stays even at 94%, with only a small amount of magnesium imported in products for use.

For the five years analysed only minor fluctuations can be observed. In total the input and output of magnesium decreased from 2016 to 2020 by around 14%, resulting in decreased imports of semi processed raw magnesium metal as well as processed forms of magnesium (Mg alloys, Al alloys) or as finished products. The same holds true for export flows of magnesium.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	13%	13%	14%	13%	13%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	20%	20%	20%	20%	21%
Collection rate	F1.4/(M4.1)	82%	83%	83%	82%	83%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	60%	58%	58%	61%	60%
Self-sufficiency Manufacturing	D1.1/M3.1	95%	94%	94%	92%	94%

Table 24: Different indicators that describe magnesium situation in the EU

4.12.4. Data sources, assumptions and reliability of results

The main data sources used for magnesium include Eurostat Comext and Prodcom and waste databases, as well as USGS, British Geological Survey, International Organization of Motor Vehicle Manufacturers database for calculation of processing and manufacturing waste flows. Further essential input presents the information from the International Magnesium Association who have conducted a material system analysis in response to the MSA by DG GROW in 2015.

Overall data for exploration to processing steps can be considered reliable.

For the manufacture step, several shares of magnesium into different applications were based on IMA information. For specific applications it was necessary to estimate some coefficients such as the average content of magnesium in cars. Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of magnesium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimation of magnesium flows at use and end-of-life. For the collection and recycling stages again information from IMA was used and shares were extrapolated to the recent timeframe. The feedback from validation workshop helped in confirming and improving the estimations made, which adds more robustness to the results.

The updated MSA in 2023 cannot directly be compared to the previous MSA. Several more applications for magnesium were included to increase the level of detail. Further, with regards to finished products and waste flows going to landfill quite significant changes have been done in the 2023 MSA due to this increased resolution. Material previously allocated to landfill was considered as going to non-functional recycling instead (in analogy to IMA).

4.13. Niobium

4.13.1. Value chain

Niobium is usually extracted together with tantalum. It mainly occurs as pyrochlore, columbite and tantalite, the first two containing more niobium than tantalum. The main source of niobium is pyrochlore. After extraction, niobium ore is mostly processed into ferroniobium, but for a few cases also niobium metal and other compounds like niobium oxide or carbide.

Niobium is mostly traded as ferroniobium, which is used to make high strength low alloy steels, stainless steels and superalloys. In steels, it is used to increase its strength, toughness, formability and weldability by being an effective microalloying element. Furthermore, due to its superconducting alloys with other metals, niobium is, e.g., used in superconductors for MRI (medical resonance imaging) as fine filaments of niobium/titanium alloy embedded in a copper matrix. In general, the application of niobium is relatively new. It only became commercially available after the Araxá deposit in Brazil was opened in the 70's.

Niobium as part of steel is used in various applications such as construction, vehicles, pipelines and aircraft engines. Apart from MRI, niobium compounds are also found in electronic equipment and others. Figure 37 below depicts the value chain of niobium, its intermediates and end-uses covered by this study. All the steps of the niobium value chain take place in the EU27.

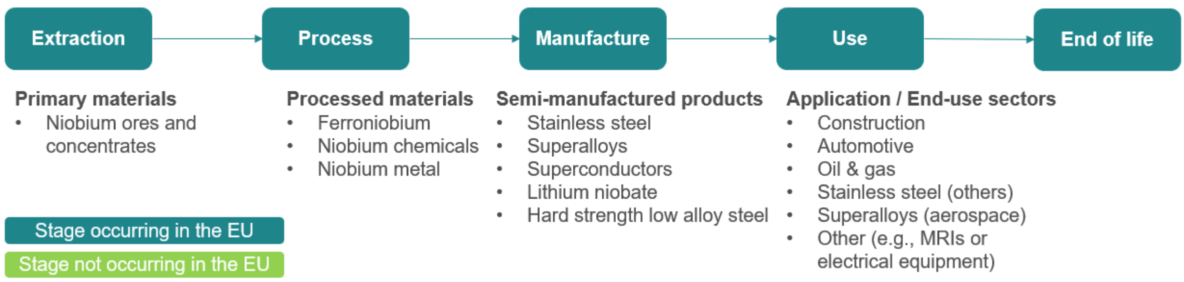


Figure 37: Value chain of niobium, steps in dark green occur at least in part in the EU, steps in light green occur only in non-EU countries

4.13.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (t Nb) equivalent and are representative of the year 2020.

Global niobium reserves are estimated at about 17 000 kt Nb, with Brazil accounting for 16 000 kt by itself. In the EU, no data about niobium reserves is found.

In 2020, the world production of niobium reached 65 kt Nb and the top producer country was Brazil, accounting for nearly 60 kt of extracted niobium volumes. In the EU, there was a small extraction of Nb in form of a niobium-tantalum concentrate from tailings in Spain (30 t) from 2018 until 2021. This is supported by importing niobium ores and concentrates containing 220 t Nb in 2020. Additionally, about 30 t Nb were supplemented from manufacturing waste generated in the EU, and 6 t Nb from post-consumer functional recycling of special steel in the EU.

The niobium ores & concentrates are mostly processed into ferroniobium, but also into niobium oxide, niobium metal or other compounds.

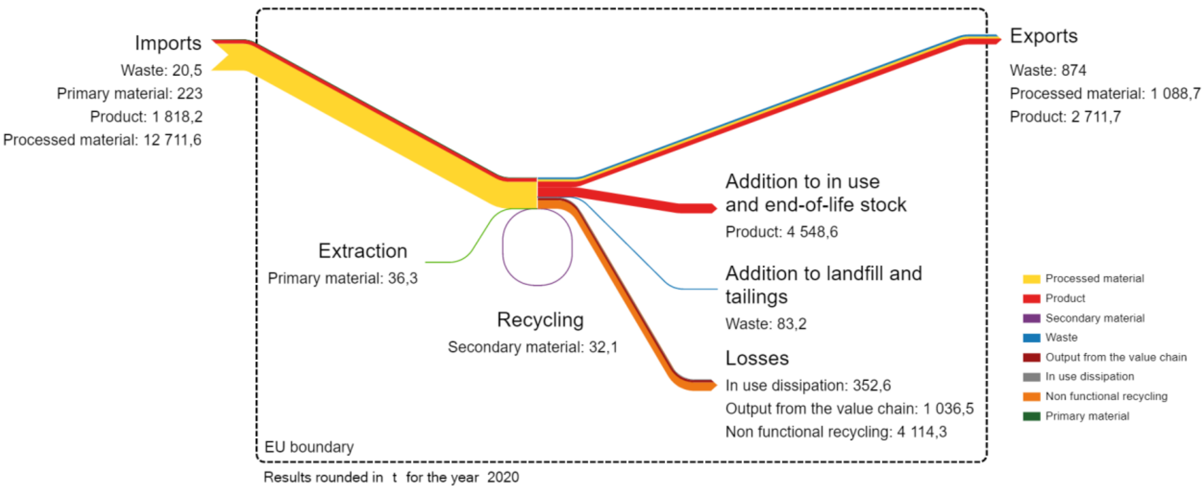


Figure 38: Simplified Sankey diagram for niobium for the year 2020 in the EU, in t.

A total of 290 t Nb of processed materials were produced in the EU. Less than 1 t Nb is generated as processing waste and sent to disposal.

Most of niobium supplied to the EU is imported as processed materials (i.e. ferroniobium, niobium metal or chemicals). As input to the EU manufacturing stage, 10 820 t Nb of processed materials were net-imported (12 710 t Nb of processed materials imported while the exports were 1 060 t Nb). The EU industry uses these materials to manufacture various finished products for construction (4 710 t Nb), automotive (steel, 2 100 t Nb), oil & gas (1 720 t Nb), stainless steel (960 t Nb), special steel (230 t Nb) and others (e.g., MRI, 800 t Nb). Most of the niobium scrap generated from product manufacturing was not recycled for the value of niobium, but mostly ending up in slags used for road construction or being diluted in other products (1 020 t Nb), with only 30 t Nb being reprocessed and 80 t Nb considered to be sent to landfill.

Figure 39 shows the distribution by end-use sector of niobium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

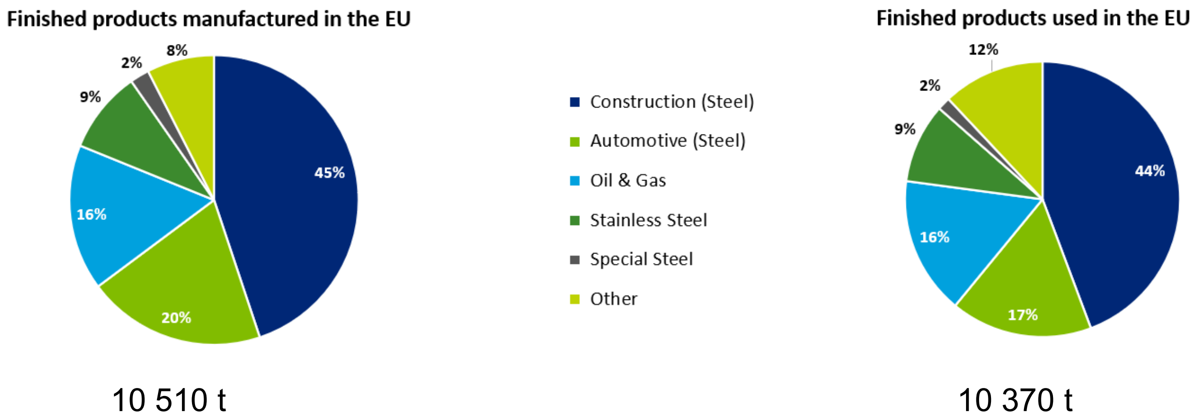


Figure 39: Shares of finished products containing niobium manufactured in the EU (left) and shares of finished products containing niobium used in the EU (right), by application

Table 25 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all niobium products.

Application	Representative product
Construction (Steel)	Steel bridges
Automotive (Steel)	Passenger vehicles
Oil & Gas	Oil or gas tubes
Stainless Steel	Stainless steel in passenger vehicles
Special Steel	Aerospace parts
Other	Superconductors in MRIs

Table 25: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 4 580 t Nb in 2020 (net addition to the stock in 2020). The total stock of products in-use is quantified at about 158 550 t Nb in 2020.

About 4 740 t Nb leaving the use phase were collected and sorted for recycling, while about 350 t Nb were lost due to dissipation during use, mostly due to unknown whereabouts of cars. Only 0.4 t Nb were directly sent to disposal. The niobium contained in the waste is mostly non-functionally recycled. There is very little post-consumer functional recycling of niobium (6 t), and most is ending up in slags during recycling of steel, which again is mostly used for construction of roadways, or diluted down, not valued for its functions (4 110 t Nb total).

4.13.3. Indicators

Table 26 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 87% in 2020, and the end-of-life recycling rate (EoL-RR) was <1%. The ratio of recycling from old scrap contributing to EUL demand for niobium (i.e., end-of-life recycling input rate, EoL-RIR) was calculated to be <1%. The differences between collection on the one hand and EoL-RR and EoL-RIR on the other hand were due to the fact that nearly all applications apart from special steel are not recycled for their niobium content and niobium is going into slag.

Regarding self-sufficiency, the EU relies on imports of extracted and processed material and is self-sufficient for manufacturing, exporting similar amounts in end products compared to import. In 2020, only 14% of niobium was extracted and 2% refined in the EU, as most niobium is imported as processed material. The amount of niobium consumed in the use phase (M.3.1) is lower than what is manufactured in the EU (D.1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the main changes are related to EU extraction, which started in 2018 with the recovery of tailings for niobium concentrates production.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	<1%	<1%	<1%	<1%	<1%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	<1%	<1%	<1%	<1%	<1%
Collection rate	F1.4/(M4.1)	87%	87%	87%	87%	87%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0.0%	0.0%	42%	40%	14%
Self-sufficiency Processing	C1.1/M2.1	1%	1%	1%	1%	2%

Self-sufficiency Manufacturing	D1.1/M3.1	106%	104%	105%	101%	101%

Table 26: Different indicators that describe niobium situation in the EU

4.13.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are USGS, the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, Eurofer publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps processing and products in manufacture). The niobium content is available from various expertise and references (CRM Factsheets and others). Overall, basic extrapolation was applied to primary data to compute reliable estimates of niobium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of niobium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of niobium flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on niobium recycling mainly originates from expertise gathered during personal communications with stakeholders.

Compared to the previous MSA, the general assumptions and methodology are similar, however, the share of the different applications differs more strongly. The market has grown, but according to experts, the recycling in the EU has not increased.

4.14. Platinum group metals (PGMs) - Palladium

4.14.1. Value chain

Palladium (Pd) is a precious metal that occurs in some nickel and copper ores, mainly in Russia, the USA and China, along with some native deposits as in South Africa. Palladium-containing ores and concentrates are then sent to a smelter to produce mattes. Refining those mattes enable the production of pure palladium metal, which is traded in powder form for industrial use.

Palladium, as other platinum group metals (PGMs), is used in a large range of manufactured products and industries for its unique properties. For instance, palladium can act as a catalyst and is exploited in a wide range of applications, where only a small quantity of the metal can have a large impact on the production. The most significant application of palladium as a catalyst is in automotive catalytic converters (hereafter named autocatalysts), where palladium reduces emissions from gasoline and diesel engines (hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter).

Palladium is also used for jewellery due to its high value and properties, in particular for the manufacture of "white gold" alloys. As a precious metal, it is also used for investment purposes. In this case, it is mainly traded as ingots. Other uses are:

the medical and biomedical field, where palladium is used for its hypoallergenic properties in pacemakers and dentistry,

electronics, where palladium is used in some printed circuit boards and in hard drives.

Figure 40 below depicts the value chain of palladium, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

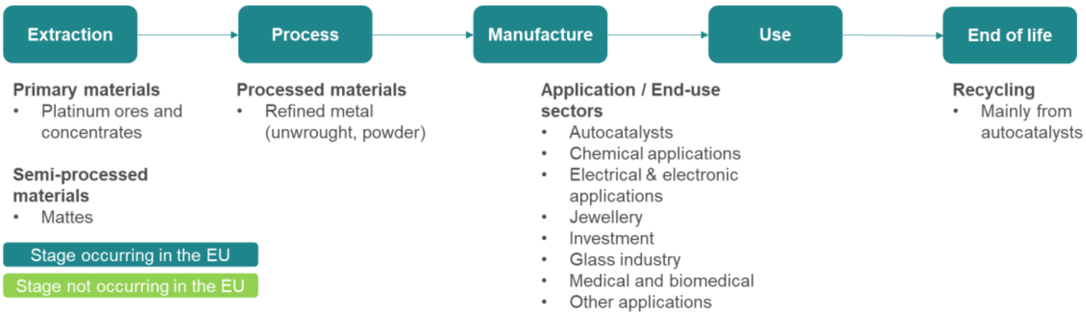


Figure 40: Value chain of palladium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.14.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of palladium (t Pd) metallic equivalent and are representative of the year 2019.

Global palladium reserves are estimated at about 6 090 t Pd out of the 69 000 t PGM total reserves worldwide, of which South Africa accounts for more than 90%. In the EU, palladium reserves are reported for Spain and Finland, however some palladium is also extracted in Poland, for which no estimation of reserves is available. Smaller reserves may exist in other EU countries but are not reported. In 2019, Spanish and Finnish reserves amounted to 6.9 t Pd.

In 2019, the world production of palladium reached 199.4 t Pd and the top producer countries were Russia and South Africa, accounting for more than 40% of extracted palladium volumes each. In the EU, about 0.7 t Pd were extracted. Finland represents 99% of the extraction volumes for 2017-2020, and no extraction volumes are reported for Spain.

All of the EU extracted palladium is sold on the EU market. The domestic input to EU palladium processing was supplemented with imports of palladium ores and concentrates (1.4 t Pd), imports of semi-processed material in the form of mattes (6.7 t Pd) and imports of secondary material (26.9 t Pd). Additionally, about 25.4 t Pd were supplemented from post-consumer functional recycling in the EU.

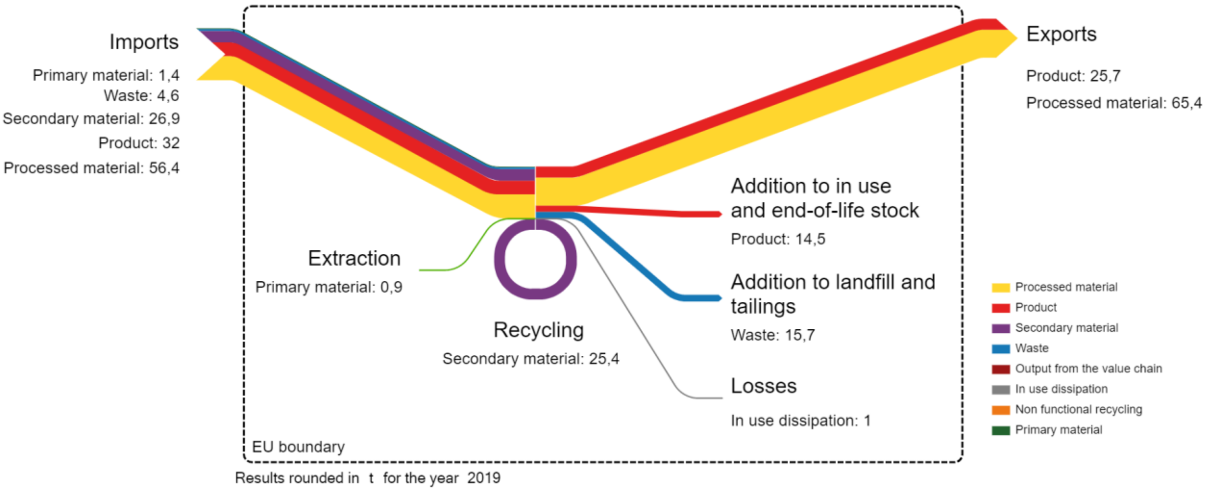
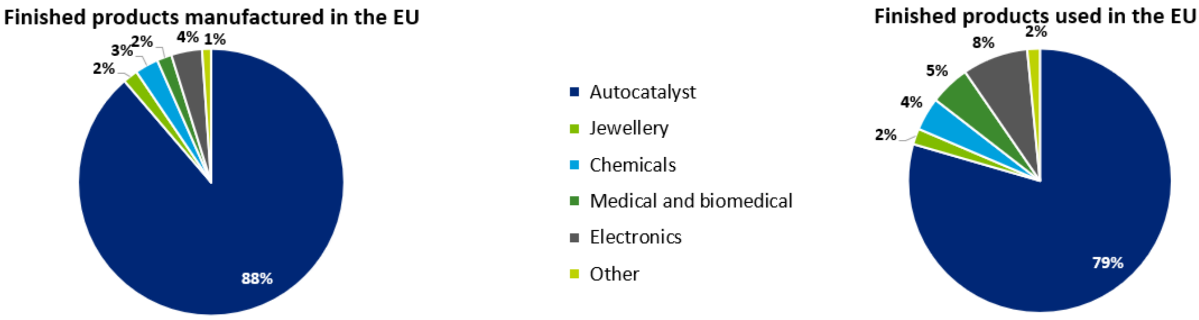


Figure 41: Simplified Sankey diagram for palladium for the year 2019 in the EU, in t, imports of products include also 14.6 t Pd of intermediate products, supplied to the manufacturing stage.

An estimated total of 60 t Pd of processed material were produced in the EU. About 1.2 t Pd is generated as processing waste, sent to disposal, and 65.4 t Pd processed material was exported outside the EU, therefore including some imports being re-exported.

As input to the EU manufacturing stage, the processed material was supplemented with 49.7 t Pd of processed material imported, and 14.6 t Pd in intermediate products net-imported from outside the EU. The palladium sent to the manufacturing steps is distributed between several applications: autocatalysts (52.7 t Pd), jewellery (1.1 t Pd), catalysts in the chemical industry (1.7 t Pd), medical and biomedical products (1.1 t Pd), electronics (2.2 t Pd) and in various other applications (0.6 t Pd). Due to high internal recycling rates at the manufacturing stage, less than 0.1 t Pd are considered unrecoverable and therefore as waste sent to disposal.

Figure 42 shows the distribution by end-use sector of palladium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.



59.4 t 55.2 t

Figure 42: Shares of finished products containing palladium manufactured in the EU (left) and shares of finished products containing palladium used in the EU (right), by application

Table 27 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all palladium products.

Application	Representative product
Autocatalysts	Autocatalysts
Jewellery	Jewellery
Chemicals	Catalysts
Medical and biomedical	Pacemakers
Electronics	Hard drives
Other	Pollution control catalysts

Table 27: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 17.9 t Pd in 2019. The total stock of products in-use is quantified at about 674.0 t Pd in 2019.

About 1.0 t Pd were lost due to dissipation during use, due to the use of palladium in the autocatalysts. This leaves about 35.0 t Pd contained in products collected for waste treatment, and 4.1 t Pd were exported for reuse, mainly in cars exported. It was supplemented with about 4.6 t Pd of imports of end-of-life autocatalysts for recycling. Among products collected for waste treatment, 13.4 t Pd were sent to landfill rather than recycled and about 0.8 t Pd of recycling waste reduced the total amount of secondary palladium input to domestic processing and manufacturing at 25.4 t Pd in 2019.

4.14.3. Indicators

Table 28 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 66% in 2019, and the end-of-life recycling rate (EoL-RR) was 64%. The ratio of recycling from old scrap contributing to EU demand for palladium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 23%. The differences between collection, EoL-RR and EoL-RIR were due to the fact that part of the collected products are landfilled rather than recycled, such as catalysts in the chemical industry, medical and biomedical equipment, and some electronics.

Regarding self-sufficiency, the EU relies largely on imports at the extraction stage and is nearly self-sufficient for processing and manufacturing. In 2019, only 2% of the palladium refined in the EU was extracted locally, the rest was imported (imports include also secondary materials). The amount of palladium consumed in the manufacturing phase (M2.1) is lower than the amount processed in the EU (C1.1), resulting in a self-sufficiency higher than 100%. Regarding the amount of palladium consumed in the EU, the amount manufactured is also higher, with more exports than imports of products. These results demonstrate that the EU processing and manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed small variations may be observed between 2016 to 2020, mainly due to price evolutions throughout the time period.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	18%	20%	19%	23%	22%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	60%	63%	56%	64%	70%
Collection rate	F1.4/(M4.1)	62%	65%	57%	66%	72%

Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	2%	3%	3%	2%	2%
Self-sufficiency Processing	C1.1/M2.1	127%	124%	110%	102%	118%
Self-sufficiency Manufacturing	D1.1/M3.1	117%	115%	105%	108%	117%

Table 28: Different indicators that describe palladium situation in the EU

4.14.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are Johnson Matthey publications, the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The palladium content is available from various expertise. Overall, basic extrapolation was applied to primary data to compute reliable estimates of palladium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of palladium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of palladium flows at use and end-of-life, in particular for the recycling of e-scrap. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on palladium recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA differ from the results of the MSA conducted in 2015, mainly due to market evolution. There is an increase in EU extraction and a decrease in imports of primary material, and palladium investment decreased significantly over the time period considered based on Johnson Matthey publications.

4.15. Platinum group metals (PGMs) - Platinum

4.15.1. Value chain

Platinum (Pt) is a precious metal that occurs in native deposits, and in some nickel and copper ores, with the largest reserves in South Africa. Platinum-containing ores and concentrates are then sent to a smelter to produce mattes. Refining those mattes enable the production of pure platinum metal, which is traded mainly in powder form for industrial use.

Platinum, as other platinum group metals (PGMs), is used in a large range of manufactured products and industries for its unique properties. For instance, platinum can act as a catalyst and is exploited in a wide range of applications, where only a small quantity of the metal can have a large impact on the production. The most significant application of platinum as a catalyst is in automotive catalytic converters (hereafter named autocatalysts), where platinum reduces emissions from gasoline and diesel engines (hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter).

Platinum is also used for jewellery due to its high value and properties. As a precious metal, it is also used for investment purposes. Other uses are:

the medical and biomedical field, where platinum is used for its hypo-allergenic properties in pacemakers and dentistry,

electronics, where platinum is used in some printed circuit boards and in hard drives,

the glass industry, in which platinum-rhodium alloys are used as refractory metals, with high thermal resistance.

Figure 43 below depicts the value chain of platinum, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

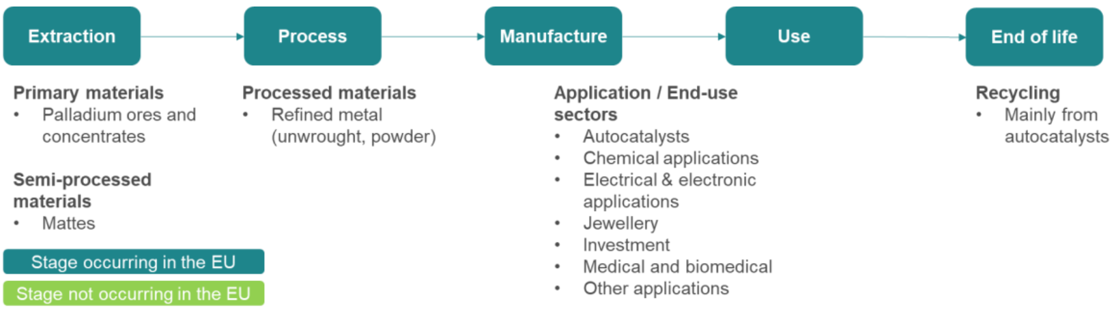


Figure 43: Value chain of platinum, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.15.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of platinum (t Pt) metallic equivalent and are representative of the year 2019.

Global platinum reserves are estimated at about 7 905 t Pt out of the 69 000 t PGM total reserves worldwide, of which South Africa accounts for more than 90%. In the EU, platinum reserves are reported for Spain and Finland, however some platinum is also extracted in Poland, for which no estimation of reserves is available. Smaller reserves may exist in other EU countries but are not reported. In 2019, Spanish and Finnish reserves amounted to 18 t Pt.

In 2019, the world production of platinum reached 185.5 t Pt and the top producer country was South Africa, accounting for more than 70% of extracted platinum volumes.

In the EU, about 1.0 t Pt were extracted in the EU, with a higher average value per year for 2016-2020, of about 1.4 t Pt. Finland represents 99% of the extraction volumes for 2017-2020, and no extraction volumes are reported for Spain.

All of the EU extracted platinum is sold on the EU market. The domestic input to EU platinum processing was supplemented with imports of platinum ores and concentrates (0.3 t Pt), imports of semi-processed material in the form of mattes (4.3 t Pt) and imports of secondary material (17.0 t Pt). Additionally, about 18.3 t Pt were supplemented from post-consumer functional recycling in the EU.

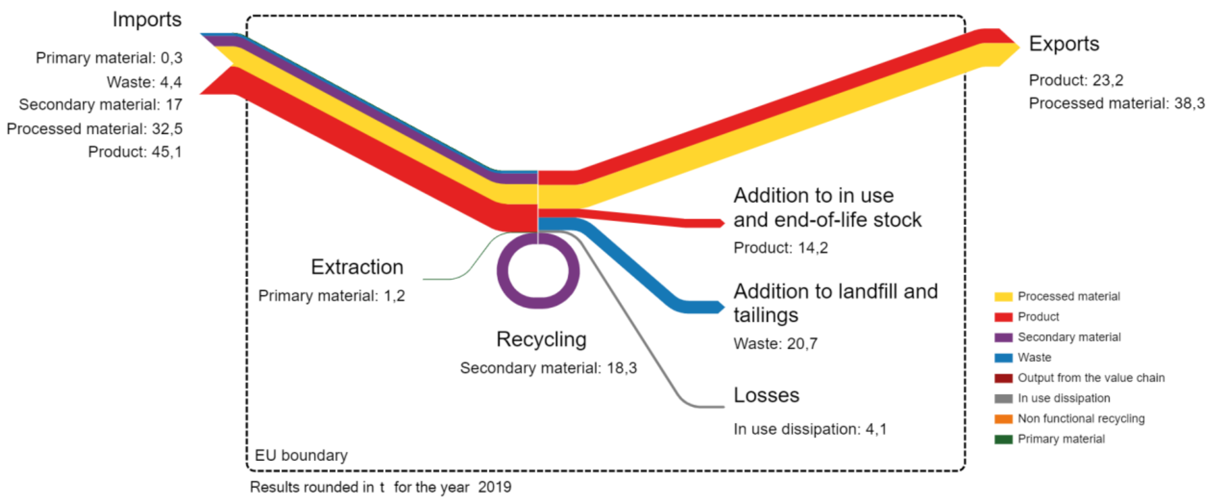


Figure 44: Simplified Sankey diagram for platinum for the year 2019 in the EU, in t, imports of products include also 24.2 t Pt of intermediate products, supplied to the manufacturing stage.

An estimated total of 40.0 t Pt of processed material were produced in the EU. About 0.8 t Pt is generated as processing waste, sent to disposal, and 38.3 t Pt processed material was exported outside the EU.

As input to the EU manufacturing stage, the processed material was supplemented with 28.3 t Pt of processed material imported, and 24.2 t Pt in intermediate products net-imported from outside the EU. The platinum sent to the manufacturing steps is distributed between several applications: autocatalysts (32.9 t Pt), jewellery (4.9 t Pt), catalysts in the chemical industry (3.1 t Pt), medical and biomedical products (1.6 t Pt), the petroleum industry (0.4 t Pt), the glass industry (0.3 t Pt), electronics (0.3 t Pt) and in various other applications (4.5 t Pt). Due to high internal recycling rates at the manufacturing stage, only 0.2 t Pt are considered unrecoverable and therefore as waste sent to disposal.

Figure 45 shows the distribution by end-use sector of platinum-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

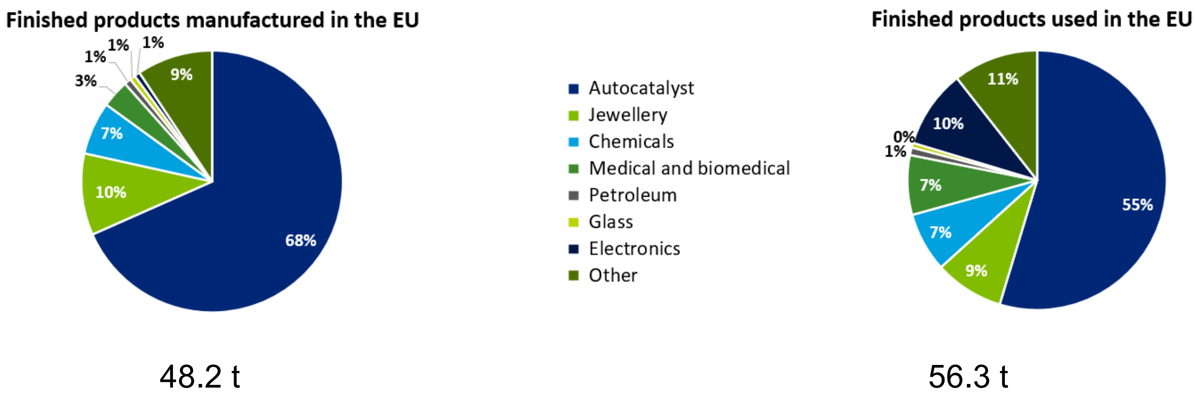


Figure 45: Shares of finished products containing platinum manufactured in the EU (left) and shares of finished products containing platinum used in the EU (right), by application

Table 29 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all platinum products.

Application	Representative product
Autocatalysts	Autocatalysts
Jewellery	Jewellery
Chemicals	Catalysts
Medical and biomedical	Pacemakers
Petroleum	Naphta reforming catalysts
Glass	Glass fibre extruding nozzles

Electronics	Hard drives
Other	Pollution control catalysts

Table 29: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 13.9 t Pt in 2019. The total stock of products in-use is quantified at about 1 341.8 t Pt in 2019.

About 4.1 t Pt were lost due to dissipation during use, mostly due to the use of platinum in the silicon industry, within the chemical applications. This leaves about 33.4 t Pt contained in products collected for waste treatment, and 10.4 t Pt were exported for reuse, mainly in cars exported. It was supplemented with about 4.4 t Pt of imports of end-of-life autocatalysts for recycling. Among products collected for waste treatment, 18.9 t Pt were sent to landfill rather than recycled and about 0.6 t Pt of recycling waste reduced the total amount of secondary platinum input to domestic processing and manufacturing at 18.3 t Pt in 2019.

4.15.3. Indicators

Table 30 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 50% in 2019, and the end-of-life recycling rate (EoL-RR) was 48%. The ratio of recycling from old scrap contributing to EU demand for platinum (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 27%. The differences between collection, EoL-RR and EoL-RIR were due to the fact that part of the collected products are landfilled rather than recycled, such as catalysts in the chemical and petroleum industry.

Regarding self-sufficiency, the EU relies largely on imports at extraction and processing stages and is nearly self-sufficient for manufacturing. In 2019, only 4% of the platinum refined in the EU was extracted locally, and 74% of the demand for platinum at the manufacturing stage was refined in the EU, the rest was imported (imports include also secondary materials). The amount of platinum consumed in the use phase (M3.1) is close to the amount manufactured in the EU (D1.1), with a self-sufficiency going from 87% to 99% depending on the year between 2016 and 2020. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the indicators tend to vary between 2016 to 2020, mainly due to price evolutions, which induced significant market evolution throughout the time period.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	21%	23%	22%	27%	23%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	52%	53%	46%	48%	53%
Collection rate	F1.4/(M4.1)	53%	55%	47%	50%	55%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	5%	6%	7%	4%	5%
Self-sufficiency Processing	C1.1/M2.1	66%	68%	78%	74%	100%
Self-sufficiency Manufacturing	D1.1/M3.1	99%	98%	86%	87%	93%

Table 30: Different indicators that describe platinum situation in the EU

4.15.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are Johnson Matthey publications, the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The platinum content is available from various expertise. Overall, basic extrapolation was applied to primary data to compute reliable estimates of platinum flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of platinum-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of platinum flows at use and end-of-life. Hypothesis used electronics are not considered entirely satisfying, with high numbers than presumed for disposal. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on platinum recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA differ from the results of the MSA conducted in 2015, mainly due to market evolution. There is an overall decrease in imports of primary material, of processed material, and of exports of processed material.

4.16. Platinum group metals (PGMs) - Rhodium

4.16.1. Value chain

Rhodium (Rh) is a rare metal that occurs in some nickel and copper ores, along with some native deposits. Rhodium-containing ores and concentrates are then sent to a smelter to produce mattes. Refining those mattes enable the production of pure rhodium metal, which is traded in powder form.

Rhodium, as other platinum group metals (PGMs), is used in a large range of manufactured products and industries for its unique properties. For instance, rhodium can act as a catalyst and is exploited in a wide range of applications, where only a small quantity of the metal can have a large impact on the production. The most significant application of rhodium as a catalyst is in automotive catalytic converters (hereafter named autocatalysts), where rhodium is used in very low quantities along with platinum and palladium to improve the overall performance and reduce emissions from gasoline and diesel engines. Other uses are:

electronics, where rhodium is used in some printed circuit boards and in hard drives,

the glass industry, in which platinum-rhodium alloys are used as refractory metals, with high thermal resistance.

Figure 46 below depicts the value chain of rhodium, its intermediates and end-uses covered by this study. All stages of the value chain except extraction take place within the EU.

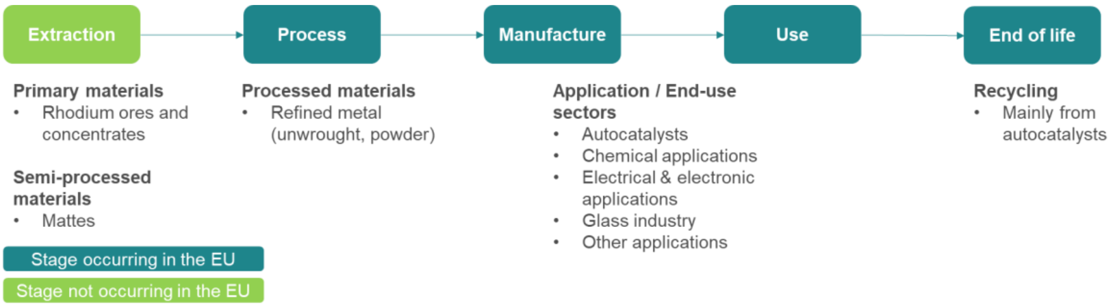


Figure 46: Value chain of rhodium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.16.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of rhodium (kg Rh) metallic equivalent and are representative of the year 2019.

Global rhodium reserves are estimated at about 583 000 kg Rh out of the 69 000 000 kg PGM total reserves worldwide, of which South Africa accounts for more than 90%. In the EU, no rhodium reserves are reported.

In 2019, the world production of rhodium reached 23 810 kg Rh and the top producer country was South Africa, accounting for more than 80% of extracted rhodium volumes. In the EU, no rhodium was extracted.

The domestic input to EU rhodium processing was supplied by imports of semi-processed material in the form of mattes (570 kg Rh) and imports of secondary material (2 270 kg Rh). Additionally, about 2 270 kg Rh were supplemented from post-consumer functional recycling in the EU.

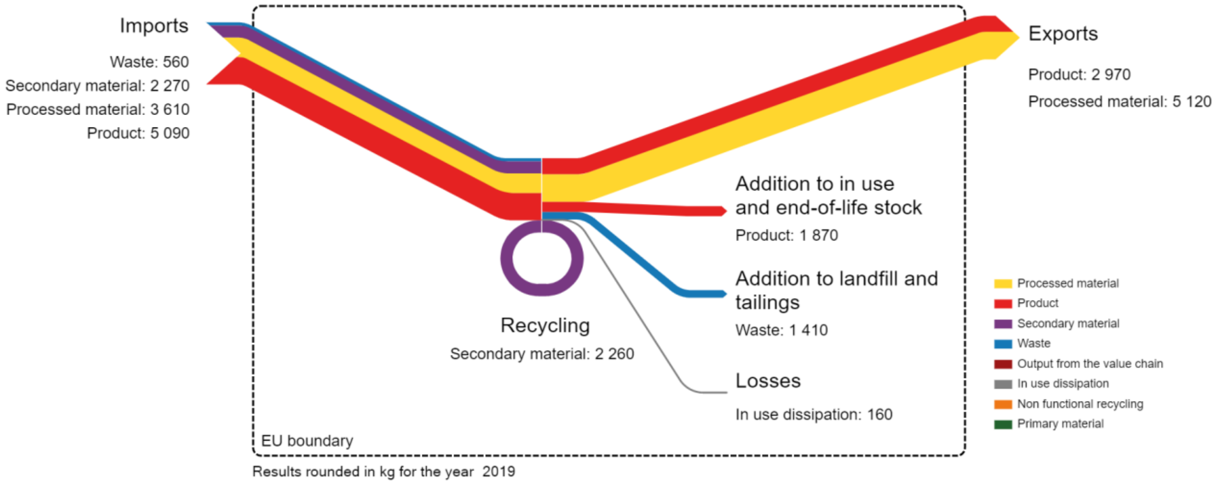


Figure 47: Simplified Sankey diagram for rhodium for the year 2019 in the EU, imports of products include also 3 150 kg Rh of intermediate products, supplied to the manufacturing stage.

An estimated total of5 000 kg Rh of processed material were produced in the EU. About 100 kg Rh is generated as processing waste, sent to disposal, and 5 130 kg processed material was exported outside the EU.

As input to the EU manufacturing stage, the processed material was supplemented with 3 040 kg Rh of processed material imported. The rhodium sent to the manufacturing steps is distributed between several applications: autocatalysts (5 610 kg Rh), the chemical industry (280 kg Rh), the glass industry (50 kg Rh), electronics (30 kg Rh) and in various other applications (90 kg Rh). Due to high internal recycling rates at the manufacturing stage, only 70 kg Rh are considered unrecoverable and therefore as waste sent to disposal.

Figure 48 shows the distribution by end-use sector of rhodium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

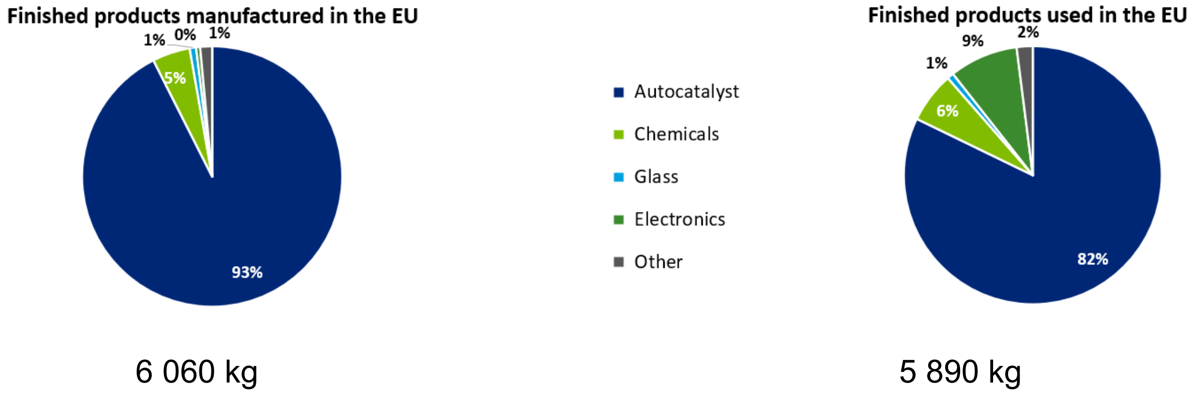


Figure 48: Shares of finished products containing rhodium manufactured in the EU (left) and shares of finished products containing rhodium used in the EU (right), by application

Table 31 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all rhodium products.

Application	Representative product
Autocatalysts	Autocatalysts
Chemicals	Catalysts
Glass	Glass fibre extruding nozzles
Electronics	Hard drives
Other	Pollution control catalysts

Table 31: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 1 850 kg Rh in 2019. The total stock of products in-use is quantified at about 76 330 kg Rh in 2019.

About 160 kg Rh were lost due to dissipation during use, mostly due to the use of rhodium in autocatalysts. This leaves about 3 000 kg Rh contained in products collected for waste treatment, and 860 kg Rh were exported for reuse, mainly in cars exported. It was supplemented with about 560 kg Rh of imports of end-of-life autocatalysts for recycling. Among products collected for waste treatment, 1 230 kg Rh were sent to landfill rather than recycled and about 70 kg Rh of recycling waste reduced the total amount of secondary rhodium input to domestic processing and 2 270 kg Rh in 2019.

4.16.3. Indicators

Table 32 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 66% in 2019, and the end-of-life recycling rate (EoL-RR) was 64%. The ratio of recycling from old scrap contributing to EU demand for rhodium (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 28%. The differences between collection, EoL-RR and EoL-RIR were due to the fact that part of the collected products are landfilled rather than recycled, such as catalysts in the chemical industry and some electronics.

Regarding self-sufficiency, the EU relies solely on imports at the extraction stage and is self-sufficient for processing and manufacturing. The amount of rhodium consumed in the manufacturing phase (M2.1) is lower than the amount processed in the EU (C1.1), for years 2016 and 2017 resulting in a self-sufficiency higher than 100%, and slightly higher since 2018. Also, the amount of rhodium consumed at the use stage (M3.1) is lower than the amount manufactured un the EU (D1.1), resulting in a self-sufficiency slightly above 100% for the manufacturing stage. These results demonstrate that the EU processing and manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed small variations may be observed between 2016 to 2020, mainly due to price evolutions throughout the time period.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	21%	24%	24%	28%	28%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	77%	82%	64%	64%	70%
Collection rate	F1.4/(M4.1)	79%	85%	66%	66%	72%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	113%	114%	93%	82%	94%
Self-sufficiency Manufacturing	D1.1/M3.1	121%	119%	105%	103%	110%

Table 32: Different indicators that describe rhodium situation in the EU

4.16.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are Johnson Matthey publications, the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The rhodium content is available from various expertise. Overall, basic extrapolation was applied to primary data to compute reliable estimates of rhodium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of rhodium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of rhodium flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on rhodium recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA differ from the results of the MSA conducted in 2015, mainly due to market evolution. There is an overall decrease in imports of primary material, of secondary material, and of exports of processed material.

4.17. Rare earth elements (REEs) – used in magnets

The magnetic rare earth elements studied in this chapter are samarium, dysprosium, neodymium, praseodymium, terbium and gadolinium, as they are used in magnets today.

4.17.1. Value chain

The Rare Earth Elements (REEs) are a group of 15 to 17 elements, depending on the inclusion of yttrium and scandium in the definition. The lanthanide group forms the major part of REEs. It comprises the 15 elements of the periodic table with atomic numbers 57 to 71: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). Yttrium (Y, atomic number 39) and scandium (Sc, atomic number 21) share physical and chemical properties with the lanthanides. However, yttrium is found in the same ore deposits and shares a great part of REEs value chain, so it is treated together with REEs. Scandium, which has quite specific geological and industrial properties, and promethium, which has no stable isotope in nature, are not considered in this study.

The REEs are typically split into two groups, the Light Rare Earth Elements (LREE) and Heavy Rare Earth Elements (HREE), both for physico-chemical and commercial reasons. Even if various definitions exist, the LREEs are most commonly defined as the lanthanide elements lanthanum through to samarium (La, Ce, Pr, Nd, Sm) and the HREEs defined as the lanthanide elements europium through to lutetium and yttrium (Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu & Y).

Rare Earth Elements are all silvery-white to grey metals, highly reactive with water and oxygen. Most of them form stable compounds in the 3+ and 4+ oxidation states, tarnish easily in air (mostly light REEs) and usually have a high electrical conductivity. The combined crustal abundance of REEs is of the order of 200 ppm. Four of them (cerium, lanthanum, neodymium and yttrium) are even more common than lead or cobalt in the upper continental crust. They are not found as pure metals in nature but form part of a great variety of minerals (more than 200 identified). The most common ones at a commercial level are bastnaesite, monazite, loparite, xenotime and lateritic ion-adsorption clays.

REEs are used for several different applications due to their specific physical and chemical properties; they have in part catalytic properties, special colours, react with impurities in smelting processes, can strengthen certain alloys and can serve as host material for phosphors.

For the MSA, the REEs are divided into three groups, the REEs used in magnets (mREEs, which are Nd, Pr, Tb, Dy, Sm, Gd), Ce and La as main mass flows and the non-magnetic REEs (Eu, Er, Y, Ho, Tm, Yb, Lu), due to their different applications and properties.

The mREEs can all serve as alloying materials for magnets, however, serving for different purposes. While Nd and Pr are mostly used for their great performance in NdFeB magnets, Tb and Dy are added to increase the temperature window for the magnet operation. Sm is used in SmCo-magnets. Some of the SmCo-magnets also include metals like Gd as an alloying component. The main advantage could be the high cost efficiency. Apart from magnets, the mREEs are mainly used for

- automotive catalysts (Nd, Pr),
- polishing powders (Pr),
- glass and ceramics (Nd, Pr, Sm),
- mischmetal for nickel metal hydride (NiMH) batteries (Nd, Pr) and
- other metallurgic applications (e.g., iron and steel production or aluminium alloys; Nd, Pr, Gd),
- lighting applications as phosphor hosts or LEDs (Tb, Dy),
- magnetic resonance imaging (MRI) as a contrast agent (Gd),
- laser dopants (Sm),
- radiography (Sm)
- and in the nuclear industry (Gd, Sm).

Figure 49 below depicts the value chain of magnetic REEs, its intermediates and end-uses covered by this study.

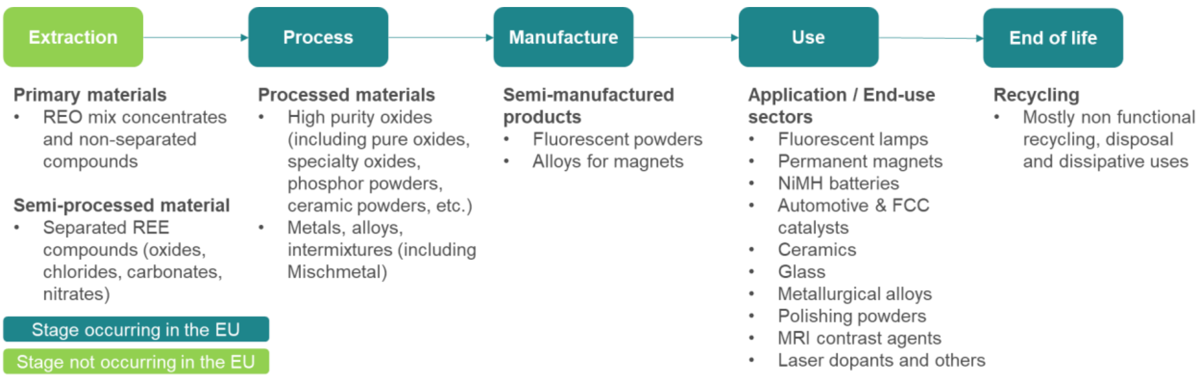


Figure 49: Value chain of REE, steps in dark green occur at least in part in the EU (processing of REE into metal or alloys does not take place in the EU), steps in light green occur only in non-EU countries

4.17.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (t mREE) equivalent and are representative of the year 2020.

Global reserves of mREEs were estimated at about 26 178 kt mREE. In the EU, mREE reserves of 84 kt are found mainly in Sweden, but also in Spain, Germany and Finland.

In 2020, the world production of magnetic rare earths reached 53 kt mREE with China being the biggest producer. There is no extraction of REE in the EU so far. All rare earths used by the EU industry are imported. It is estimated that rare earth oxide mix concentrates and non-separated compounds containing 23 t mREE were imported in 2020. Additionally, separated mREE compounds in the form of oxides or others were imported (91 t mREE). Processing took place in France and Estonia, where separated REE compounds and high purity oxides (114 t mREE) were produced. About 1 t mREE were generated as waste in the process, which was disposed. There was no metal or alloy production in the EU in the period under consideration.

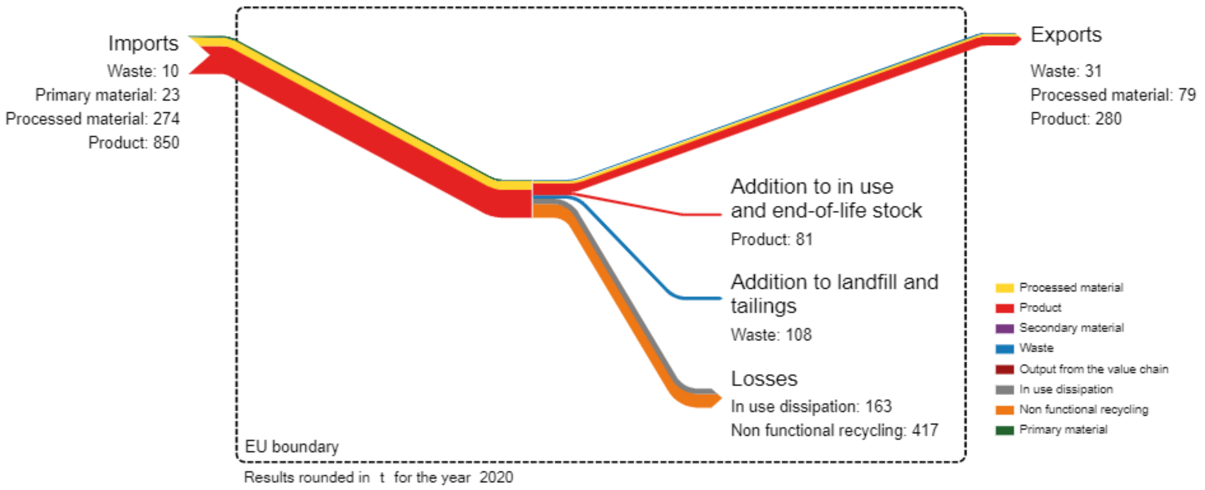


Figure 50: Simplified Sankey diagram for mREE for the year 2020 in the EU, in t.

A small amount of mREE supplied to the EU are imported as semi-processed materials (92 t mREE), but also processed material (i.e., metals, alloys, intermixtures or high purity oxides) are imported in the EU (182 t mREE). These were combined with the materials processed in the EU. The EU industry uses these materials to manufacture various finished products for magnets (293 t mREE), automotive catalysts (21 t mREE), glass and ceramics (65 t mREE), nickel metal hydride batteries (17 t mREE) and other metals and alloys (excl. batteries, 20 t mREE), phosphors (16 t mREE), contrast agent for MRI (9 t mREE) and other uses (laser dopants, radiography, nuclear industry, etc.; 37 t mREE). All manufacture waste was sent for disposal within the EU (28 kg mREE) or exported (20 t mREE). There is no recycling of mREE taking place in the EU.

Figure 51 shows the distribution by end-use sector of mREE-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

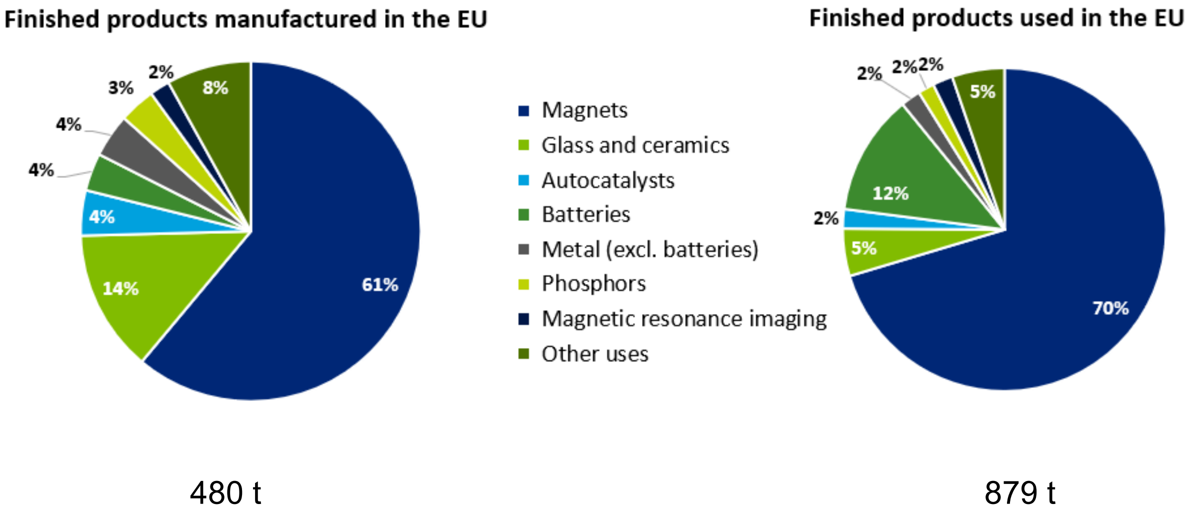


Figure 51: Shares of finished products containing mREE manufactured in the EU (left) and shares of finished products containing mREE used in the EU (right), by application

Table 33 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all mREE products.

Application	Representative product
Magnets	Magnets in cars Magnets in industrial robots
Glass and ceramics	Pigments in glass tableware Pigments in ceramic tiles
Autocatalysts	Cars
Batteries	NiMH batteries (in portable devices)
Metal (excl. batteries)	Iron and steel production Jet plane engines
Phosphors	Fluorescent lamps
Magnetic resonance imaging	Contrast agent for MRI

Other uses	Polishing powders Control rods in nuclear industry LEDs

Table 33: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 146 t mREE (net addition to the stock in 2020). The total stock of products in-use is quantified at about 10 271 t mREE in 2020.

About 163 t mREE were lost due to dissipation during use, mostly due to dissipation of pigments in glass and ceramics. About 533 t mREE contained in products at end-of-life were collected and sorted for recycling, while 505 t mREE in were directly sent to disposal. The mREEs contained in the waste were non-functionally recycled (417 t mREE) ending up in slags during recycling of scraps for other metals, which again was mostly used for construction of roadways, or diluted down, not valued for their functions. About 88 t mREEs were disposed after being treated in a recycling process. There is no post-consumer functional recycling of mREE in the EU. Products at end-of-life valued for their mREE content are exported (111 t mREE), especially to China.

4.17.3. Indicators

Table 34 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 95% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. The ratio of recycling from old scrap contributing to EU demand for mREE (i.e., end-of-life recycling input rate, EoL-RIR) was also considered to be 0%. The differences between collection on the one hand and EoL-RR and EoL-RIR on the other hand were due to no recycling for mREE content in any application in the EU but exported (for example to China to be recycled there) or treated in the EU with mREE going into slag.

Regarding self-sufficiency, the EU relies on imports of extracted material to be processed. There was no processing of Sm, Tb or Dy for further use in the considered period. mREE metals are only imported as processed material to be further manufactured in the EU. The same goes for manufacturing, where the EU is importing about half of the used products containing mREE. No mREE were extracted, but 24% were refined in the EU. These results demonstrate that the EU refinement capabilities are not sufficient to cover the demand for specific sectors.

However, one has to differentiate between mREE oxides and mREE metal or alloys, as the latter is not refined in the EU.

For the five years analysed, the values stay relatively similar. The only exceptions are the values for self-sufficiency for processing and manufacturing. The reason mainly lies in the changing market for rare earths, especially due to a strong decline in the market share of NiMH batteries and fluorescent lamps compared to other technologies.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D 1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	90%	92%	93%	91%	95%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	18%	22%	24%	35%	24%
Self-sufficiency Manufacturing	D1.1/M3.1	69%	74%	69%	61%	53%

Table 34: Different indicators that describe the mREE situation in the EU

4.17.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), USGS, Eurostat PRODCOM and COMEXT databases, the ASTER project, the MiMa report, Roskill, and other elements from the literature, especially for all relevant applications. Eurostat database is not only used for all the trade flows of the relevant materials, but also for various products for which the corresponding code is available (mostly for steps processing and products in manufacture). The REE content is available from the MiMa report, Eurostat CN10 numbers (confidential) and the ASTER project, as no newer sources were available. Overall, basic extrapolation was applied to primary data to compute reliable estimates of REE flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of REE-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of REE flows at use and end-of-life. The feedback from the validation workshops helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on different uses and recycling mainly originates from expertise gathered during personal communications with stakeholders.

Compared to the previous MSA, the more detailed information for each of the REE has been collected. Some general assumptions, e.g., the REE content in certain flows, are similar as no newer data was available, however, updated information was available for the share of the different applications and this has been completely updated. The market has grown since 2015, but according to experts, there is still no recycling taking place in the EU.

4.18. Rare earth elements (REEs) – lanthanum and cerium

The magnetic rare earth elements studied in this chapter are lanthanum and cerium.

4.18.1. Value chain

REEs are used for several different applications due to their specific physical and chemical properties; they have in part catalytic properties, special colours, react with impurities in smelting processes, can strengthen certain alloys and can serve as host material for phosphors.

Cerium and Lanthanum are the most abundant REEs, and also the most used in the European industry (and abroad). Those two REEs are used in various kinds of applications, with the most important being autocatalysts in cars, metals and batteries, and also fluidized catalytic cracking (FCC). The list of the uses of cerium and lanthanum is below:

FCC for oil refinery

Autocatalysts for cars

Glass and ceramics

Metals & Batteries

Polishing powders

Lighting

Figure 52 below depicts the value chain of lanthanum and cerium, their intermediates and end-uses covered by this study.

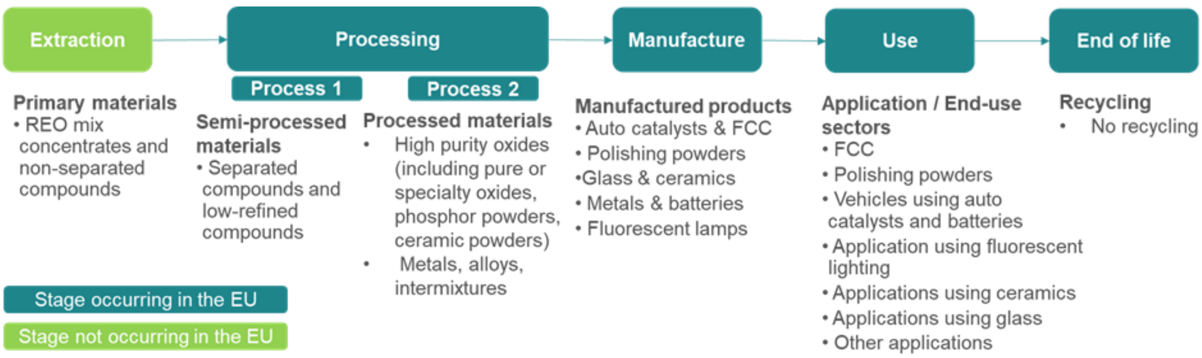


Figure 52: Value chain of cerium and lanthanum, steps in dark green occur at least in part in the EU, steps in light green occur only in non-EU countries

4.18.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (t Ce&La) equivalent and are representative of the year 2020.

Global reserves of Ce & La are estimated at about 63.2 Mt. The EU reserves of lanthanum and cerium of 115 kt are found mainly in Sweden, but also in Spain, Germany and Finland.

In 2020, the world production of Ce & La reached 130.8 kt, with China being the biggest player. There is no extraction of REE in the EU27 so far.

All rare earths used by the EU industry are imported. It is estimated that rare earth oxide mix of concentrates and non-separated compounds containing 1.54 kt La&Ce were imported in 2020. Additionally, separated REE compounds in the form of oxides or others were imported (containing 3.4 kt La&Ce). Processing took place in France and Estonia, where separated REE compounds and high purity oxides (4.95 kt La&Ce) were produced.

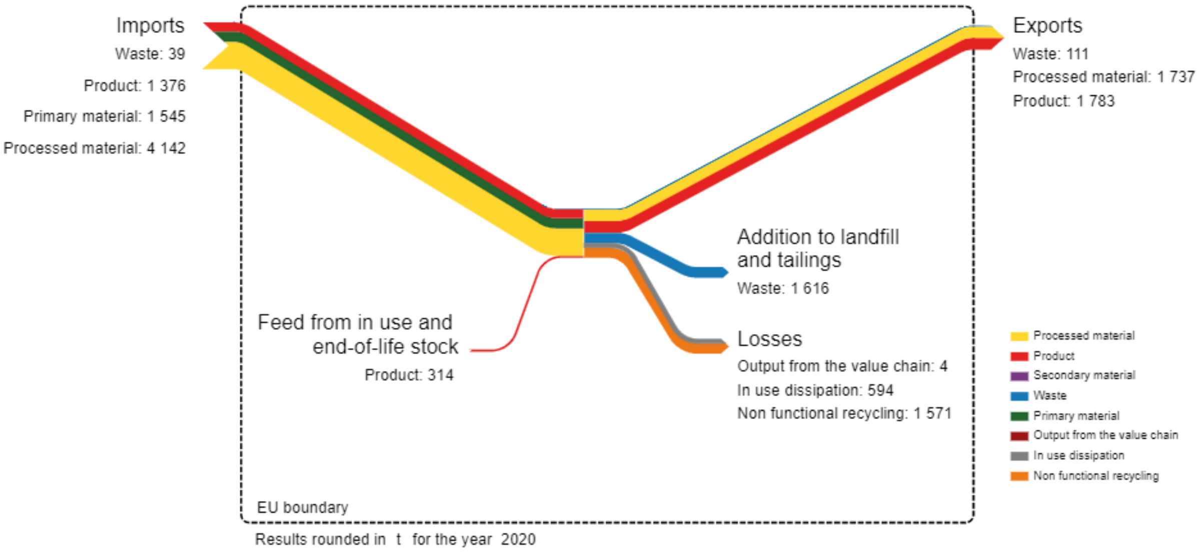


Figure 53: Simplified Sankey diagram for lanthanum & cerium for the year 2020 in the EU, in t.

Most of lanthanum & cerium supplied to the EU are imported as semi-processed materials, but also processed material (i.e., metals, alloys, intermixtures or high purity oxides) are imported in the EU (798 t La&Ce). These were combined with the materials processed in the EU. The EU industry uses these materials to manufacture various finished products for automotive catalysts (1.62 kt La&Ce), Fluid Cracking Catalysts (697 t La&Ce), metals and batteries (703 t La&Ce), polishing powders (514 t La&Ce), fluorescent lamps & LEDs (67 t La&Ce), and glass and ceramics (402 t La&Ce). Most of the scrap generated from product manufacturing was internally recycled. The rest was considered to be sent to landfill (0.2 t La&Ce) or used in another value chain (03.8 t La&Ce). There is no recycling of lanthanum and cerium taking place in the EU.

Figure 54 shows the distribution by end-use sector of La&Ce-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

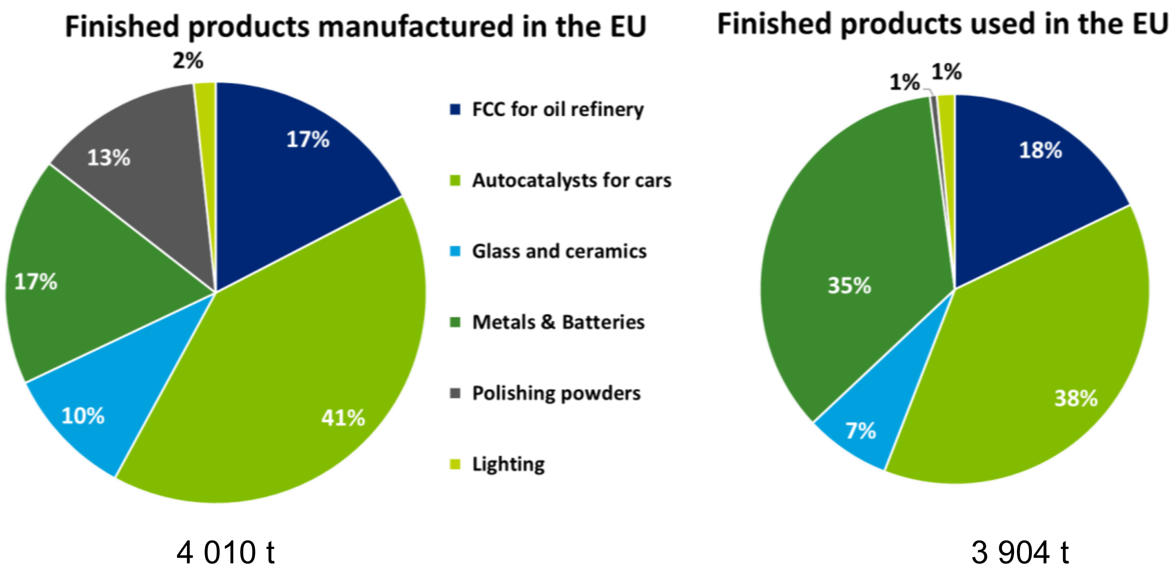


Figure 54: Shares of finished products containing lanthanum & cerium manufactured in the EU (left) and shares of finished products containing lanthanum & cerium used in the EU (right), by application

Table 35 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of lanthanum and cerium products.

Application	Representative product
Autocatalysts for cars	Cars
Glass and ceramics	Coloured glass Pigmented tableware
Metals & Batteries	Portable NiMH Batteries Iron and steel production
Lighting	Fluorescent lamps
FCC for oil refinery	FCC

Polishing powders	Polishing powders

Table 35 : List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about -113 t La&Ce (net subtraction from? the stock in 2020). The total stock of products in-use is quantified at about 39.6 kt La&Ce in 2020.

About 594 t La&Ce were lost due to dissipation during use. About 2.2 kt La&Ce contained in products at end-of-life were collected and sorted for recycling, while 1.62 kt La&Ce in waste products were sent to disposal. Some lanthanum and cerium contained in the waste are non-functionally recycled (1.57 kt La&Ce) ending up in slags during recycling of scraps for other metals, which again is mostly used for construction of roadways, or diluted down, not valued for their functions. There is no post-consumer functional recycling of cerium and lanthanum in the EU.

4.18.3. Indicators

Table 36 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 67% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. The ratio of recycling from old scrap contributing to EU demand for oREE (i.e., end-of-life recycling input rate, EoL-RIR) was also considered to be 0%.

Regarding self-sufficiency, the EU entirely relies on imports of extracted material to be processed. However, it is quite self-sufficient considering the processing and manufacturing step. These results demonstrate that the EU manufacturing capabilities are mostly sufficient to cover the demand for all the main application sectors of lanthanum and cerium.

For the five years analysed the values stay relatively similar.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	66%	66%	66%	67%	67%

Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	89%	129%	117%	164%	123%
Self-sufficiency Manufacturing	D1.1/M3.1	96%	96%	95%	102%	98%

Table 36: Different indicators that describe lanthanum & cerium situation in the EU

4.18.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), USGS, Eurostat PRODCOM and COMEXT databases, the ASTER project, the MiMa report, Roskill and other elements from the literature, especially for all relevant applications. Eurostat database is not only used for all the trade flows of the materials, but also used for various products for which the corresponding code is available (mostly for steps processing and products in manufacture). The REE content is available from the MiMa report, Eurostat CN10 numbers (confidential) and the ASTER project, as no newer sources were available. Overall, basic extrapolation was applied to primary data to compute reliable estimates of REE flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of REE-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of REE flows at use and end-of-life. The feedback from validation workshop helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on different uses and recycling mainly originates from expertise gathered during personal communications with stakeholders.

Compared to the previous MSA, the more detailed information for each of the REE has been collected. Some general assumptions, e.g., the REE content in certain flows, are similar as no newer data was available, however, updated information was available for the share of the different applications and this has been completely updated. The market has grown since 2015, but according to experts, there is still no recycling taking place in the EU.

4.19. Rare earth elements (REEs) – other elements

The rare earth elements studied in this chapter are yttrium, erbium, europium, lutetium, holmium, ytterbium and thulium.

4.19.1. Value chain

REEs are used for several different applications due to their specific physical and chemical properties; they have in part catalytic properties, special colours, react with impurities in smelting processes, can strengthen certain alloys and can serve as host material for phosphors.

The other REEs are the following ones: yttrium, erbium, europium, lutetium, holmium, ytterbium and thulium. Yttrium is the most abundant one, followed by erbium. Those REEs are used in various kinds of applications, with the most important being lighting and oxygen sensors in cars. The list of the uses of other REEs is below:

- Lighting, mainly fluorescent lamps & LEDs (Y, Eu, Yb, Lu, Ho)
- Ceramics-based oxygen sensors for cars (Y),
- Glass and ceramics (Y, Er, Yb, Ho),
- Optical fibres and medical lasers & imaging (Er, Y, Eu, Tm, Lu)
- Automotive catalysts (Y),
- Metals & batteries (Y, Er, Ho).

Figure 55 below depicts the value chain of other REEs, their intermediates and end-uses covered by this study.

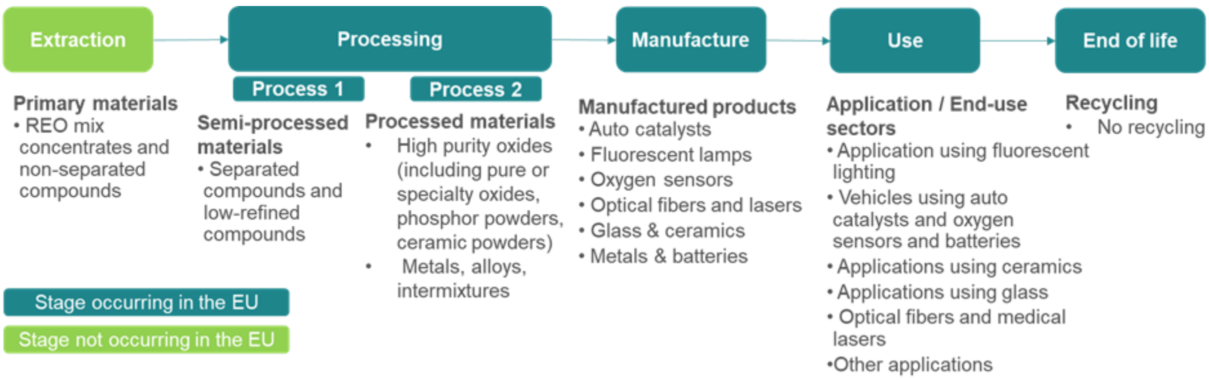


Figure 55: Value chain of other REEs, steps in dark green occur at least in part in the EU, steps in light green occur only in non-EU countries

4.19.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (t oREE) equivalent and are representative of the year 2020.

Global reserves of other REEs are estimated at about 6.86 Mt oREE. In the EU27, other rare earth reserves of 114 kt are found mainly in Sweden, but also in Spain, Germany and Finland.

In 2020, the world production of other rare earths reached 8.25 kt oREE with China being the biggest producer. There is no extraction of REE in the EU27 so far.

All rare earths used by the EU industry are imported. It is estimated that rare earth oxide mix of concentrates and non-separated compounds containing 2.1 t oREE were imported in 2020. Additionally, few separated REE compounds in the form of oxides or others were imported (0.5 t oREE). Processing took place in France and Estonia, where separated REE compounds and high purity oxides (28.8 t oREE) were produced (mainly yttrium and a little lutetium). About 14.8 t oREE are generated as waste in the process (especially due to the disposal of REE that are not separated in the EU and of which the concentrates are disposed, such as erbium, europium, holmium, thulium, and ytterbium).

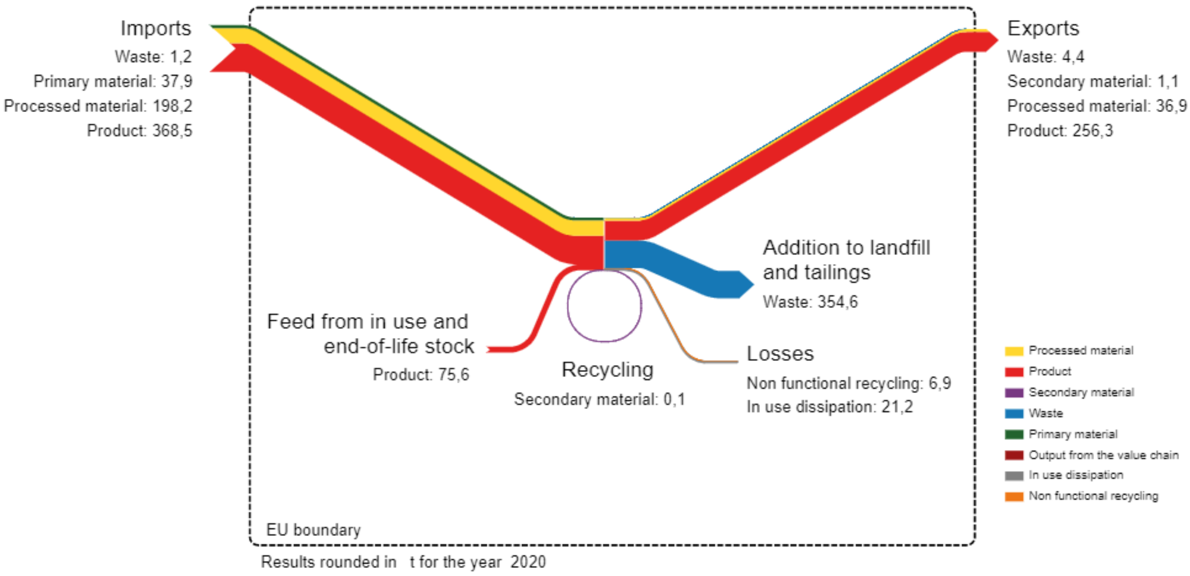


Figure 56: Simplified Sankey diagram for other REEs for the year 2020 in the EU, in t.

Most of other REEs supplied to the EU are imported as semi-processed materials, but also processed material (i.e., metals, alloys, intermixtures or high purity oxides) are imported in the EU (432 t oREE). These were combined with the materials processed in the EU. The EU industry uses these materials to manufacture various finished products for fluorescent lamps & LEDs (249 t oREE), oxygen sensors (74 t oREE), glass and ceramics (35 t oREE), optical fibres (29 t oREE), medical laser & imaging (24 t oREE), automotive catalysts (10 t oREE), and metals and batteries (11 t oREE). Most of the scrap generated from product manufacturing was internally recycled. The rest was considered to be sent to landfill (4 t oREE) or used in another value chain (0.5 t oREE). There is no recycling of other REEs taking place in the EU.

Figure 57 shows the distribution by end-use sector of other-REEs-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

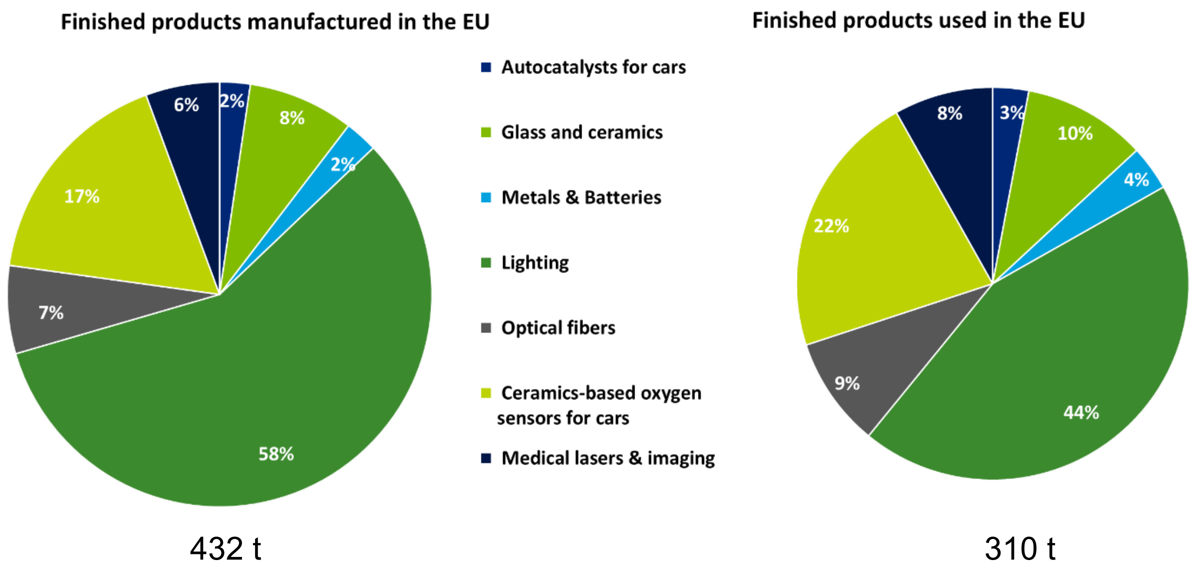


Figure 57: Shares of finished products containing other REEs manufactured in the EU (left) and shares of finished products containing other REEs used in the EU (right), by application

Table 37 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all other REEs products.

Application	Representative product
Autocatalysts for cars	Cars
Glass and ceramics	Coloured glass Cameras Tiles
Metals & Batteries	Aluminium alloys, bars, rods and profiles for aerospace and military applications Control rods in nuclear industry

Lighting	Fluorescent lamps OLED
Optical fibers	Optical fibers
Ceramics-based oxygen sensors for cars	Cars
Medical lasers & imaging	YAG laser for dentistry and dermatology or surgery X-ray devices for radiography PET detectors

Table 37 : List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about -68 t oREE (net subtraction from the stock in 2020). The total stock of products in-use is quantified at about 2.5 kt oREE in 2020.

About 21 t oREE were lost due to dissipation during use. About 218 t oREE contained in products at end-of-life were collected and sorted for recycling, while 336 t oREE in waste products were directly sent to disposal. The other REEs contained in the waste are non-functionally recycled (6.9 t oREE) ending up in slags during recycling of scraps for other metals, which again is mostly used for construction of roadways, or diluted down, not valued for their functions. There is no post-consumer functional recycling of other REEs in the EU.

4.19.3. Indicators

Table 38 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 63% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. The ratio of recycling from old scrap contributing to EU demand for oREE (i.e., end-of-life recycling input rate, EoL-RIR) was also considered to be 0%.

Regarding self-sufficiency, the EU entirely relies on imports of extracted material to be processed, as well as for processed materials to be transformed into end products. However, it is quite self-sufficient considering the manufacturing step. These results demonstrate that the EU manufacturing capabilities are mostly sufficient to cover the demand for all the main application sectors of other REEs.

For the five years analysed the values stay relatively similar, except for the self-sufficiency at the manufacturing stage (the drop is due to the strong decrease of luminophore/fluorescent lamp market in the EU between 2016 and 2020, that impacted the quantities of products using Yttrium and Europium produced in the EU)

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	63%	64%	63%	63%	63%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	2%	4%	5%	5%	7%
Self-sufficiency Manufacturing	D1.1/M3.1	306%	194%	202%	169%	135%

Table 38: Different indicators that describe other REEs situation in the EU

4.19.4. Data sources, assumptions, and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), USGS, Eurostat PRODCOM and COMEXT databases, the ASTER project, the MiMa report, Roskill and other elements from the literature, especially for all relevant applications. Eurostat database is not only used for all the trade flows of the materials, but also used for various products for which the corresponding code is available (mostly for steps processing and products in manufacture). The REE content is available from the MiMa report, Eurostat CN10 numbers (confidential) and the ASTER project, as no newer sources were available. Overall, basic extrapolation was applied to primary data to compute reliable estimates of REE flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of REE-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of REE flows at use and end-of-life. The feedback from the validation workshops helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on different uses and recycling mainly originates from expertise gathered during personal communications with stakeholders.

Compared to the previous MSA, the more detailed information for each of the REE has been collected. Some general assumptions, e.g., the REE content in certain flows, are similar as no newer data was available, however, updated information was available for the share of the different applications and this has been completely updated. The market has grown since 2015, but according to experts, there is still no recycling taking place in the EU.

4.20. Silicon metal

4.20.1. Value chain

The MSA focuses on silicon metal only, i.e. excluding silica or ferrosilicon and their applications.

Silicon is the most abundant element in the earth's crust after oxygen, and is found under the form of silica (SiO_2) notably in silica sands, quartz and quartzite. Silicon metal is processed from ores containing high purities of silica: mostly quartz, in various forms (vein quartz, quartz pebbles); and to a lesser extent, quartzite. Silica sands are not used for the Si industry because silica sands are not suitable for the furnaces.

Silicon metal is processed into metallurgical grade (MG) silicon with a purity of 99% and a part of the metallurgical grade silicon (MG) is processed into polysilicon, with a Si content higher than 99.99%.

Silicon metal is used in a large variety of manufacturing applications. It may be used as very high purity Si (for electronic and solar applications), high purity Si (in alloys), or in chemical forms such as silicones and silanes (with a large panel of forms: sealants, foam control agents, airbags…).

MG silicon is mainly processed into silanes and silicones used in a large variety of chemical applications, mostly to increase thermal stability and chemical inertia: as sealants in construction, as insulated cables in the electronical sector, in shampoos in the healthcare sector, in the transportation sector in airbags, in paints and coatings and in the industrial sector as foam control agents. MG silicon is also used in aluminium alloys to improve its castability and reduce the coefficient of thermal expansion, in the automotive industry and in the construction industry (e.g. as window frames). Polysilicon is used in two main applications: as wafers in Si photovoltaic panels and as semi-conductor wafers in electronic devices.

Figure 1 below depicts the value chain of silicon metal, its intermediates and end-uses covered in this study. All stages of the value chain take place within the EU.

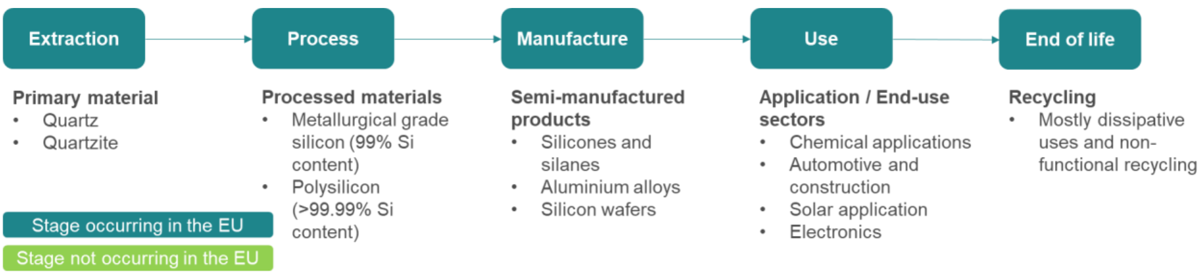


Figure 58: Value chain of silicon metal, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.20.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of silicon metal (t Si) metallic equivalent and are representative of the year 2020.

There is no data on global silicon reserves in high purity silica deposits. However, it is acknowledged that reserves are large enough to meet the worldwide consumption needs for the next decades. As for the global reserves, there is no data on the EU reserves of silicon metal.

In 2020, the world production of silicon metal reached 4 063 kt Si. The EU processed about 246 kt Si in 2020. It was estimated that about 326 kt Si are coming from quartz extraction in the EU (and potentially quartzite), the rest (47 kt Si) being imported in the EU as quartz to supply the processing industry. Among the EU countries importing quartz, Spain represents about 85% of the total volumes of quartz imported. Around 40% of the EU extracted quartz is sold on the EU market. To note that as Norway has a big ferro-silicon industry, only 55% of exports of quartz to Norway are considered used for the Si industry (thus not considered in the MSA).

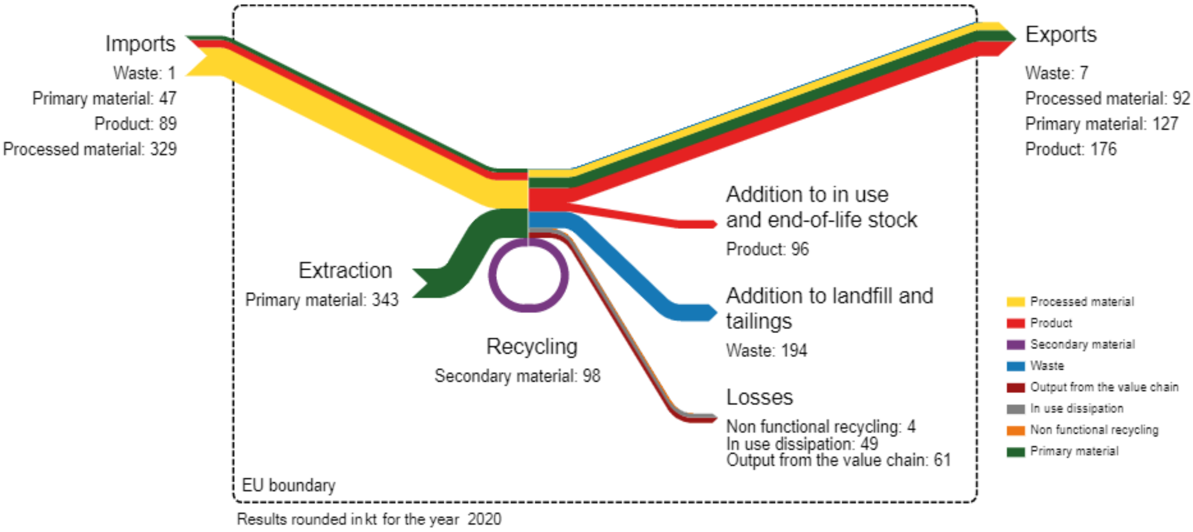


Figure 59: Simplified Sankey diagram for silicon metal for the year 2020 in the EU, in kt.

A total of 169 kt Si of processed material were produced in the EU: 129 kt Si in metallurgical grade silicon, and 40 kt Si in polysilicon. About 22 kt Si is generated as processing waste, sent to disposal. Also, during the processing of quartz into silicon metal in the electric arc furnaces, 58 kt Si, called silica fumes and slags, are generated. These are mainly used in construction industry and are considered as being an output from the value chain as this specific use of Si is not included in the perimeter of the MSA for silicon metal.

Further input to the EU manufacturing stage was:

237 kt Si of processed material net-imported (imports were 329 kt Si of processed material while the exports were 92 kt Si),

There are no imports to the EU of products requiring further manufacturing steps in the EU considered,

About 13 kt Si from post-consumer functional recycling in the EU.

The EU industry manufactures various semi-finished products (such as silanes and silicones, alloys, wafers, chips, etc.) which are then incorporated into finished products in the EU: chemicals applications (253 kt Si) (sealants sector (106 kt Si), electrical and electronics (15 kt Si), foam agent controls industry (48 kt Si), healthcare sector (30 kt Si), automotive as in airbags (15 kt Si), coatings and paints (38 kt Si)), aluminium alloys industry (72 kt Si for construction and 114 kt Si for aluminium alloys used in automotive industry), solar applications (28 kt Si), and electronics (5 kt Si). Considering chemical applications, when silanes are produced, fumed silica are co-produced. Fumed silica is considered in this study as an output from the value chain because they are sent to various industries which do not require Si metal. The rest of the manufacturing waste, for all the applications covered, is considered as sent to landfill (19 kt Si).

Figure 3 shows the distribution by end-use sector of silicon metal-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

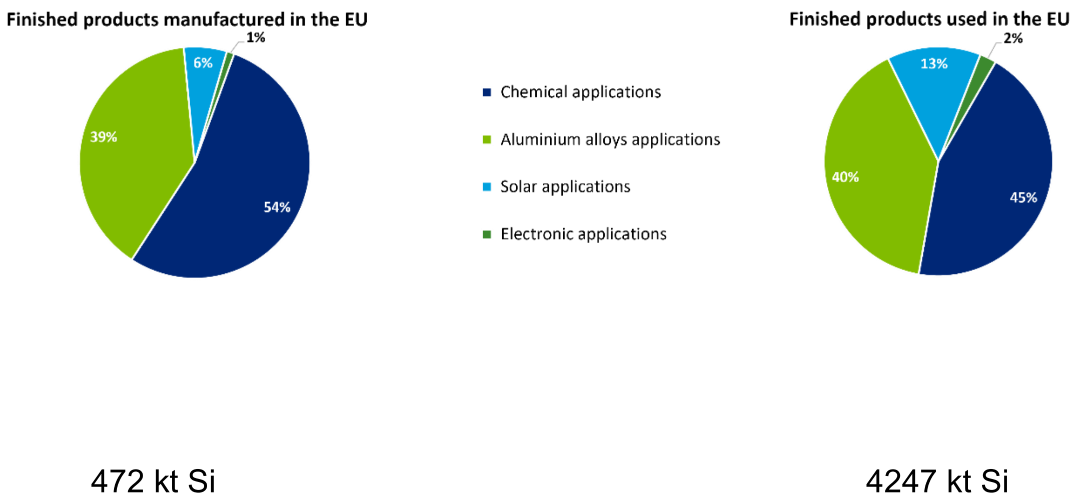


Figure 60: Shares of finished products containing silicon metal manufactured in the EU (left) and shares of finished products containing silicon metal used in the EU (right), by application

Table 1 lists for each of the applications the corresponding representative product chosen, which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all silicon metal products.

Application	Representative product
Chemical applications	Silicones and silanes used in: - Sealants - Insulated cables - Chemicals as a foam agent control - Airbags in cars - Shampoos - Paints and varnishes
Aluminium alloys	For the construction industry: in window frames For the automotive industry: in cars
Solar application	PV panels
Electronic applications	Semi-conductors in electronic devices as laptop & PCs

Table 39: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 97 kt Si in 2020. The total stock of products in-use is quantified at about 7 106 kt Si in 2020.

About 49 kt Si were dissipated during the use of the products, mostly due to the use of silicones in healthcare sector (e.g. shampoos) and as foam control agent. A total of 2039 kt Si in products at end of life were collected for treatment, among which slightly less than half is sent to landfill (101 kt Si) from mostly chemical applications (construction, electronics and foam control agent industry) but also from solar and electronic applications. The remaining part was contained in aluminium alloys at end of life sent for recycling. For this application, the silicon metal is not recovered during the recycling process: a tiny part of aluminium alloys, about 35 kt Si, is sent to disposal and the rest (98%) is valued as such, i.e. used as aluminium alloys containing already silicon metal: 93kt Si in motor vehicles and window frames goes is considered to be functional recycling.

4.20.3. Indicators

Table 1 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 55% in 2020, and the end-of-life recycling rate (EoL-RR) was 40% due to the high recycling rate of aluminium alloys. Therefore, the ratio of recycling from old scrap contributing to EU demand for silicon metal (i.e., end-of-life recycling input rate, EoL-RIR) is also higher than for other material (14% in 2020). The differences between collection and EoL rates were due to the fact that part of the collected products are landfilled rather than recycled, such as silicones in construction, in electronics, as chemicals in foam control agent industry, and solar and electronic applications.

Regarding self-sufficiency, the EU relies on imports at processing stage and is self-sufficient for extraction and manufacturing stages, exporting more that the amount imported. In 2020, 133% of silicon metal was extracted and 42% was refined in the EU, the rest was imported (imports include also secondary materials). The amount of silicon metal consumed in the use phase (M3.1) is lower than what is manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the main changes are related to EU extraction and processing.

Table 1: Different indicators that describe silicon metal situation in the EU

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	14%	14%	15%	15%	14%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	39%	40%	40%	41%	40%
Collection rate	F1.4/(M4.1)	55%	55%	56%	56%	55%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	117%	113%	116%	121%	133%
Self-sufficiency Processing	C1.1/M2.1	51%	52%	46%	46%	42%
Self-sufficiency Manufacturing	D1.1/M3.1	111%	111%	111%	110%	111%

4.20.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the Eurostat PRODCOM and COMEXT databases, BRGM publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The silicon metal content is available from various expertise and references (Eurostat and SCRREEN). Overall, basic extrapolation was applied to primary data to compute reliable estimates of silicon metal flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made on distribution between silicon metal industry and ferro-silicon industry and evaluating the characteristics of silicon metal-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of silicon metal flows at use and end-of-life. The feedback from the validation workshops helped in confirming and improving the estimations made, which adds more robustness to the results.

Data provided in the MSA on silicon metal recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA are comparable with results of the MSA conducted in 2015. In the 2023 MSA, small changes of methodology can be observed: two representative products have been changed for chemical applications.

4.21. Strontium

4.21.1. Value chain

The industrial production of strontium starts with the treatment of concentrates of the minerals celestine, composed of strontium sulphate ($SrSO_4$) or strontianite, composed of strontium carbonate ($SrCO_3$). The later occurs much less frequently; in the EU strontium is solely gained from celestine from deposits in Spain (Granada).

Primary strontium is processed to strontium carbonate; from there further downstream strontium compounds are produced, mostly strontium nitrate. Other strontium compounds are less significantly used and only for niche applications. Strontium metal from strontium carbonate is not produced in the EU but in China.

The main applications for strontium in the EU are in ferrite magnets, in ceramics, in zinc refining and for different chemical uses (such as in pyrotechnics and in paint pigments). Permanent magnets made of strontium ferrite - which are produced with strontium carbonate - offer a high degree of chemical stability, resistance to corrosion and are non-toxic. Typical uses of strontium ferrite magnets are in the automobile industry and electronic applications, e.g. in small direct current motors, in automobile windshield wipers, loudspeakers, etc. In addition, strontium has a range of other metallurgical uses. In zinc refining, strontium is added to the electrolysis to remove lead impurities. In chemicals, Strontium nitrate provides the red colour in pyrotechnics. Strontium nitrate is also used in the manufacture of glass substrates for display glass (LCD). In paint pigments, strontium allows for luminescence requirements and anti-corrosive coatings, respectively.

Figure 61 below depicts the value chain of strontium, its intermediates and end-uses covered by this study.

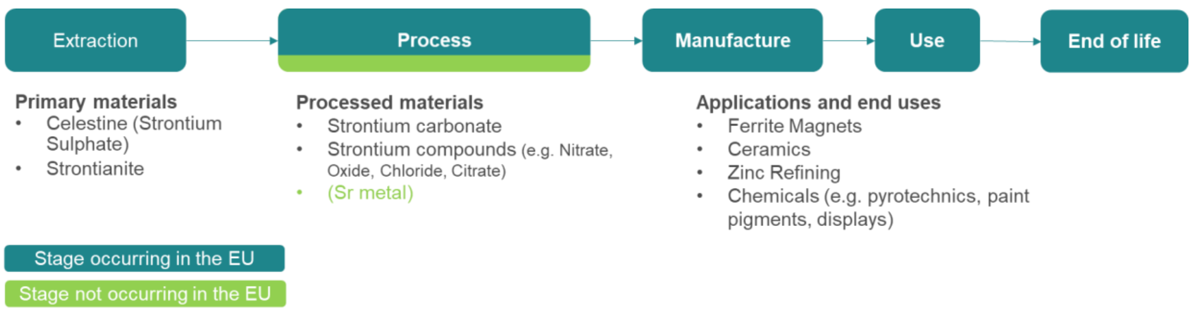


Figure 61: Value chain of strontium, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.21.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (kt Sr) equivalent and are representative of the year 2020 if not otherwise mentioned.

Global strontium reserves are estimated at about 47 000 kt Sr, with considerable reserves in Mexico and China. In Europe, reserves are located in Spain reaching approximately 3 400 kt Sr.

The global production of Celestine in 2019 was around 200 kt Sr (~410 kt SrO4). The major producer of strontium mineral is Spain (120 kt Sr), followed by Iran, China, Mexico and Argentina. Spain is the only producer of strontium in the EU.

In 2020, almost all strontium extracted is sold on the EU market, though 8 kt Sr are exported to China. 82 kt Sr are sent for processing in the EU. Only a minor amount of strontium mineral is imported to the EU (approximately 0.8 kt Sr). Thus, around 83 kt Sr are sent to processing in the EU.

Celestine (Strontium sulphate) is processed to strontium carbonate (90%), and from there further strontium compounds are produced; mostly strontium nitrate (9%) and other compounds such as oxide, citrate or chloride for niche applications

Strontium carbonate is the main strontium compound being traded; around 1.8 kt Sr are exported and 0.2 kt Sr imported to the EU according to Eurostat trade statistics. Around 2.2 kt of Sr nitrate are imported and very minor volumes of Sr metal (0.1 kt Sr). There are no exports of strontium metal as it is only produced outside of EU27.

There are no flows of secondary strontium in the EU.

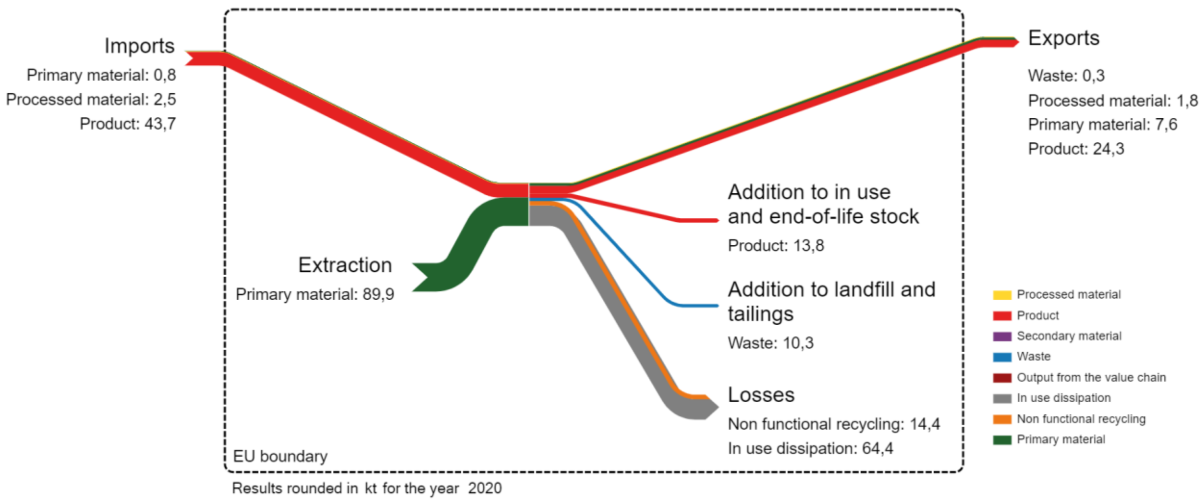


Figure 62: Simplified Sankey diagram for strontium for the year 2020 in the EU, in kt.

A total of 83 t Sr of processed material were produced in the EU: 90% strontium carbonate, 9% strontium nitrate and 1% oxides. Negligible waste occurs during processing.

As input to the EU manufacturing stage, the strontium was supplemented with: 0.7 kt Sr of processed material net-imported (imports accounted 2.5 kt Sr of processed material while the exports were 1.8 kt Sr).

No flows of post-consumer functional recycling occur in the EU (or globally).

The EU industry manufactures various semi-finished products (such as oxides, metal, etc.) which are then incorporated into finished products in the EU: ferrite magnets (23 kt°Sr), ceramics (20 kt°Sr), chemicals (28 kt°Sr), and zinc refining (13 kt°Sr). Manufacturing wastes are negligible.

Figure 63 shows the distribution by end-use sector of strontium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU

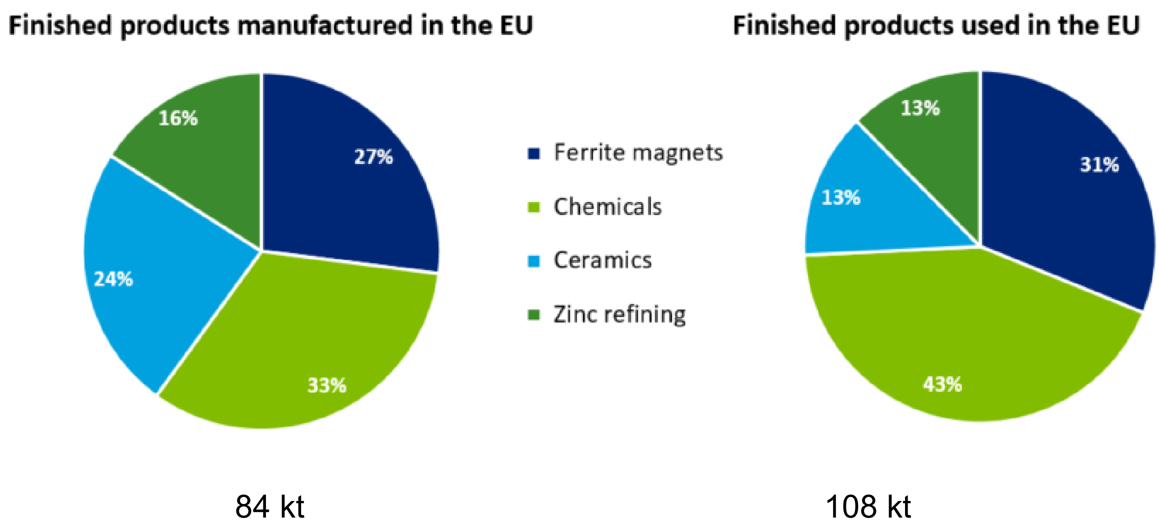


Figure 63: Shares of finished products containing 84 kt Sr manufactured in the EU (left) and shares of finished products containing 108 kt Sr used in the EU (right), by application

For each of the applications, Table 40 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all strontium products.

Application	Representative product

Ferrite magnets	Permanent magnets and articles intended to become permanent magnets
Chemicals	Vitrifiable enamels and glazes, engobes (slips) and similar preparations for ceramics, enamelling or glass
Ceramics	Fireworks
Zinc refining	-

Table 40: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The total in-use stock of strontium is estimated to be 650 kt Sr. The largest stock of strontium is related to strontium ferrite magnets (470 kt Sr) followed by ceramics (180 kt Sr). For all other applications, it is considered that strontium is dissipated during use and not recoverable (64 kt Sr). The annual addition to in-use stock of strontium containing products is estimated at around 14 kt Sr.

The amount of strontium in end-of-life products (ferrite magnets and ceramics) collected and sent for treatment is about 25 kt Sr. For the given timeframe (2016-2020) it is considered that there is no functional recycling of strontium from ferrite magnets (even though strontium from magnets could theoretically be recycled). It is thus assumed that 15 kt Sr flows into non-functionally recycling without any possibility to recover strontium for the strontium industry. Around 10 kt Sr from ceramics is considered to be sent to disposal. No secondary strontium is traded within or outside of the EU.

4.21.3. Indicators

Table 41 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life resulted in 58% in 2020. This is due to the assumption that most ferrite magnets are used in the automobile industry, thus parameters on the collection rates from cars in the EU were considered. Except for strontium in ceramics it is considered that strontium in chemicals and zinc refining is dissipated during use and thus unavailable for collection. As no functional recycling takes place in the EU, the end-of-life recycling rate (EoL-RR) is 0% as well as the end-of-life recycling input rate (EoL-RIR).

Regarding self-sufficiency, the EU extracts more than it uses for production resulting in a self-sufficiency well above 100%. At the processing stage the EU covers up to 99% of the demand for the processing, the rest being supplemented by imports. At the manufacturing stage the self-sufficiency rate is at 77%, meaning that the EU relies on imports for a certain amount of finished products at the use stage.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	66%	66%	66%	66%	58%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	99%	99%	100%	119%	108%
Self-sufficiency Processing	C1.1/M2.1	97%	97%	96%	98%	99%
Self-sufficiency Manufacturing	D1.1/M3.1	76%	76%	76%	76%	77%

Table 41: Different indicators that describe strontium situation in the EU

4.21.4. Data sources, assumptions and reliability of results

The main data sources used for strontium comprise the panorama report from IGME (Instituto Geológico y Minero de España), the Spanish foreign trade statistics database, as well as Eurostat database Comext and Prodcom. Further information provided by USGS, BGS and Minerals4EU were considered, mainly for comparison.

Further essential input presents information provided by Canteras Industriales as well as Kandelium, who provided several data and validated the strontium value chain.

A Strontium Market report by Transparency Market Research (TMR) gave a broad overview of strontium applications and trade in EU27. However, according to industry experts the shares provided in the report did not represent the actual use and trade of strontium in the EU27. Thus, data provided by industry experts were preferred over the TMR information as well as COMEXT data, which were also considered inaccurate for certain strontium compounds.

Overall data for exploration to processing steps can be considered reliable. Yet trade data of strontium compounds from Eurostat was considered not accurate according to expert feedback, thus trade volumes provided by experts were used for trade of strontium were applicable.

For the manufacturing step, several shares of strontium into different applications were based on expert feedback from Kandelium. The shares presented by TMR market report were not considered for the analysis given the feedback by experts.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of strontium-containing products (lifetime, dissipation, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimation of strontium flows at use and end-of-life. For the collection and recycling stages expert input was considered. Because most ferrite magnets are used in automotive industry, for the use stage, it was assumed that collection rates for vehicles are representative as a proxy; suggestions for parameters were provided by Oeko-Institut. With regard to recycling, experts confirmed that no functional recycling of strontium takes place for the respective timeframe in the EU. It was, thus, assumed that strontium-containing magnets flow into unknown non-functional recycling processes and that there is a lack to recover strontium at EoL.

In general, the feedback from the validation workshops helped in confirming and improving the estimations made, which adds more robustness to the results.

The MSA in 2023 was the first MSA being conducted, thus, no comparison to previous analysis is possible.

4.22. Titanium

4.22.1. Value chain

Titanium is the 9th most abundant element in Earth's crust, with an average TiO_2 abundance of 0.7 weight percent. Titanium can be found in nearly all rocks and sediments but is widely distributed in nature. Titanium is mainly obtained from rutile, ilmenite and rarely from leucoxene.

Ilmenite, rutile, and leucoxene are processed mainly into titanium-rich slag or synthetic rutile and then further processed for use in pigments and as titanium metal. There are different processes to produce TiO_2 pigments (the main application of titanium): the sulphate and the chloride processes, both taking place in the EU. Ti pigments are used for their excellent properties as white pigment in a vast range of different applications (colors, coatings, polymers, paper, cosmetic products and many more).

As first step of Ti metal production, $TiCl_4$ is produced from TiO_2 at 700 to 1 000 °C with chlorine and coke and then reduced to titanium with liquid magnesium to form titanium sponge. It is not possible to reduce Ti by carbon. Ti sponge is the most traded form of titanium metal. No Ti sponge is produced in the EU, all Ti sponge is imported. The further processing to gain Ti metal ingots, bars, and other metal forms takes place in the EU.

Titanium metal is used for strong and lightweight applications; it is corrosion resistant and has a high strength to density ratio. It is also biocompatible, meaning it is non-toxic and not rejected by the body and can be used for medical implants. Furthermore, it can be superconducting and is therefore used in alloys with other metals like niobium for superconductors in MRIs. In general, it is used in various applications in the aerospace industry, in medical equipment, automotive parts, chemistry applications, like chemical resistant tubes, and as coating for tools.

Figure 64 below depicts the value chain of titanium, its intermediates and end-uses covered by this study.

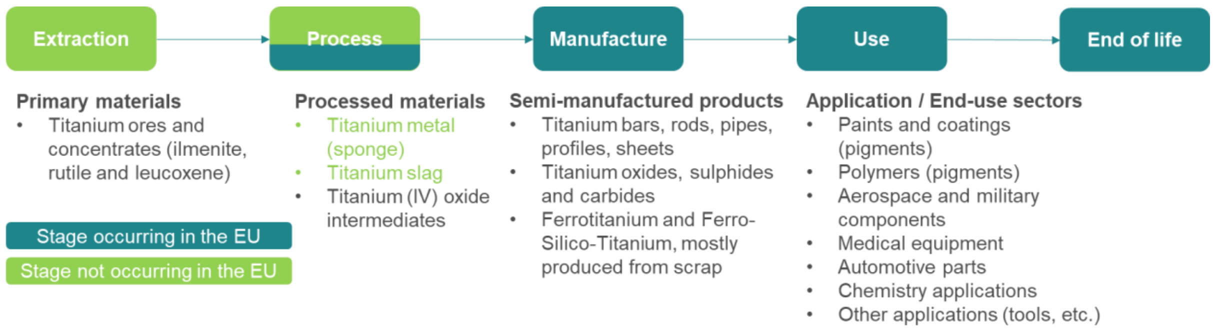


Figure 64: Value chain of titanium, steps in dark green occur at least in part in the EU (processing of Ti into Ti metal or slag does not take place in the EU), steps in light green occur only in non-EU countries

4.22.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of material (kt Ti) equivalent and are representtative of the year 2020.

Global titanium reserves are estimated at about 443 560 kt Ti. In the EU, titanium reserves of 10 t are found in Slovakia. In 2020, the world production of titanium reached 3 636 kt Ti with China, Australia and Canada being the biggest producers. In the EU, there is no extraction of Ti. All titanium used by the EU industry is imported. It is estimated that titanium ores and concentrates containing 379 kt Ti were imported in 2020.

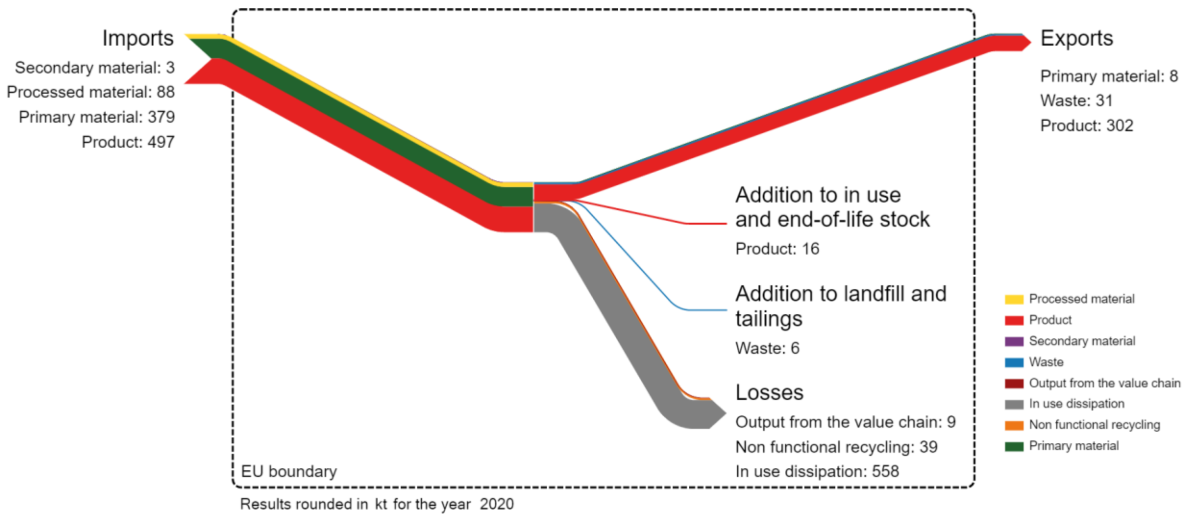


Figure 65: Simplified Sankey diagram for titanium for the year 2020 in the EU, in kt.

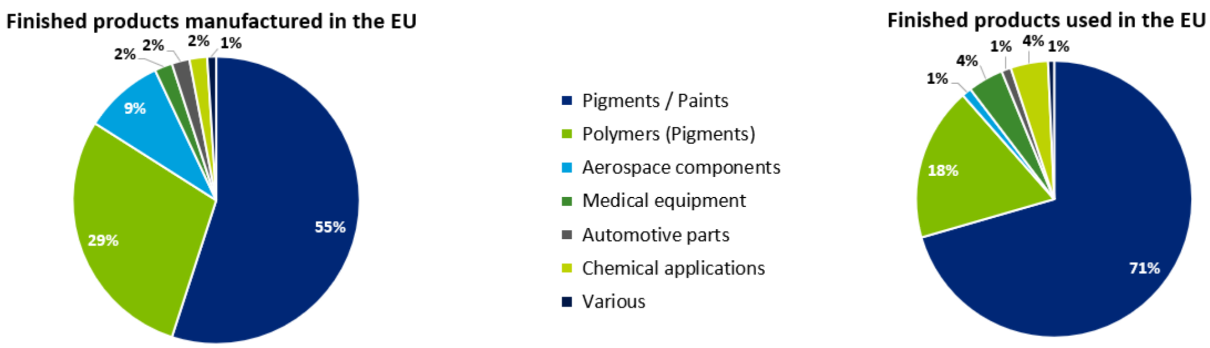
A total of 392 kt Ti pigments for paints, coatings and polymers are manufactured in the EU from ores, concentrates and pre-processed slags imported and processed by an integrated industry. About 4 kt Ti are generated as waste in the process.

As mentioned earlier, there is no production of Ti sponge in the EU.

The EU manufactured other Ti products, from imports of processed material in form of unwrought titanium (mostly titanium sponge) and titanium powders (8 kt Ti) as input to the EU manufacturing stage. Furthermore, ferrotitanium is imported as semi-manufactured material with a net-import of 8 kt Ti. Imports of secondary material in form of titanium waste and scrap are considered as well (3 kt Ti). As the amounts for imports and exports of titanium oxides are very similar and the exact content is not known, it is considered that the net imports can be neglected.

The EU industry uses these materials to manufacture various finished products. As mentioned before, the largest share of titanium is manufactured as TiO2 to pigments for paints and coatings (259 kt Ti), and for polymers (136 kt Ti). The remainder (all using Ti sponge) is used for aerospace components (42 kt Ti), medical equipment and implants (9 kt Ti), automotive parts (9 kt Ti), chemical applications like tubes (9 kt Ti) and others (e.g., tools, 5 kt Ti). Most of the titanium scrap generated from product manufacturing was exported (26 kt Ti), internally recycled or sent to a recycling plant in France –not reflected in the MSA, as it is occurring within the manufacturing stage - or used for ferrotitanium production (also therefore not leaving the manufacturing stage and not being reflected in the MSA). Apart from this, Ti is not recycled for the value of titanium, but mostly ending up in slags used for road construction or being diluted in other products (9 kt Ti), with 4 kt Ti from manufacturing waste considered to be sent to landfill.

Figure 66 shows the distribution by end-use sector of titanium-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.



471 kt

626 kt

Figure 66: Shares of finished products containing titanium manufactured in the EU (left) and shares of finished products containing titanium used in the EU (right), by application

For each of the applications, Table 42 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all titanium products.

Application	Representative product
Pigments / paints	TiO2 pigments in coatings
Polymers (pigments)	Pigments in polymers
Aerospace components	Planes (civil)
Medical equipment	Titanium implants
Automotive parts	Cars
Chemical applications	Tubes for chemical production
Various	Tools

Table 42: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about 16 kt Ti (net addition to the stock in 2020). The total stock of products in-use is quantified at about 801 kt Ti in 2020.

About 558 kt Ti were lost due to dissipation during use, mostly due to dissipation of pigments. About 46 kt Ti contained in products at end-of-life were collected and sorted for recycling, while 2 kt Ti in waste products were directly sent to disposal. The titanium contained in the waste is non-functionally recycled (39 kt Ti) ending up in slags during recycling of scraps for other metals, which again is mostly used for construction of roadways, or diluted down, not valued for its functions. There is no post-consumer functional recycling of titanium in the EU. Scraps valued for their titanium content are exported, especially to the USA.

4.22.3. Indicators

Table 43 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 83% in 2020, and the end-of-life recycling rate (EoL-RR) was 0%. The ratio of recycling from old scrap contributing to EU demand for titanium (i.e., end-of-life recycling input rate, EoL-RIR) was also considered to be 0%. The differences between collection on the one hand and EoL-RR and EoL-RIR on the other hand were due to the fact that no application is recycled for its titanium content in the EU but exported or treated with titanium going into slag.

Regarding self-sufficiency, the EU relies on imports of extracted material to be processed to pigments. There, it is self-sufficient considering the processing to intermediates for pigment production. Titanium metal is only imported as processed material (Ti sponge) to be further manufactured in the EU. In general, the EU is self-sufficient for manufacturing, exporting similar amounts in end products compared to import. No titanium was extracted, but 96% was refined in the EU (all for pigment production). The amount of titanium consumed in the use phase (M.3.1) is in part lower than what is manufactured in the EU (D.1.1), resulting in a self-sufficiency higher than 100% for 2016 and 2017. These results demonstrate that the EU manufacturing capabilities are mostly sufficient to cover the demand for all the main application sectors, however, one has to differentiate between Ti pigments and Ti metal.

For the five years analysed the main changes are related to strongly increasing values for the import of pigments over the years and changing the self-sufficiency for manufacturing.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	0%	0%	0%	0%	0%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	0%	0%	0%	0%	0%
Collection rate	F1.4/(M4.1)	83%	83%	83%	84%	83%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	0%	0%	0%	0%	0%
Self-sufficiency Processing	C1.1/M2.1	94%	95%	95%	95%	96%
Self-sufficiency Manufacturing	D1.1/M3.1	110%	108%	71%	75%	69%

Table 43: Different indicators that describe titanium situation in the EU

4.22.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are USGS, the World Mining Data database (WMD, 2022), BGS, Eurostat PRODCOM and COMEXT databases, studies by Conversio for pigments in polymers and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (for imports/exports of material, for the stages processing and products in manufacture). The titanium content is available from various expertise and references (CRM Factsheets and others). Overall, basic extrapolation was applied to primary data to compute reliable estimates of titanium flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of titanium-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of titanium flows at use and end-of-life. The feedback from the validation workshops helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on titanium recycling mainly originates from expertise gathered during personal communications with stakeholders.

There has been no previous MSA, on which this study could be based.

4.23. Tungsten

4.23.1. Value chain

Tungsten (W) is a metal mainly found in ores such as scheelite and wolframite. Tungsten extracted from these ores is mainly processed into ammonium paratungstate (APT thereafter), tungsten oxides (further processed forms of APT) or ferrotungsten. APT and tungsten oxides are manufactured into two main tungsten semi-finished products: tungsten metal powder (highly conductive when pure, and highly dense when alloyed), and tungsten carbides (robustness and wear resistance). Ferrotungsten is used in tungsten-containing steel, to increase toughness and the melting point temperature.

Tungsten is used in various manufactured products. For instance, incandescent lamps have a filament made of pure tungsten metal; mill and cutting tools or mining and construction tools are made of tungsten carbides. Aeronautics and energy applications are based on both tungsten metal and alloys.

Figure 67 below depicts the value chain of tungsten, its intermediates and end-uses covered by this study. All stages of the value chain take place within the EU.

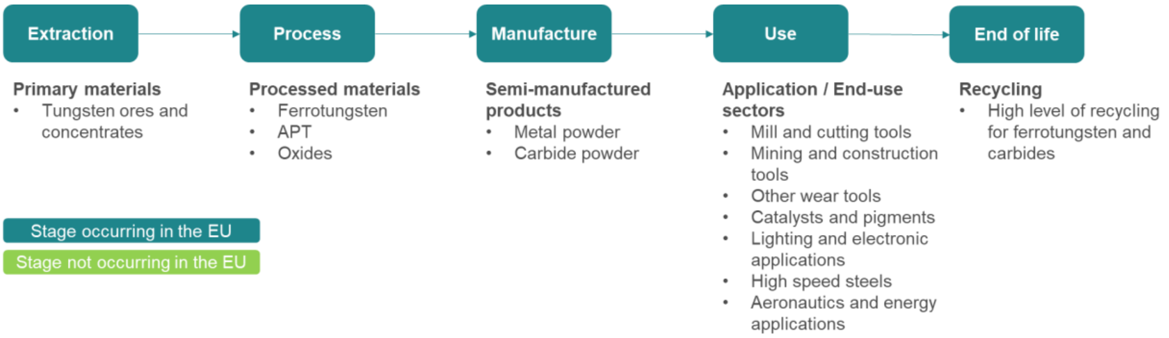


Figure 67: Value chain of tungsten, steps in dark green occur in the EU, steps in light green occur only in non-EU countries

4.23.2. Description of the main flows and stocks

Flows and stocks are accounted in mass of tungsten (t W) metallic equivalent and are representative of the year 2020.

Global tungsten reserves are estimated at about 3 633 kt W, with more than half of the global tungsten reserves in China. In the EU, tungsten reserves are reported for Spain, Portugal and Austria, which are the main extracting countries. They are estimated at about 67 100 t W. Smaller reserves also exist in other EU countries, but are not reported.

In 2020, the world production of tungsten reached 87 kt W and the top producer country was China, accounting for more than 80% of extracted tungsten volumes. In the EU, about 2 110 t W were extracted (including also extraction waste of around 420 t W), i.e. in Austria (53% of total tungsten extraction in EU), in Portugal (33%) and in Spain (14%). It is to be noted that the distribution between the three countries was more balanced before 2019, with Spain representing 32% of EU extraction in 2016. This is due to a drop in production in Spain in 2019 and 2020.

Around 58% of the EU extracted tungsten is sold on the EU market. The domestic input to EU tungsten processing was supplemented with imports of tungsten ores and concentrates and imports of secondary material (respectively 2 050 t W and 1 370 t W). Additionally, about 1 700 t W were supplemented from manufacturing waste generated in the EU, and 2 270 t W from post-consumer functional recycling in the EU.

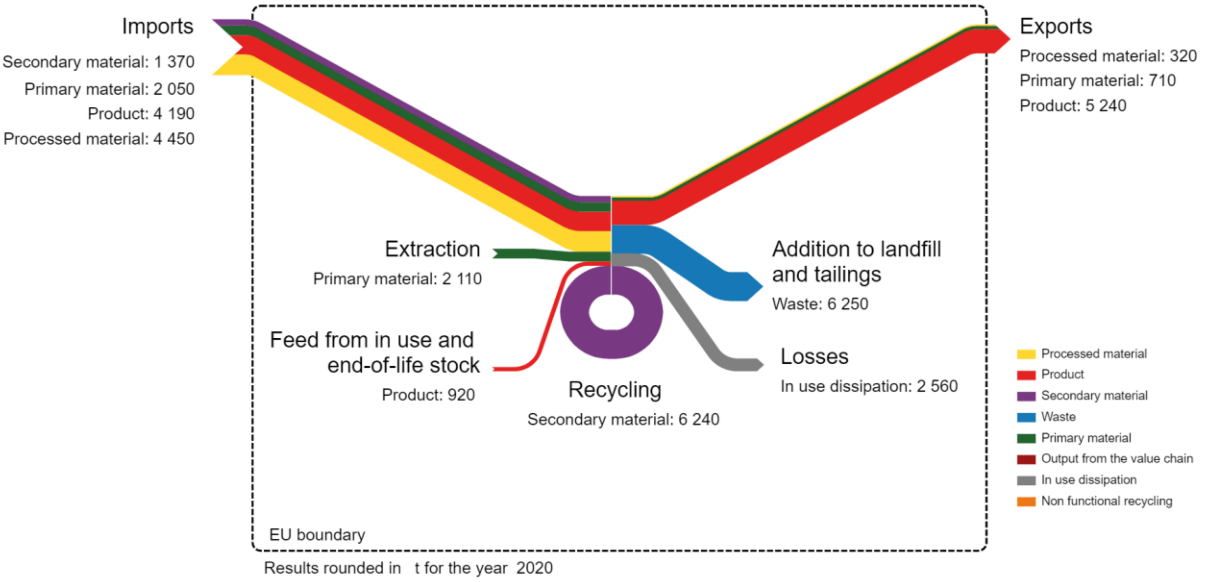


Figure 68: Simplified Sankey diagram for tungsten for the year 2020 in the EU, in t, imports of products include also 950 t W of intermediate products, supplied to the manufacturing stage.

A total of 8 030 t W of processed material were produced in the EU: 6 950 t W in APT and tungsten oxides, and 1 080 t W in ferrotungsten. About 330 t W is generated as processing waste, sent to disposal.

Further input to the EU manufacturing stage was:

4 130 t W of processed material net-imported (imports were 4 450 t W of processed material while the exports were 320 t W)

950 t W in intermediate products net imported,

about 2 270 t W from post-consumer functional recycling in the EU.

The EU industry manufactures various semi-finished products (such as oxides, metal, etc.) which are then incorporated into finished products in the EU: mill and cutting tools (3 960 t W), mining and construction tools (3 200 t W), other wear tools (1 600 t W), catalysts and pigments (1 460 t W), lighting and electronic applications (170 t W), high speed steels applications (1 720 t W), aeronautics and energy applications (1 490 t W). Most of the tungsten new scrap generated from product manufacturing was sent for reprocessing, with only 80 t W sent to landfill.

Figure 69 shows the distribution by end-use sector of tungsten-containing finished products manufactured (pie-chart on the left-hand side) and used (pie chart of the right-hand side) in the EU.

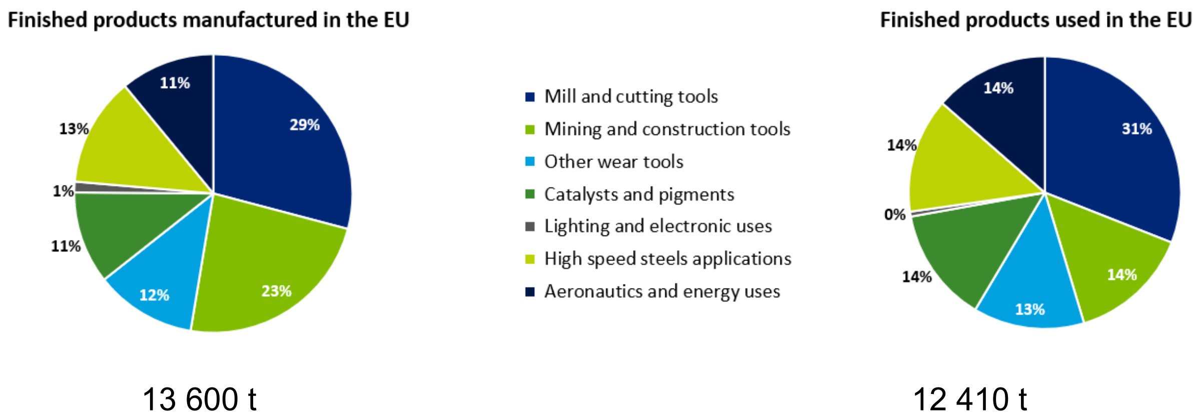


Figure 69: Shares of finished products containing tungsten manufactured in the EU (left) and shares of finished products containing tungsten used in the EU (right), by application

For each of the applications, Table 44 lists the corresponding representative product chosen which was used as a basis for the assumptions made to model trade, use, collection and recycling steps of all tungsten products.

Application	Representative product
Mill and cutting tools	Milling tool
Mining and construction tools	Drilling head
Other wear tools	Turning tool
Catalysts and pigments	DeNOx catalysts
Lighting and electronic applications	Tungsten filament light-bulb
High speed steels applications	High speed steel

Aeronautics and energy applications	Gyroscope

Table 44: List of the applications and of the corresponding representative product used for the assumptions made to model trade, use, collection and recycling steps for each application.

The quantity annually entering the in-use stock was estimated at about -620 t W in 2020 (net removal from the stock in 2020, due to a higher amount of products reaching end-of-life than new products entering the use phase), while in the previous years about 190 t W were removed from stock annually. The total stock of products in-use is quantified at about 64,930 t W in 2020.

About 2,560 t W were lost due to dissipation during use, mostly due to the wear of carbides tools. This leaves about 9,960 t W contained in products collected for waste treatment, and 810 t W were exported for reuse, in aeronautics applications. Among products collected for waste treatment, 4,200 t W were sent to landfill rather than recycled. During the recycling process about 1,220 t W of the available material was considered wasted, leaving 4,540 t W of secondary tungsten supplied to domestic processing and manufacturing in 2020.

4.23.3. Indicators

Table 45 summarises recycling and EU self-sufficiency indicators.

The collection rate at end-of-life was 58% in 2020, and the end-of-life recycling rate (EoL-RR) was 46%. The ratio of recycling from old scrap contributing to EU demand for tungsten (i.e., end-of-life recycling input rate, EoL-RIR) resulted in 34%. The differences between collection, EoL-RR and EoL-RIR were due to the fact that part of the collected products are landfilled rather than recycled, such as catalysts, pigments, and filament light bulbs.

Regarding self-sufficiency, the EU relies on imports at extraction and processing stages, and is self-sufficient for manufacturing, exporting more than importing. In 2020, only 38% of tungsten was extracted and 61% was refined in the EU, the rest was imported (imports include also secondary materials). The amount of tungsten consumed in the use phase (M3.1) is lower than the volume manufactured in the EU (D1.1), resulting in a self-sufficiency higher than 100%. These results demonstrate that the EU manufacturing capabilities are sufficient to cover the demand for all the main application sectors.

For the five years analysed the main changes are related to EU extraction, which increased in 2018 with the recovery of tailings from outside of the EU for tungsten concentrates production, and the reduction in extraction for Spain in 2019 and 2020.

Indicator	Formula	2016	2017	2018	2019	2020
EOL-RIR	(G.1.1+G.1.2)/(B.1.1+B.1.2-B1.3+C.1.3+C.1.4+C1.8+D.1.3+D1.9+G.1.1+G.1.2)	26%	29%	32%	32%	34%
EOL-RR	(G1.1+G1.2+G1.3)/(E1.6+F1.2-F1.1)	41%	42%	43%	43%	46%
Collection rate	F1.4/(M4.1)	52%	53%	55%	55%	58%
Self-sufficiency Extraction	(B1.1+B1.2)/(M1.1+M1.2)	57%	65%	75%	48%	38%
Self-sufficiency Processing	C1.1/M2.1	46%	43%	45%	51%	61%
Self-sufficiency Manufacturing	D1.1/M3.1	122%	119%	104%	111%	110%

Table 45: Different indicators that describe tungsten situation in the EU

4.23.4. Data sources, assumptions and reliability of results

The main sources of production and trade data are the World Mining Data database (WMD, 2022), Eurostat PRODCOM and COMEXT databases, ITIA publications and other elements from the literature. Eurostat database is used for various products for which the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The tungsten content is available from various expertise and references (BGS, MDPI, DERA). Overall, basic extrapolation was applied to primary data to compute reliable estimates of tungsten flows and stock in the EU.

Due to lack of information, some assumptions based on average knowledge were made for evaluating the characteristics of tungsten-containing products (lifetime, market share, end-of-life, trade, etc.). For this reason, higher uncertainty likely affects the estimate of tungsten flows at use and end of life. The feedback from the validation workshops helped in confirming and improving the estimates made, which adds more robustness to the results.

Data provided in the MSA on tungsten recycling mainly originates from expertise gathered during personal communications with stakeholders.

The results of the 2023 MSA are comparable with results of the MSA conducted in 2015. A few changes can be observed, with an overall increase in imports of secondary material, and a smaller amount of recycled material coming from end-of-life products due to more conservative hypothesis (e.g., no recycling from the aircraft industry).

5. Conclusions

For all the materials analysed, quantities of products manufactured in the EU27 and products used in the EU27 vary significantly from one to another.

The table below summarize the flows and stocks of each material under study within the EU economy of the year 2020, except for the **platinum group metals** which are based on the **2019** dataset. For PGM, the year 2020 was considered atypical due to a significant impact of the **COVID crisis** on the automotive industry.

The following table compares finished products containing the analysed materials manufactured in the EU27 and those used in the EU27. Products flows for aggregates, chromium, coking coal and magnesite/magnesia are significantly higher than those for other materials, with over 1 million tons.

Table 46: Quantities of finished products containing the material manufactured in the EU and used in the EU

Material	Manufactured in the EU (in t)	Used in the EU (in t)
Aggregates	2 795 092 812	2 782 663 170
Antimony	30 909	39 993
Beryllium	24	25
Borate	55 776	52 200
Chromium	1 207 566	1 097 588
Coking coal	28 628 289	26 283 250
Fluorspar	283 353	335 452
Gallium	5	84
Germanium	43	45
Indium	44	56
Magnesite/Magnesia	1 530 736	1 261 283
Magnesium	153 742	163 368
Niobium	10 513	10 372
Platinum	48	56
Palladium	59	55

Rhodium	6	6
REEs	480	879
in Magnets		
Lanthanum and Cerium	4 009	3 904
Other REEs	432	310
Silicon metal	472 160	423 683
Strontium	83 768	108 155
Titanium	471 263	625 395
Tungsten	13 603	12 409

In this study, various indicators are presented for each material: the End-of-Life Recycling Input Rate also called EoL-RiR, which corresponds to end-of-life recycling's contribution to the EU's demand for the material, the End-of-Life Recycling Rate or EoL-RR which represents the share of a material in waste flows that is sent to recycling, the Collection rate and 3 self-sufficiency indicators.

The EU is quite efficient in collecting end-of-life products for all the materials analysed (collection rate higher than 50%, except for germanium, fluorspar, magnesite and borates due to high in-use dissipation). In the end, however, a large share of the materials are lost for their value chain due to non-functional recycling or because of the fact that they were not targeted during the recycling process.

Table 47: Indicators of collection and recycling of the materials analysed for the year of reference

Material	Indicators		
	EOL-RIR	**EOL-RR**	**Collection rate**
Aggregates	8%	72%	72%
Antimony	43%	50%	71%
Beryllium	0%	0%	89%
Borate	3%	10%	10%
Chromium	30%	68%	83%
Coking coal	0%	Not applicable	
Fluorspar	0%	1%	28%
Gallium	0%	0%	69%

Germanium	0%	0%	5%
Indium	0%	0%	50%
Magnesite	2%	8%	30%
Magnesium	13%	21%	83%
Niobium	0%	0%	87%
Platinum	27%	48%	50%
Palladium	18%	50%	51%
Rhodium	28%	64%	66%
REEs in Magnets	0%	0%	95%
Lanthanum and Cerium	0%	0%	67%
Other REEs	0%	0%	63%
Silicon metal	14%	40%	55%
Strontium	0%	0%	58%
Titanium	0%	0%	83%
Tungsten	34%	46%	58%

Most of the materials analysed showed a very strong dependence on extra-European imports along their value chain: all of these materials are highly dependent on imports of primary materials and intermediate products. In the EU, a consolidated manufacturing stage exists for a large part of the materials analysed (self-sufficiencies between 69% and 135%) except for gallium (41%) and REEs used in magnets (53%). As regards magnesite and tungsten, the EU manufacturing capacity covers more than 110% of the EU demand, which means that the EU27 exports many of its manufacturing products.

Table 48: Indicators of self-sufficiency of the materials analysed for the year of reference

Material	Indicators		
	Self-sufficiency Extraction	**Self-sufficiency Processing**	**Self-sufficiency Manufacturing**
Aggregates	100%	99%	100%
Antimony	7%	139%	77%
Beryllium	Not applicable	0%	97%
Borate	0%	19%	107%
Chromium	38%	101%	110%
Coking coal	100%	30%	109%
Fluorspar	29%	66%	106%
Gallium	0%	46%	41%
Germanium	39%	39%	97%
Indium	41%	103%	80%
Magnesite	114%	71%	121%
Magnesium	0%	60%	94%
Niobium	14%	2%	101%
Platinum	4%	74%	87%
Palladium	2%	102%	108%
Rhodium	0%	82%	103%
REEs	0%	24%	53%
in Magnets			
Lanthanum and Cerium	0%	123%	98%
Other REEs	0%	7%	135%
Silicon metal	133%	42%	111%

Strontium	108%	99%	77%
Titanium	0%	96%	69%
Tungsten	38%	61%	110%

Those indicators show that the EU is not yet able to reduce its dependency on the extraction of primary material and raw material imports by using secondary materials that are domestically recycled. However, for some materials (e.g. tungsten), significant efforts are undertaken to change this situation in the future and to improve the EU's circularity. Additionally, the stocks in use may become another potential source of raw materials in the future with the development of recycling technologies.

Since the overall MSA for a material must be consistent and as reliable as possible, it is important to systematically review the quality of the data sources used and to have a critical look at the data provided.

For instance, when using Eurostat databases, the initial reporting or the data provided by a Member State might be inaccurate, which impacts the results at the European Union's level. It is important to take a comprehensive, system-wide perspective of the EU industry, check potential inconsistencies in the data provided and compare different data sources. In the specific case of Eurostat databases, checking all information that differs by more than 20% from one year to the other can enhance the quality of the results.

The commercial trade of some materials is not traceable due to the absence of corresponding trade codes for these materials. Even where such codes existed, they could not always be used in the MSA because their material content was unknown or highly variable, as in the case of PGMs. The list of codes studied and of the ones that could not be used is available in Appendix 2: References.

Due to confidentiality reasons, data collection from stakeholders was also limited for the materials where only a limited number of actors are concerned in the EU, as for germanium.

Despite all the modifications brought about by the new methodology used for this 2023 exercise to overcome the limitations highlighted during the 2015 exercise, there is still room for improving the MSA methodology. During the development of the current MSA studies, the project team encountered that it was necessary to increase the level of detail in the processing and manufacturing stages, as several materials undergo numerous intermediate transformations in those stages. Therefore, it is recommended to add substages to manufacturing and processing including also the necessary trade flows of intermediate materials and products in the Sankey diagram.

When tracking the collection and recycling flows, the project team was limited in terms of the level of detail used to describe the collection and recycling stages. In fact, collected products may be dismantled into their component parts, and traded, either for reuse, refurbishment or recycling. Adding a substage for product dismantling may improve the level of detail with regard to the materials available for the recycling stage.

6. Appendix 1: Material Flow/Stock Parameters

Table 49: List of material flow and stock parameters

A.1.1 Reserves in the EU A.1.2 Reserves in ROW
B.1.1 Production of primary material as main product in the EU B.1.2 Production of primary material as by product in the EU B.1.4 Extraction waste disposed in situ/tailings in the EU B.1.5 Stock in tailings in the EU Production of primary material as main product in the world
B.1.3 Exports from the EU of primary material C.1.3 Imports to the EU of primary material C.1.4 Imports to the EU of secondary material C.1.8 Imports of semi-processed material send to processing in the EU M.1.1 Primary material sent to processing in the EU M.1.2 Primary material sent to manufacturing in the EU
C.1.1 Production of processed material in the EU C.1.5 Processing waste in the EU sent for disposal in the EU C.1.7 Output from the value chain Production of processed material as main product in the world

C.1.2 Exports from the EU of processed material C.1.6 Exports from the EU of processing waste D.1.3 Imports to the EU of processed material sent to manufacturing D.1.8 Imports to the EU of products requiring further manufacturing steps in the EU D.1.9 Imports of secondary material send to manufacturing in the EU M.2.1 Processed material sent to manufacturing in the EU
D.1.1 Production of manufactured products in the EU D.1.4 Manufacture waste in the EU sent for disposal in the EU D.1.5 Manufacture waste in the EU sent for reprocessing in the EU D.1.7 Output from the value chain Material share distribution between end uses
D.1.2 Exports from the EU of manufactured products E.1.4 Imports to the EU of manufactured products D.1.6 Exports from the EU of manufacture waste M.3.1 Manufactured products send to use in the EU
E.1.1 Stock of manufactured products in use in the EU E.1.2 Stock of manufactured products at end-of-life that are kept by users in the EU E.1.5 In use dissipation in EU E.1.6 Products at end-of-life collected for treatment in the EU E.1.7 Annual addition to in-use stock of manufactured products in the EU E.1.8 Annual addition to end-of-life stock of manufactured products at end-of-life that are kept by users in the EU
E.1.3 Exports from the EU of manufactured products for reuse F.1.2 Imports to the EU of manufactured products at end-of-life M.4.1 Products at end-of-life in the EU collected for treatment

F.1.1 Exports from the EU of manufactured products at end-of-life F.1.3 Manufactured products at end-of-life in the EU sent for disposal in the EU F.1.4 Manufactured products at end-of-life in the EU sent for recycling in the EU F.1.5 Stock in landfill in the EU F.1.6 Annual addition to stock in landfill in the EU
G.1.1 Production of secondary material from post-consumer functional recycling in the EU sent to processing in the EU G.1.2 Production of secondary material from post-consumer functional recycling in the EU sent to manufacture in the EU G.1.3 Exports from the EU of secondary material from post-consumer recycling G.1.4 Production of secondary material from post-consumer non-functional recycling G.1.5 Recycling waste in EU sent for disposal in the EU

7. Appendix 2: References

This appendix presents the list of data sources and commodities used in the MSA of each material, as well as the main stakeholders who contributed. The project team would like to thank again the stakeholders, who provided important insights and helped through confirming or infirming some preliminary results. However, please note that the stakeholders did not revise the overall MSA for their material of interest.

7.1. Appendix 2 – Data sources for aggregates

Table 50: Main stakeholders involved in the MSA for aggregates

List of stakeholders
European Aggregates Association - UEPG
Global Aggregates Information Network – GAIN
Asociación Nacional de Empresarios Fabricantes de Áridos - ANEFA

Table 51: Data sources used in the MSA for aggregates

List of data sources	Year	
USGS	2017-2021	Natural Aggregates Statistics and Information: Mineral Commodity Summaries for Sand and Gravel & Crushed Stone
BGS (British Geological Survey)	2022	WORLD MINERAL PRODUCTION 2016–20: Production of primary aggregates (sand and gravel and crushed rock)
UEPG (European Aggregates Association)	2017-2021	Annual Reviews 2017-2018; 2018-2019; 2019-2020; 2020-2021

List of data sources	Year	
Prodcom	2022	Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]
Various expert feedback	2023	Expert feedback at MSA Workshop in February 2023
Prodcom	2022	Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data [DS-066341]
COMEXT	2022	EU trade since 1988 by HS2-4-6 and CN8 [DS-645593]
Eurostat	2022	Population change - Demographic balance and crude rates at national level (online data code: DEMO_GIND) Source of data: Eurostat
Eurostat	2022	Service center feedback
GAIN	2022	Expert feedback GAIN regarding global aggregates production (via mail)
EC	2015	MSA for aggregates 2015
Eurostat	2022	Generation of waste by waste category, hazardousness and NACE Rev. 2 activity [ENV_WASGEN__custom_3827828]
Eurostat	2022	Production in construction - annual data [STS_COPR_A__custom_3826911]
Various expert feedback	2023	Varions expert feedback communication via mail

Table 52: Commodities used in the MSA for aggregates

List of commodities		
COMEXT	25059000	Natural sands of all kinds, whether or not coloured (excl. silica sands, quartz sands, gold- and platinum-bearing sands, zircon, rutile and ilmenite sands, monazite sands, and tar or asphalt sands)
	25171010	Pebbles and gravel for concrete aggregates, for road metalling or for railway or other ballast, shingle and flint, whether or not heat-treated
	25171020	Broken or crushed dolomite and limestone flux, for concrete aggregates, for road metalling or for railway or other ballast
	25171080	Broken or crushed stone, for concrete aggregates, for road metalling or for railway or other ballast, whether or not heat-treated (excl. pebbles, gravel, flint and shingle, broken or crushed dolomite and limestone flux)
	25174100	Marble granules, chippings and powder, whether or not heat-treated
	25174900	Granules, chippings and powder, whether or not heat-treated, of travertine, ecaussine, alabaster, basalt, granite, sandstone, porphyry, syenite, lava, gneiss, trachyte and other rocks of heading 2515 and 2516 (excl. marble)
PRODCOM	23611130	Building blocks and bricks of cement, concrete or artificial stone
	23611150	Tiles, flagstones and similar articles of cement, concrete or artificial stone (excluding building blocks and bricks)
	236919Z0	Pipes and other articles of cement, concrete or artificial stone, and accessories
	23691980	Articles of cement, concrete or artificial stone for non-constructional purposes (including vases, flower pots, architectural or garden ornaments, statues and ornamental goods)
	23631000	Ready-mixed concrete

List of commodities		
	23991310	Bituminous mixtures based on natural and artificial aggregate and bitumen or natural asphalt as a binder
	23641000	Factory made mortars

Table 53: Commodities not used in the MSA for aggregates

List of commodities			Reason why not used
NA			

7.2. Appendix 2 – Data sources for antimony

Table 54: Main stakeholders involved in the MSA for antimony

List of stakeholders
International Antimony Association
International Lead Association
Campine
WMD
Umicore
University of Geneva

Table 55: Data sources used in the MSA for antimony

List of data sources	Year	Title
WMD	2022	World Mining Data 2022 (Iron and Ferro-Alloy Metals, Non-Ferrous Metals, Precious Metals, Industrial Minerals, Mineral Fuels)
BSGS	2022	WORLD MINERAL PRODUCTION, 2016–20
USGS	2022	Mineral Commodity Summary - Antimony
Magnus Gislev and Milan Grohol	2018	Report on Critical Raw Materials and the Circular Economy
I2a	2022	Webpage: Antimony --> cites Roskill 2014
I2a	2017	SUBSTANCE IDENTITY PROFILE: ANTIMONY METAL massive & powder (Sb) - April 2017
WMD	2022	6.4. Production of Mineral Raw Materials of individual Countries by Minerals.xlsx
Boliden	2018	Boliden Summary Report: Resources and Reserves | 2018 - Rocklien
Corby G Anderson	2019	Antimony Production and Commodites, table 6
Perpetua Resources	2021	Antimony white paper
Baron et al.	2020	RoHS substance review dossier for Diantimony trioxide
IHS Markit	2020	An Analysis of EU Collection and Recycling of Lead-based Automotive Batteries During the Period 2015-2017

List of data sources	Year	Title
European Commission	2017	Study on the review of the list of critical raw materials: critical raw materials factsheets
Filella, M., Hennebert, P., Okkenhaug, G. & Turner, A.	2019	Occurrence and fate of antimony in plastics
Eurostat	2022	Waste statistics - electrical and electronic equipment
Eunomia	2022	PET MARKET IN EUROPE STATE OF PLAY 2022 - PRODUCTION, COLLECTION AND RECYCLING
Claire Arkin	2019	Waste Exports: The rubbish dump is closed
EC	2021	COMMISSION STAFF WORKING DOCUMENT EVALUATION of Directive (EC) 2000/53 of 18 September 2000 on end-of-life vehicles {SWD(2021) 61 final}
European Commission	2020	Study on the EU's list of Critical Raw Materials – Final Report
Lindner, C., Schmitt, J. & Hein, J.	2020	Stoffstrombild Kunststoffe in Deutschland 2019
Statista	2023	Volume of plastic waste exported by the European Union (EU-27) from 2005 to 2021* (in million metric tons)
Plastics Europe	2021	Plastics - the Facts 2021 - An analysis of European plastics production, demand and waste data
Benedikt Kauertz & Andreas Detzel	2017	Verwendung und Recycling von PET in Deutschland - Verwendung von PET und PET Rezyklaten aus Verpackungen in Deutschland Eine Kurzstudie im Auftrag des NABU - Naturschutzbund Deutschland e.V.

Table 56: Commodities used in the MSA for antimony

List of commodities		
COMEXT	26171000	Antimony ores and concentrates
	81100011	Unwrought antimony; antimony powders
	282580	Antimony oxide
	811020	Antimony waste and scrap

PRODCOM	24453045	Antimony. Unwrought antimony; powders
	201201975	Antimony oxides
	24431150	Unwrought lead containing antimony (excluding lead powders or flakes)
	24442350	Copper wire with cross-sectional dimension > 0,5 mm, ≤ 6 mm (excluding twine or cord reinforced with wire, stranded wire and cables
	24442370	Copper wire with cross-sectional dimension ≤ 0,5 mm (excluding twine or cord reinforced with wire, stranded wire and cables)
	27202110	Lead-acid accumulators of a kind used for starting piston engines (starter batteries), working with liquid electrolyte (excl. spent
	27202100	Lead-acid accumulators for starting piston engines
	27202120	Lead-acid accumulators of a kind used for starting piston engines (starter batteries), working with non-liquid electrolyte (excl. spent)
	27202200	Lead-acid accumulators excluding for starting piston engines
	22221450	Plastic carboys, bottles, flasks and similar articles for the conveyance or packing of goods, of a capacity ≤ 2 litres
	22221470	Plastic carboys, bottles, flasks and similar articles for the conveyance or packing of goods, of a capacity > 2 litres
	25401300	Cartridges and other ammunition and projectiles and parts thereof, including shot and cartridge wads (excluding for military purposes)
	20302170	Liquid lustres and similar preparations; glass frit and other glass in powder; granules or flakes

Table 57: Commodities not used in the MSA for antimony

List of commodities			
COMEXT	26110000	Ash and residues containing mainly antimony	Empty
	262091	Slag, ash and residues, containing antimony, beryllium, cadmium, chromium or their mixtures (excl. those from the manufacture of iron or steel)	Disregarded
	81100019	Antimony waste and scrap	Empty
PRODCOM	20134111	Sulphides of calcium, of antimony or of iron	Empty
	27202210	Lead-acid accumulators of a kind used for starting piston engines (starter batteries), working with liquid electrolyte (excl. spent)	Empty

7.3. Appendix 2 – Data sources for beryllium

Table 58: Main stakeholders involved in the MSA for beryllium

List of stakeholders
BeST, covering the following stakeholders:
Materion
Berylco
Ridens
Tropag

Table 59: Data sources used in the MSA for beryllium

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Beryllium
BGS	2022	World Mineral Production 2016-2020
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
BEST	2022	Beryllium Science and Technology Association (BeST) expertise. Personal communication (2022/08/25)
Eurostat	2022	Eurostat - Comext database
BRGM	2010	Panorama 2010 du Marché du Beryllium
European Commission	2020	CRM: Study on the EU's list of Critical Raw Materials (2020)
USGS	2018	USGS Mineral Yearbook (2018) - Beryllium
Workshop 1	2022	Expertise shared during the workshop
Eurostat	2022	Eurostat - Prodcom database

List of data sources	Year	Title
ACEA	2022	THE AUTOMOBILE INDUSTRY POCKET GUIDE 2020 / 2021
Eurostat	2019	Total recycling and reuse rate of end-of-life vehicles, 2008–2019 (% of weight of vehicles)
Zhao et al.	2020	Disposal and Recycle Economic Assessment for Aircraft and Engine End-of-life Solution Evaluation
JRC	2020	Analysis of durability, reusability and reparability. Application to washing machines and dishwashers
JRC	2021	Technical assessment of nuclear energy with respect to the ‘do no significant harm’ criteria of Regulation (EU) 2020/852 (‘Taxonomy Regulation’)
Júnior SousaRibeiro, Jefferson de OliveiraGomes	2015	Proposed Framework for End-of-life Aircraft Recycling
L'indice de réparabilité	2020	Recyclage : Que se passe-t-il lorsque vous emmenez votre électroménager à la décharge ?
Larry D. Cunningham	2000	Beryllium Recycling in the United States in 2000
United Nations Environment Programme	2020	Used vehicles and the environment - A global overview of light duty vehicles: Flow, scale and regulation
Made in China	2022	4 Gallon Plastic Bucket Mould with Beryllium Copper/Moldes De Baldes
Bjorn Fehrm	2017	The aircraft market will double in 20 years
Lisa Tostado	2021	End-Of-Life Vehicles: Final Destination
GSM Arena	2019	Counterclockwise: As 5G arrives we track the 3G and 4G adoption

List of data sources	Year	Title
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
DGE	2022	Improved WEEE data give a better picture of collection and recycling rates
Rauch et al.	2007	Copper In-Use Stock and Copper Scrap in the State of Connecticut, USA
Nia Bell, Rachel Waugh and David Parker	2017	Magnesium Recycling in the EU - Material flow analysis of magnesium (metal) in the EU and a derivation of the recycling rate

Table 60: Commodities used in the MSA for beryllium

List of commodities		
COMEXT	28259020	Be oxides and hydroxides

Table 61: Commodities not used in the MSA for beryllium

List of commodities			Reasons why not used
COMEXT	81121200	Unwrought beryllium; beryllium powders	excluded by experts
	81121900	Articles of beryllium, n.e.s. (excluding waste and scrap)	not usable
	81121300	Beryllium waste and scrap (excl. ashes and residues containing beryllium)	not usable
	81121110	Unwrought beryllium; beryllium powders	empty
	81121190	Beryllium waste and scrap (excl. ashes and residues containing beryllium)	empty
PRODCOM	20121980	Be oxides and hydroxides	excluded by experts
	24453060	Unwrought beryllium; beryllium powders	excluded by experts

List of commodities			Reasons why not used
	24453061	Articles of beryllium, n.e.s. (excluding waste and scrap)	not usable

7.4. Appendix 2 – Data sources for boron/borates

Table 62: Main stakeholders involved in the MSA for boron/borates

List of stakeholders
IMA Europe (including the European Borates Association)
Etimine
Rio Tinto
FCM

Table 63: Data sources used in the MSA for boron/borates

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Borates
BGS	2022	World Mineral Production 2016-2020
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
Eurostat	2022	Eurostat - Comext database
Eurostat	2022	Eurostat - Prodcom database
Roger Doome, Lara Carrier, Hakan Kanli	2015	Reported data from experts used in the previous assessment

List of data sources	Year	Title
Etimine S.A.	2014	Etimine S.A. Comments to the European Commission's Consultation on the 6th Priority List of Substances for Inclusion in Annex XIV
CNRS	2021	Prior knowledge of the data on the production capacity of boron facilities in Turkey
Boron Today	2022	Boron Carbide
Glass Alliance Europe	2021	Production evolution of glass
Coenraad D. Westbroek, et al.	2021	Global material flow analysis of glass: From raw materials to end-of-life
DG GROW	2022	Sectors – Raw Materials – Related industries - Non-metallic products and industries – Glass
Saint Gobain	2020	Objective 50% of cullet in the Saint-Gobain glass by 2025
JRC	2013	Manufacture of Glass
European Commission	2014	Building stock characteristics
20 Mule Team Borax	2021	Borates for fire retardancy in cellulosic materials
Eurostat	2022	ENV_WASTRT
Scarlet, N. et al.	2010	Assessment of the availability of agricultural crop residues in the European Union: Potential and limitations for bioenergy use

Table 64: Commodities used in the MSA for boron/borates

List of commodities		
COMEXT	25280000	Borates, natural, and concentrates thereof, whether or not calcined, and natural boric acids containing <= 85% of H3BO3 calculated on the dry weight (excl. borates separated from natural brine)
	28100010	Diboron trioxide
	28100090	Oxides of boron and boric acids (excluding diboron trioxide)
	28401100	Anhydrous disodium tetraborate « refined borax »
	28401910	Disodium tetraborate pentahydrate
	28401990	Disodium tetraborate « refined borax » (excl. Anhydrous and disodium tetraborate pentahydrate)
	28402010	Borates of sodium, anhydrous (excl. Disodium tetraborate « refined borax »)
	28402090	Borates (excl. Of sodium, anhydrous and disodium tetraborate « refined borax »)
	28403000	Peroxoborate
	28499010	Carbides of boron, whether or not chemically defined
PRODCOM	20132460	Oxides of boron ; boric acids (2016-2018)
	20132462	Diboron trioxide (2019-2020)
	20132465	Oxides of boron and boric acids (excluding diboron trioxide) (2019-2020)
	20136230	Borates ; peroxoborates (perborates)
	20136420	Carbides of boron, whether or not chemically defined

Table 65: Commodities not used in the MSA for boron/borates

List of commodities			Reasons why not used
COMEXT	28045010	Boron	not usable, content unknown
	28452000	Boron enriched in Boron-10 and its compounds	not usable, content unknown
PRODCOM	20132141	Boron	not usable, content unknown
	20132469	Other inorganic acids and other inorganic oxygen compounds of non-metals (excluding hydrogen fluoride)	not usable, content unknown

7.5. Appendix 2 – Data sources for chromium

Table 66: Main stakeholders involved in the MSA for chromium

List of stakeholders
ICDA
SMR
ISSF
EUROALLIAGEs
World stainless

Table 67: Data sources used in the MSA for chromium

List of data sources	Year	Title
Eurostat	Last update: 2022	EU trade since 1988 by HS2,4,6 and CN8 [DS-645593]
USGS	2017	Chromium Data Sheet - Mineral Commodity Summaries 2017
USGS	2018	Chromium Data Sheet - Mineral Commodity Summaries 2018
USGS	2019	Chromium Data Sheet - Mineral Commodity Summaries 2019
USGS	2020	Chromium Data Sheet - Mineral Commodity Summaries 2020
USGS	2021	Chromium Data Sheet - Mineral Commodity Summaries 2021
National Center for Biotechnology Information	2022	PubChem Compound Summary for CID 23976, Chromium

List of data sources	Year	Title
National Center for Biotechnology Information	2022	PubChem Compound Summary for CID 159832, Atomic oxygen
British Geological Survey	2021	World Mineral Production 2015-2019
Worldstainless	2022	Stainless Steel in Figures 2022 edition
Outokumpu Oyj	2017-2020	Outokumpu Annual Reports (2017-2020)
JRC	2017	Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries
Afarak	2017-2020	Afarak Annual Report
EWW	n.a.	Elektrowerke Weisweiler GmbH; Product specifications
Vargön Alloys AB	n.a.	Vargön Company Product specifications
Yildiri Group	2016-2020	Annual Report Yildirim
Outokumpu Oyj	2018	Kemi mine – 50 million tons chromite ore, 50 years of production
EC	2015	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Material
Eurostat	2022	Prodcom - Total production by PRODCOM list (NACE Rev. 2) - annual data [DS-066342]
Fastmarket	2022	Chrome and chromite - A comprehensive market guide for chrome and chromite
Eurostat	2022	EU trade since 1988 by HS2,4,6 and CN8 [DS-645593]

List of data sources	Year	Title
Minerals4EU	2014	EUROPEAN MINERALS YEARBOOK - DATA FOR Chromium
Rasilainen et al.	2016	Quantitative assessment of undiscovered resources in stratiform and podiform chromite deposits in Finland
MDO	2022	Mining data solutions - Kemi mine
WMD	2022	Data Section - Chapters of WMD 2022 with production figures 2016 - 2020:
EC	2022	CRM Chromium; global production based on combined sources of USGS and BGS
Expert feedback	2022	Various expert feedback received at first and second WS in Brussels (09/2022 and 02/2023) and via mail
ICDA	2021	Statistical bulletin 2021 ICDA
Eurostat	2023	EU trade since 1988 by HS2,4,6 and CN8 [DS-645593]
Eurofer	2022	European steel in figures
PRODCOM	2023	Total production [DS-056121__custom_4551473]
Eurostat	2022	End-of-life vehicles by waste management operations - detailed data; End-of-life vehicles - reuse, recycling and recovery, totals
Outokompu	2022	Sustainability Review 2021
Team Stainless	2021	The Global Life Cycle of Stainless Steels
chemicals		miscellaneous
ICDA	2021	Chromium in Special steels
COMEXT	2022	EU trade since 1988 by HS2,4,6 and CN8 [DS-645593]

List of data sources	Year	Title
Leder-Info	2021	Leder-Info - Chromgerbung
Öko-Institut	2023	Expert suggestion for automotive sectors parameter settings
Eurostat	2023	EU Buildings Factsheets

Table 68: Commodities used in the MSA for chromium

List of commodities		
COMEXT	261000	Chromium ores and concentrates
	72287090	Angles, shapes and sections of alloy steel other than stainless, n.e.s. (excl. products not further worked than hot-rolled, hot-drawn or extruded)
	72287010	Angles, shapes and sections of alloy steel other than stainless, not further worked than hot-rolled, hot-drawn or extruded
	72283070	Bars and rods of alloy steel other than stainless steel, of rectangular "other than square" cross-section, hot-rolled on four faces (other than of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.30.41 and 7228.30.49 and excl. semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72283061	Bars and rods of alloy steel other than stainless steel, only hot-rolled, hot-drawn or hot-extruded, of circular cross-section, of a diameter of >= 80 mm (other than of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.30.41 and excl. semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)

List of commodities		
	72283089	Bars and rods of alloy steel other than stainless steel, only hot-rolled, hot-drawn or hot-extruded, of other than rectangular {other than square} cross-section, rolled on four faces, or of circular cross-section (other than of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.30.49 and excl. semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72286080	Bars and rods of alloy steel, other than stainless steel, cold-formed or cold-finished and further worked or hot-formed and further worked (excl. bars and rods of high-speed steel, silico-manganese steel or tool steel, semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72285080	Bars and rods of alloy steel, other than stainless steel, not further worked than cold-formed or cold-finished (excl. of circular cross-section and products of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.50.40, semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72285069	Bars and rods of alloy steel, other than stainless steel, not further worked than cold-formed or cold-finished, of circular cross-section, of a diameter of < 80 mm (excl. of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.50.40, semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72285061	Bars and rods of alloy steel, other than stainless steel, not further worked than cold-formed or cold-finished, of circular cross-section, of a diameter of >= 80 mm (excl. of high-speed steel, silico-manganese steel, tool steel, articles of subheading 7228.50.40, semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72284090	Bars and rods of alloy steel, other than stainless steel, only forged (excl. of high-speed steel, silico-manganese steel, tool steel, semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)

List of commodities		
	72283069	Bars and rods or alloy steel other than stainless steel, only hot-rolled, hot-drawn or hot-extruded, of circular cross-section, of a diameter of < 80 mm (other than of high-speed steel, silico-manganese steel, tool steel and articles of subheading 7228.30.49 and excl. semi-finished products, flat-rolled products and hot-rolled bars and rods in irregularly wound coils)
	72279095	Bars and rods, hot-rolled, in irregularly wound coils of alloy steel other than stainless (excl. of high-speed steel or silico-manganese steel and bars and rods of subheadings 7227.90.10 and 7227.90.50)
	72269199	Flat-rolled products of alloy steel other than stainless steel, simply hot-rolled, of a thickness of < 4,75 mm, of a width of < 600 mm (excl. of tool steel, silicon-electrical steel or high speed steel)
	72269191	Flat-rolled products of alloy steel other than stainless steel, simply hot-rolled, of a thickness of >= 4,75 mm, of a width of < 600 mm (excl. of tool steel, silicon-electrical steel or high speed steel)
	72269910	Flat-rolled products of alloy steel other than stainless, of a width of < 600 mm, hot-rolled or cold-rolled "cold-reduced" and electrolytically plated or coated with zinc (excl. products of high-speed steel or silicon-electrical steel)
	72269970	Flat-rolled products of alloy steel other than stainless, of a width of < 600 mm, hot-rolled or cold-rolled "cold-reduced" and further worked (excl. plated or coated with zinc, and products of high-speed steel or silicon-electrical steel)
	72269930	Flat-rolled products of alloy steel other than stainless, of a width of < 600 mm, hot-rolled or cold-rolled "cold-reduced" and plated or coated with zinc (excl. electrolytically plated or coated, and products of high-speed steel or silicon-electrical steel)
	72269200	Flat-rolled products of alloy steel other than stainless, of a width of < 600 mm, not further worked than cold-rolled "cold-reduced" (excl. products of high-speed steel or silicon-electrical steel)

List of commodities		
	72259100	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and electrolytically plated or coated with zinc (excl. products of silicon-electrical steel)(2007-2500);Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and electrolytically plated or coated with zinc (excl. products of high-speed steel or silicon-electrical steel)(2004-2006)
	72259900	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and further worked (excl. plated or coated with zinc and products of silicon-electrical steel)(2007-2500);Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and further worked (excl. plated or coated with zinc and products of high-speed steel or silicon-electrical steel)(2004-2006)
	72259200	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and plated or coated with zinc (excl. electrolytically plated or coated and products of silicon-electrical steel)(2007-2500);Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, hot-rolled or cold-rolled "cold-reduced" and plated or coated with zinc (excl. electrolytically plated or coated and products of high-speed steel or silicon-electrical steel)(2004-2006)
	72255080	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than cold-rolled "cold-reduced" (excl. products of high-speed steel or silicon-electrical steel)
	72253090	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than hot-rolled, in coils (excl. products of tool steel, high-speed steel or silicon-electrical steel)

List of commodities		
	72254090	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than hot-rolled, not in coils, of a thickness of < 4,75 mm (excl. products of tool steel, high-speed steel or silicon-electrical steel)(2004-2500);Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than hot-rolled, not in coils, of a thickness of < 3 mm "ECSC" (excl. products of high-speed steel or silicon-electrical steel)(1988-1995)
	72254040	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than hot-rolled, not in coils, of a thickness of > 10 mm (excl. products of tool steel, high-speed steel or silicon-electrical steel)
	72254060	Flat-rolled products of alloy steel other than stainless, of a width of >= 600 mm, not further worked than hot-rolled, not in coils, of a thickness of >= 4,75 mm but <= 10 mm (excl. products of tool steel, high-speed steel or silicon-electrical steel)
	72052100	
	73065020	Precision steel tubes, welded, of circular cross-section, of alloy steel other than stainless
	73045181	Precision tubes, seamless, of circular cross-section, of alloy steel other than stainless, cold-drawn or cold-rolled "cold-reduced" (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil and tubes, and pipes and hollow profiles, straight and of uniform wall-thickness, containing by weight >= 0,9% but <= 1,15% carbon and >= 0,5% but <= 2% chrome, whether or not containing by weight <= 0,5% molybdenum)
	72249018	Semi-finished products of alloy steel other than stainless steel, of square or rectangular cross-section, forged (excl. of tool steel)

List of commodities		
	72249007	Semi-finished products of alloy steel other than stainless steel, of square or rectangular cross-section, hot-rolled or obtained by continuous casting, the width measuring < twice the thickness (excl. of tool steel, high-speed steel and articles of subheading 7224.90.05)
	72249014	Semi-finished products of alloy steel other than stainless steel, of square or rectangular cross-section, hot-rolled or obtained by continuous casting, the width measuring >= twice the thickness (excl. of tool steel)
	72249090	Semi-finished products of alloy steel, other than stainless steel, forged (excl. of tool steel and products of square or rectangular, circular or polygamol cross-section)
	73045189	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, not cold-drawn or cold-rolled "cold-reduced" (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil, precision tubes, and , pipes and hollow profiles, straight and of uniform wall-thickness, containing by weight >= 0,9% but <= 1,15% carbon and >= 0,5% but <= 2% chrome, whether or not containing by weight <= 0,5% molybdenum)
	73045992	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, not cold-drawn or cold-rolled "cold-reduced", of an external diameter of <= 168,3 mm (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas and tubes, pipes and hollow profiles of heading 7304.59.10 to 7304.59.38)
	73045993	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, not cold-drawn or cold-rolled "cold-reduced", of an external diameter of > 168,3 mm but <= 406,4 mm (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas and tubes, pipes and hollow profiles of heading 7304.59.10 to 7304.59.38)

List of commodities		
	73045999	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, not cold-drawn or cold-rolled "cold-reduced", of an external diameter of > 406,4 mm (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas and tubes, pipes and hollow profiles of heading 7304.59.10 to 7304.59.38)
	73045910	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of alloy steel other than stainless, not cold-drawn or cold-rolled "cold-reduced", unworked, straight and of uniform wall-thickness, for use solely in the manufacture of tubes and pipes with other cross-sections and wall-thicknesses
	73065080	Tubes, pipes and hollow profiles, welded, of circular cross-section, of alloy steel other than stainless (excl. tubes and pipes having internal and external circular cross-sections and an external diameter of > 406,4 mm, and line pipe of a kind used for oil or gas pipelines or casing and tubing of a kind used in drilling for oil or gas, and precision steel tubes)
	72299090	Wire of alloy steel other than stainless, in coils (excl. rolled bars and rods, wire of high-speed steel or silico-manganese steel and articles of subheading 7229.90.50)
	73041100	Line pipe of a kind used for oil or gas pipelines, seamless, of stainless steel
	73042200	Drill pipe, seamless, of stainless steel, of a kind used in drilling for oil or gas
	73042400	Casing and tubing, seamless, of a kind used for drilling for oil or gas, of stainless steel
	73044100	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of stainless steel, cold-drawn or cold-rolled "cold-reduced" (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas)

List of commodities		
	73044910	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of stainless steel, not cold-drawn or cold-rolled "cold-reduced", unworked, straight and of uniform wall-thickness, for use solely in the manufacture of tubes and pipes with other cross-sections and wall-thicknesses
	73044993	Tubes, pipes and hollow profiles, seamless, of circular cross-section, of stainless steel, not cold-drawn or cold-rolled "cold-reduced", of an external diameter of <= 168,3 mm (excl. line pipe of a kind used for oil or gas pipelines, casing and tubing of a kind used for drilling for oil or gas and tubes, pipes and hollow profiles of heading 7304.49.10)
	73061110	Line pipe of a kind used for oil or gas pipelines, longitudinally welded, of flat-rolled products of stainless steel, of an external diameter of <= 406,4 mm
	73061190	Line pipe of a kind used for oil or gas pipelines, spirally welded, of flat-rolled products of stainless steel, of an external diameter of <= 406,4 mm
	73062100	Casing and tubing of a kind used in drilling for oil or gas, welded, of flat-rolled products of stainless steel, of an external diameter of <= 406,4 mm
	73064020	Tubes, pipes and hollow profiles, welded, of circular cross-section, of stainless steel, cold-drawn or cold-rolled "cold-reduced" (excl. products having internal and external circular cross-sections and an external diameter of > 406,4 mm, and line pipe of a kind used for oil or gas pipelines or casing and tubing of a kind used in drilling for oil or gas)
	73064080	Tubes, pipes and hollow profiles, welded, of circular cross-section, of stainless steel (excl. products cold-drawn or cold-rolled "cold-reduced", tubes and pipes having internal and external circular cross-sections and an external diameter of > 406,4 mm, and line pipe of a kind used for oil or gas pipelines or casing and tubing of a kind used in drilling for oil or gas)
	73066110	Tubes and pipes and hollow profiles, welded, of square or rectangular cross-section, of stainless steel

List of commodities		
	73066910	Tubes, pipes and hollow profiles, welded, of non-circular cross-section, of stainless steel (excl. tubes and pipes having internal and external circular cross-sections and an external diameter of > 406,4 mm, line pipe of a kind used for oil or gas pipelines or casing and tubing of a kind used in drilling for oil or gas, and tubes and pipes and hollow profiles of square or rectangular cross-section)
	73072100	Flanges of stainless steel (excl. cast products)
	73072210	Sleeves, of stainless steel, threaded (excl. cast products)
	73072290	Elbows and bends, of stainless steel, threaded (excl. cast products)
	73072310	Butt welding elbows and bends of stainless steel (excl. cast products)
	73072390	Butt welding tube or pipe fittings of stainless steel (excl. cast products and elbows and bends)
	73072910	Threaded tube or pipe fittings of stainless steel (excl. cast products, flanges, elbows, bends and sleeves)
	73072980	Tube or pipe fittings of stainless steel (excl. cast, threaded, butt welding fittings and flanges)
	73141200	Endless bands of stainless steel wire, for machinery
	73141400	Woven cloth, incl. endless bands, of stainless steel wire (excl. woven products of metal fibres of a kind used for cladding, lining or similar purposes and endless bands for machinery)
	73181210	Wood screws of stainless steel (excl. coach screws)
	73181530	Screws and bolts, of stainless steel "whether or not with their nuts and washers", without heads (excl. screws turned from bars, rods, profiles, or wire, of solid section, threaded, of a shank thickness of <= 6 mm, and screws and bolts for fixing railway track construction material)

List of commodities		
	73181551	Slotted and cross-recessed screws and bolts, of stainless steel "whether or not with their nuts and washers", with heads (excl. wood screws and self-tapping screws)
	73181561	Hexagon socket head screws and bolts, of stainless steel "whether or not with their nuts and washers" (excl. wood screws, self-tapping screws and screws and bolts for fixing railway track construction material)
	73181570	Hexagon screws and bolts, of stainless steel "whether or not with their nuts and washers", with heads (excl. socket head screws, wood screws, self-tapping screws and screws and bolts for fixing railway track construction material)
	73181630	Nuts of stainless steel (excl. nuts turned from bars, rods, profiles, or wire, of solid section, with an inside diameter of <= 6 mm)
	28191000	Chromium trioxide
	28199010	Chromium dioxide
	28199090	Chromium oxides and hydroxides (excl. chromium trioxide and chromium dioxide)
	28332300	Sulphates of chromium
	28413000	Sodium dichromate
	28415000	Chromates and dichromates; peroxochromates (excl. sodium dichromate and inorganic or organic compounds of mercury) […]
	28499050	Carbides of aluminium, of chromium, of molybdenum, of vanadium, of tantalum, and of titanium, whether or not chemically defined
	72024110	Ferro-chromium, containing by weight > 4% but <= 6% carbon

List of commodities		
	72024190	Ferro-chromium, containing by weight > 6% carbon(2004-2500);Ferro-chromium, containing by weight > 6 % carbon(1988-1993)
	72024191	Ferro-chromium, containing by weight > 6% carbon and <= 60% chromium
	72024199	Ferro-chromium, containing by weight > 6% carbon and > 60% chromium
	72024910	Ferro-chromium, containing by weight <= 0,05% carbon
	72024950	Ferro-chromium, containing by weight > 0,05% but <= 0,5% carbon
	72024990	Ferro-chromium, containing by weight > 0,5% but <= 4% carbon
	72025000	Ferro-silico-chromium
	72042110	Waste and scrap of stainless steel, containing by weight >= 8% nickel (excl. radioactive, and waste and scrap from batteries and electric accumulators)(1996-2500);Waste and scrap, of stainless steel (ECSC), containing >= 8% nickel (other than radioactive)(1995-1995)
	72042190	Waste and scrap of stainless steel (not containing >= 8% nickel, radioactive, or waste and scrap from batteries and electric accumulators)(1996-2500);Waste and scrap, of stainless steel (ECSC) (not containing >= 8% of nickel or radioactive)(1995-1995)
	72042900	Waste and scrap of alloy steel (excl. stainless steel, and waste and scrap, radioactive, or waste and scrap from batteries and electric accumulators)(1996-2500);Waste and scrap, of alloy steel "ECSC" (excl. stainless steel, and waste and scrap, radioactive)(1988-1995)
	72181000	Steel, stainless, in ingots and other primary forms (excl. waste and scrap in ingot form, and products obtained by continuous casting)

List of commodities		
	72241090	Steel, alloy, other than stainless, in ingots or other primary forms (excl. of tool steel, waste and scrap in ingot form and products obtained by continuous casting)
	81122200	Chromium waste and scrap (excl. ash and residues containing chromium and chromium alloys containing > 10% by weight of nickel)
PRODCOM	24106470	Bars and rods of stainless steel, cold-formed or cold-finished and further worked, or hot-formed and further worked, n.e.s. (excluding forged products)
	24106660	Bars and rods, of alloy steel, cold-formed or cold-finished (e.g. by cold-drawing), painted, coated, clad or further worked (excluding stainless steel)
	2410T131	Crude steel: alloy steel other than stainless steel produced in electric furnaces
	2410T132	Crude steel: alloy steel other than stainless steel produced by other processes than in electric furnaces
	2410T141	Crude steel: stainless and heat resisting steel produced in electric furnaces
	2410T142	Crude steel: stainless and heat resisting steel produced by other processes than in electric furnaces
	24312040	Bars and rods, of alloy steel, not further worked than cold-formed or cold-finished (e.g. by cold-drawing) (excluding stainless steel, high-speed steel, silico-manganese steel, alloy bearing steel, tool steel)
	24312050	Sections, of alloy steel other than stainless, cold-finished or cold-formed (e.g. by cold-drawing)
	24313000	Cold-drawn bars and solid profiles of stainless steel

Table 69: Commodities not used in the MSA for chromium

List of commodities			Reason why not used
NA			

7.6. Appendix 2 – Data sources for coking coal

Table 70: Main stakeholders involved in the MSA for coking coal

List of stakeholders
JSW S.A.
Silesian University of Technology
ITPE
EURACOAL

Table 71: Data sources used in the MSA for coking coal

List of data sources	Year	Title
BGR	2022, 2020, 2019	Energiestudie 2021/2019/2018/2017
BP	2021	Statistical Review of World Energy 2021
World Mining Data	2022	World mining Data 2022
Panagiotis Grammelis, Nikolaos Margaritis and Emmanouil Karampinis	2016	2 - Solid fuel types for energy generation: Coal and fossil carbon-derivative solid fuels
VDKI	2021	Annual Report 2021
EU	2022	Comext EU trade since 1988 by HS2-4-6 and CN8 [DS-645593]
Kot-Niewiadomska et al.	2021	Safeguarding of Key Minerals Deposits as a Basis of Sustainable Development of Polish Economy
EC	2015	MSA of Coking Coal 2015

List of data sources	Year	Title
EU	2022	EU trade since 1988 by HS2-4-6 and CN8 [DS-645593]
VDKI	2021	Annual Report 2021
Eurostat	2022	Prodcom - Verkaufte Produktion, Exporte und Importe je PRODCOM Liste (NACE Rev. 2) - Jährliche Daten [DS-066341]
EC	2017	Best available techniques (BAT) reference document for the non-ferrous metals industries
Eurostat	2022	Supply, transformation and consumption of solid fossil fuels [nrg_cb_sff]
EC	2022	Coking coal: Impact assessment for supply security
Various	2022	Expert feedback Silesian University of Technology
Various	2022	Expert feedback JSW SA
Richa refractories	2018	Metallurgical Coke
Expert feedback	2022	Expert feedback by JSW via mail on 28/10/2022
IEA	2022	Coal Analysis and forecast to 2024 – International Energy Agency
Expert feedback	2023	Email contact with Bartosz Mertas (ITPE) (17.02.2023 and 07.03.2023)
Expert feedback	2023	Expert feedback 2nd Workshop in Brussels (17.02.2023)

Table 72: Commodities used in the MSA for coking coal

List of commodities		
Supply, transformation and consumption of solid fossil fuels [NRG_CB_SFF]	Indigenous production	Coke oven coke
	Indigenous production	Coking Coal
	Import	Coke oven coke
	Import	Coking Coal
	Export	Coke oven coke
	Export	Coking Coal
PRODCOM	27901330	Carbon electrodes Carbon electrodes for furnaces
	27901350	Carbon electrodes (except for furnaces)
COMEXT	27011210	Coking coal, whether or not pulverised, non-agglomerated
	27040010	Coke and semi-coke of coal, whether or not agglomerated

Table 73: Commodities not used in the MSA for coking coal

List of commodities			Reason why not used
NA			

7.7. Appendix 2 – Data sources for fluorspar

Table 74: Main stakeholders involved in the MSA for fluorspar

List of stakeholders
Cefic
Chemours
University of Geneva
CSIS
Instituto Geológico y Minero de España
Peter Huxtable

Table 75: Data sources used in the MSA for fluorspar

List of data sources	Year	Title
USGS	2018-2022	Mineral Commodity Summary - Fluorspar 2018-2022
BGS	2022	World Mineral Production - Fluorspar
BGS	2011	British Geological Survey, Mineral factsheet - Fluorspar, 2011
BGS	2010	BGS, Mineral Planning Factsheet - Fluorspar, 2010
BGS	2011	BGS, Commodity Profile - Fluorspar, 2011
Luis Fontbote	2022	Personal communication after expert validation workshop
WMD	2022	World Mining Data 2022 - Fluorspar
USGS	2019	USGS, 2019 Minerals Yearbook - Spain, 2019 - Fluorspar

List of data sources	Year	Title
Eurostat - Comext database	2021	Eurostat Comext database - Codes 252922 - Acid grade fluorspar; 252921 - Metallurgical grade fluorspar; 281111 - Hydrogen fluoride (hydrofluoric acid); 282630 - Sodium hexafluoroaluminate "synthetic cryolite"; 28261200 - Fluoride of aluminium
KronosMetal	2021	Fluorite Fluorspar CaF2
EurGeo	2018	Spain's fluorspar resources, production & markets
Deloitte	2015	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials
Rafael Navarro	2022	Personal communication after expert validation workshop
Eurostat - Prodcom	2022	Eurostat Prodcom - code 20132473 Hydrogen fluoride (hydrofluoric acid)
Gobierno de Espana	2022	ESTADÍSTICA MINERA DE ESPAÑA 2020
USGS	2017	USGS, 2012 Minerals Yearbook - Fluorspar, 2017
Expert interview	2012	Peng Paternostre, personal communication, 02/07/2014 (previous MSA)
VROM	2008	VROM (2008) ALUMINIUM FLUORIDE SUMMARY RISK ASSESSMENT REPORT (ENVIRONMENT), 17 pp.
Synthetic Cryolite Plant	2022	Synthetic Cryolite Plant
Eurostat	2022	Reply from Eurostat to questions on Fluorspar statistics
CRM Alliance	2017	Mineral Planning Factsheet - Fluorspar
SCREENN workshop	2022	Expert validation during CRM & MSA SCREENN workshop held in September 2022 and February 2023

List of data sources	Year	Title
Soricom	2022	Soricom SOCIETA' RICERCHE COLTIVAZIONI MINERARIE - About us
Baystreet	2021	How China's Surge of Iron Ore Imports Seems to be Impacting Global Steel Production
Eurofer	2021	European Steel in Figures 2021
European Aluminium	2022	Europe increasingly relies on aluminium imports
Silveira et al.	2022	Red Mud from the Aluminium Industry: Production, Characteristics, and Alternative Applications in Construction Materials—A Review
Weston et al.	2010	Streamlined Life Cycle Approaches for Use at Oil Refineries and Other Large Industrial Facilities
Castro et al.	2022	Characterization of Stainless Steel Spent Pickling Sludge and Prospects for Its Valorization
World Nuclear Association	2022	Uranium Enrichment
Euratom	2021	Annual report 2020
Öko-Institut	2022	Fluorinated greenhouse gases 2022- Data reported by companies on the production, import, export and destruction of fluorinated greenhouse gases in the European Union, 2007-2021
EFPIA	2021	International EU27 pharmaceutical production, trade, dependencies and vulnerabilities: a factual analysis
Mondillo et al.	2017	Evaluation of the amount of rare earth elements -REE in the Silius fluorite vein system (SE Sardinia, Italy)

List of data sources	Year	Title
BRGM	2015	La fluorine, une substance à criticité élevée pour l'Union Européenne
Peter Huxtable	2023	Personal communication after expert validation workshop
European Commission	2023	MSA of aggregates
EDF	2023	L'uranium : le combustible nucléaire
Eurostat Statistics Explained	2023	Gross nuclear electricity production from 2017 to 2021
Eurostat	2023	Prodcom: Sold production, exports and imports
European Union	2015	The Durability of Products - Final report
Ecosystem	2022	DEEE ménagers et lampes Rapport Développement Durable 2021

Table 76: Commodities used in the MSA for fluorspar

List of commodities		
COMEXT	252922	Acid grade fluorspar
	252921	Metallurgical grade fluorspar
	281111	Hydrogen fluoride (hydrofluoric acid)
	28261200	Fluoride of aluminium
	282630	Sodium hexafluoroaluminate "synthetic cryolite"
PRODCOM	20132473	Hydrogen fluoride (hydrofluoric acid)

Table 77: Commodities not used in the MSA for fluorspar

List of commodities			Reasons why not used
COMEXT	28013010	Fluorine	not usable, content unknown
	28269080	Fluorosilicates; fluoroaluminates and other complex fluorine salts (excl. sodium hexafluoroaluminate "synthetic cryolite"; dipotassium hexafluroziirconate and inorganic or organic compounds of mercury)	not usable, content unknown
	28261910	Fluoride of ammonium or of sodium	not usable, content unknown
	28261990	Fluorides (excl. Of ammonium, sodium, aluminium and mercury)	not usable, content unknown
	28269010	Dipotassium hexafluorozirconate	not usable, content unknown
	390461	Polytetrafluoroethylene, in primary forms	not usable, content unknown
PRODCOM	20132116	Iodine; fluorine; bromine	not usable, content unknown
	20133115	Fluorides; fluorosilicates; fluoroaluminates and other complex fluorine salts (Lithium hexafluorophosphate (1-), Lithium difluorophosphate, Lithium hexafluoroarsenate monohydrate, Lithium tetrafluoroborate)	not usable, content unknown

List of commodities			Reasons why not used
	20133119	Fluorides; fluorosilicates; fluoroaluminates and other complex fluorine salts (excl. sodium hexafluoroaluminate "synthetic cryolite"; hexafluorophosphate (1-), difluorophosphate, hexafluoroarsenate monohydrate andtetrafluoroborate of lithium; inorganic or organic compoundsof mercury)	not usable, content unknown
	20133110	Fluorides, fluorosilicates, fluoroaluminates and other complex fluorine salts	not usable, content unknown
	20141910	Fluorinated, brominated or iodinated derivatives of acyclic hydrocarbons	not usable, content unknown
	20163060	Fluoropolymers	not usable, content unknown

7.8. Appendix 2 – Data sources for gallium

Table 78: Main stakeholders involved in the MSA for gallium

List of stakeholders
Indium Corporation
VitalChem
FCM
Omnis Mineria

Table 79: Data sources used in the MSA for gallium

Author	Year	Title
USGS	2018	Mineral Commodity Summary - Gallium
USGS	2019	Mineral Commodity Summary - Gallium
USGS	2020	Mineral Commodity Summary - Gallium
USGS	2021	Mineral Commodity Summary - Gallium
USGS	2022	Mineral Commodity Summary - Gallium
Indium Corporation	2019	Availability of indium and gallium
European Commission	2020	CRM: Study on the EU's list of Critical Raw Materials (2020) - Gallium
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
Claire Mikolajczak	2022	Expert personal communication, August 2022
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
BGS	2022	World Mineral Production - Bauxite
European Commission	2014	CRM (2014) Critical Raw Materials Report - Critical material profiles issues
Eurostat - Comext database	2022	Eurostat, Comext
Fameree	2012	Fameree (2012) Mémoire fin études - Le Ga, un métal rare, inépuisable grâce à sa production secondaire

Author	Year	Title
GONZALO MAYORAL FERNÁNDEZ	2021	EUROPEAN PROJECT SCRRENN – GALLIUM - NOTES AFTER MEETING 21 OCTOBER 2021
SCREENN workshop	2022	Expert validation during CRM & MSA SCREENN workshop held in September 2022
Industrial player	2022	Interview with industrial player
Made in China.com		210W CIGS Panneau solaire souple (Flex-03M-1.7M)
BGR	2016	Supply and Demand of lithium and gallium
Indium Corporation	2019	Availability of indium and gallium
Eurostat	2020	The EU in the world
Deloitte	2015	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials
Ericsson, Sony Mobile	2022	Life Cycle Assessment of a Smartphone
9to5mac	2021	Report: iPhone owners more likely to sell or trade in their old devices than Android users
USINESS WIRE-Research and Markets	2016	Worldwide Smartphone Market Forecast, 2016-2020 - Research and Markets
Chowdhury et al.	2020	An overview of solar photovoltaic panels' end-of-life material recycling
IEA-PVPS	2018	End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies
Fraunhoger ISE	2022	PHOTOVOLTAICS REPORT
PV magasine	2021	European consortium develops pilot line for complete PV module recycling
Centre for European Policy Studies	2019	Identifying the impact of the circular economy on the Fast-Moving Consumer Goods Industry: opportunities and challenges for businesses, workers and consumers - mobile phones as an example
Markets & markets	2017	Radar sensors market by type & technology - forecast to 2023
Zhou et al.	2019	Recovery of gallium from waste light emitting diodes by oxalic acidic leaching
Sun Vision Display	2020	The Lifespan of Digital Display Technologies
USINESS WIRE-Research and Markets	2016	Global LED Backlight Display Driver ICs Market 2016-2020 - Expected to Grow at CAGR of 8.24% - Research and Markets
Forti et al.	2020	The Global E-waste Monitor 2020 - Quantities, flows, and the circular economy potential

Author	Year	Title
Wilson et al.	2017	The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery
SCREENN workshop	2022	Expert validation during MSA workshop held in February 2023
HSSMI	2021	The Economics of Gallium Extraction from LED Lamps
Eurostat - Prodcom database	2023	Prodcom code 26.11.22.20 Semiconductor light emitting diodes (LEDs)
Zhou J et al.	2019	Recovery of gallium from waste light emitting diodes by oxalic acidic leaching
Eurostat – Comext database	2023	Comext code 853950- Light-emitting diode "LED" lamps
Eurostat - Comext database	2023	Comext code 85414090 - Photosensitive semiconductor devices, incl. photovoltaic cells

Table 80: Commodities used in the MSA for gallium

List of commodities		
COMEXT	81129289	UNWROUGHT GALLIUM ; GALLIUM POWDERS
	85414090	Photosensitive semiconductor devices, incl. photovoltaic cells
	853950	Light-emitting diode "LED" lamps
PRODCOM	26.11.22.20	Semiconductor light emitting diodes (LEDs)

Table 81: Commodities not used in the MSA for gallium

List of commodities			Reason why not used
NA			

7.9. Appendix 2 – Data sources for germanium

Table 82: Main stakeholders involved in the MSA for germanium

List of stakeholders
UMICORE
Vital Materials
Indium Corporation
International Zinc Association
International Cadmium Association
Prysmian Group

Table 83: Data sources used in the MSA for germanium

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Germanium
BGS	2022	World Mineral Production 2016-2020
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
Eurostat	2022	Eurostat - Comext database
Eurostat	2022	Eurostat - Prodcom database
BRGM	2011	Panorama du marché 2010 du Germanium
DERA	2012	Current and future germanium availability from primary sources
Licht et al.	2015	Global Substance Flow Analysis of Gallium, Germanium and Indium

List of data sources	Year	Title
Krzysztof	2021	LA-ICP-MS Trace element study sphalerites from the MVT Cracow-Silesia district, Poland
BisReport Mining Research Center	2022	Global Germanium Market Status, Trends and COVID 19 Impact Report 2022
Institute of Fluid Dynamics at HZDR	2013	Waste that is brimming with energy
Wafer World	2022	Can Silicon Wafers Be Recycled?
SOREN	2021	Rapport d'activité 2021
JRC	2020	Analysis of durability, reusability and reparability. Application to washing machines and dishwashers
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
JRC	2018	Towards Recycling Indicators based on EU flows and Raw Materials System Analysis data
Statista	2021	LED market revenue share worldwide in 2021, by application
Mordor intelligence	2018	Global transistor Market
Sycabel	2022	Espérance de vie des infrastructures optiques passives
DGE	2022	Improved WEEE data give a better picture of collection and recycling rates
Lisa Tostado	2021	End-Of-Life Vehicles: Final Destination
Reale F., et al.	2019	Basket of products indicators on household appliances

Table 84: Commodities used in the MSA for germanium

None used for germanium flows, as content is unknown, or codes are empty.

Table 85: Commodities not used in the MSA for germanium

List of commodities			Reasons why not used
COMEXT	28256010	Germanium oxides	empty
	81129295	Unwrought germanium and germanium powders	replaced by commercial trade data, which is available for all germanium forms
	81129920	Articles of hafnium "celtium" and germanium, n.e.s.	not usable
	81129940	Articles of germanium, n.e.s.	not usable
	81129221	Niobium "columbium", rhenium, gallium, indium, vanadium and germanium waste and scrap (excl. ashes and residues containing these metals)	not usable
	81123020	Unwrought germanium; germanium powders	empty
	81123040	Germanium waste and scrap (excl. ashes and residues containing germanium)	empty
	81123090	Articles of germanium, n.e.s.	empty
PRODCOM	20121970	Germanium oxides and zirconium dioxide	considered to contain 0% of germanium as the correspondding COMEXT code is empty
	24453079	Unwrought germanium and germanium powders	not useable
	24453063	Articles of hafnium "celtium" and germanium, n.e.s.	not usable
	24453066	Niobium "columbium", rhenium, gallium, indium, vanadium and germanium waste and scrap (excl. ashes and residues containing these metals)	not usable

7.10. Appendix 2 – Data sources for indium

Table 86: Main stakeholders involved in the MSA for indium

List of stakeholders
BRGM
Indium Corp
International Zinc Association
Vital Materials
WMD
Umicore

Table 87: Data sources used in the MSA for indium

List of data sources		
USGS	2017-2021	Mineral Commodity Summaries
Ulrich Schwarz-Schampera	2014	"Critical Metals Handbook", chapter "indium"
WMD	2022	6.2.World Production of Mineral Raw Materials by Mineral Raw Materials.xlsx
WMD	2022	6.4.Production of Mineral Raw Materials of individual Countries by Minerals.xlsx
University of Southampton		NEETE database- indium corrected - reordered.xls (NERC Grant - NE/L002329/1 - Natural Enrichments in E- Tech Elements (Co, Ga, In, Te, Li, REE) [NEETE])
Dr. Laura LAURI (GTK)	2018	Identification and quantification of primary CRM resources in Europe
BGS	2021	Production of indium, refinery (statisticsExport.xlsx)
Werner et al.	2017	The world's by-product and critical metal resources part III: A global assessment of indium.
Ayres et al.	2014	Handbook on recycling, chapter 4 "Recycling Rare Metals"
BRGM	2017	Fiche de synthèse sur la criticité des métaux - L'indium
BGS	2021	Production of zinc, slab

List of data sources		
mindat.org	2022	Indium
Team 2	2020	Interview: Xavier Constant, zinc producer Made in France
Saxore Bergbau GmbH	2022	Geological Overview
Jonsson et al.	2013	Roquesite and Associated Indium-Bearing Sulfides from a Paleoproterozoic Carbonate-Hosted Mineralization: Lindbom's Prospect, Bergslagen, Sweden
Cookab et al.	2011	Indium mineralisation in A-type granites in southeastern Finland: Insights into mineralogy and partitioning between coexisting minerals
EC	2017	Study on the review of the list of critical raw materials: critical raw materials factsheets
Moeller et al.	2015	Background report for the development of an EMAS Sectoral Reference Document on Best Environmental Management Practice for the Electrical and Electronic Equipment manufacturing sector - Preparatory findings supporting the development of an EMAS Sectoral Reference Document
Virolainen et al.	2011	Recovery of indium from LCD screens
EL Latunussa et al.		Study on the EU's list of Critical Raw Materials, Critical Raw Materials Factsheets (Final)
Stahl et al.		Assessment of Options to Improve Particular Aspects of the EU Regulatory Framework on Batteries Final Report
EC	2020	COMMISSION STAFF WORKING DOCUMENT EVALUATION of Directive (EC) 2000/53 of 18 September 2000 on end-of-life vehicles {SWD(2021) 61 final}
PV magasine	2021	European consortium develops pilot line for complete PV module recycling
SCREENN workshop	2022	Expert validation during MSA workshop held in February 2023 for Galium
SCREENN workshop	2022	Expert validation during MSA workshop held in February 2023 for Galium
Made in China.com		210W CIGS Panneau solaire souple (Flex-03M-1.7M)
Indium Corporation	2019	Availability of Indium and Gallium

List of data sources		
Deloitte	2015	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials
Chowdhury et al.	2020	An overview of solar photovoltaic panels' end-of-life material recycling

Table 88: Commodities used in the MSA for indium

Eurostat codes used for the MSA of indium:

List of commodities		
COMEXT	26080000	Zinc ores and concentrates
	81129281	Unwrought indium; indium powders
PRODCOM	27902020	Indicator panels incorporating liquid crystal display (LCD) production, export and import:
	26114070	Parts of diodes, transistors and similar semiconductor devices, photosensitive semiconductor devices and photovoltaic cells, light-emitting diodes and mounted piezo-electric crystals
	27201100	Primary cells and primary batteries --> years 2016-2018, other years missing
	23121150	Optical glass of HS 7003, 7004 or 7005, bent, edge-worked, engraved, etc.
	23121190	Other glass of HS 7003, 7004 or 7005, bent, edge-worked, engraved, etc.
	29102100	Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³

	2910223 0	Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	2910231 0	Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	2910233 0	Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)

Table 89: Commodities not used in the MSA for indium

List of commodities			Reason why not used
COMEXT	81129181	Unwrought indium; indium powders;	empty
	81129250	Gallium and indium waste and scrap;	empty
	81129221	Niobium "columbium", rhenium, gallium, indium, vanadium and germanium waste and scrap (excl. Ashes and residues containing these metals);	empty
	81129150	Gallium, Indium and thallium waste and scrap;	empty
	81129190	Gallium, Indium and thallium, unwrought; powders and waste and scrap of these metals;	empty
	811291	Unwrought hafnium "celtium", niobium….	empty
Prodcom	27201110	Manganese dioxide cells and batteries, alkaline, in the form of cylindrical cells (excl. spent)	Partial data – does not fit with trend of production/trade for earlier years
	27201115	Other manganese dioxide cells and batteries, alkaline (excl. spent, and cylindrical cells) --> years 2019 + 2020	Partial data – does not fit with trend of production/trade for earlier years

7.11. Appendix 2 – Data sources for magnesite/magnesia

Table 90: Main stakeholders involved in the MSA for magnesite

List of stakeholders
Nedmag B.V.
RHI Magnesita
Euromines
IMA Europe
FEFAC
Confederation of European Paper Industries
EuroGeoSurveys
GTK
Polish Geological Institute
BGS

Table 91: Data sources used in the MSA for magnesite

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Magnesite
Eurostat	2022	Eurostat database (PRODCOM and ComExt)
Li et al.	2021	Study on regulators of purifying magnesite ore by cationic reverse flotation
International organizing comittee for the world mining congresses	2022	World Mining Data
World Mineral Production	2022	BGS
European Commission	2020	Study on the EU's list of Critical Raw Materials - Non-Critical Raw Materials Factsheets

List of data sources	Year	Title
L'elementarium	2022	Fiche complète Carbonate de magnesium
Shanmugasundaram, V., Shanmugam, B.	2021	Characterisation of magnesite mine tailings as a construction material
Euromines	2020	The European Magnesite/Magnesia Industry: enabler in the transition to a low-carbon economy
Chaouki Sadik, Omar Moudden, Abdselam El Bouari, Iz-Eddine El Amrani,	2016	Review on the elaboration and characterization of ceramics refractories based on magnesite and dolomite,
MordorIntelligence	2023	EUROPE FERTILIZERS MARKET - SIZE, SHARE, COVID-19 IMPACT & FORECASTS UP TO 2028
MordorIntelligence	2023	EUROPE PAPER MARKET - GROWTH, TRENDS, COVID-19 IMPACT, AND FORECASTS (2023- 2028)
Beatrice Plešingerová, Pavol Vadász, Rastislav Kamenský, Ján Derďak, Jana Bounziová, Eva Dedinská, Marek Vojtko	2018	Spent magnesia-carbon refractory bricks from steel production: Potentiality of MgO-clinker recovery
J T Schonewille 1, H Everts, S Jittakhot, A C Beynen	2008	Quantitative prediction of magnesium absorption in dairy cows

Table 92: Commodities used in the MSA for magnesite

List of commodities		
COMEXT	25191000	Natural magnesium carbonate "magnesite"
	28273100	Magnesium chloride
	25199090	Fused magnesia

List of commodities		
	25199030	Dead-burned "sintered" magnesia, whether or not containing small quantities of other oxides added before sintering
	25199010	Magnesium oxide, whether or not pure (excl. calcined natural magnesium carbonate)
PRODCOM	23201210	Refractory ceramic constructional goods containing >50 % of MgO, CaO or Cr_2O_3 including bricks, blocks and tiles excluding goods of siliceous fossil meals or earths, tubing and piping
	17127755	Bleached paper and paperboard in rolls or sheets, coated, impregnated or covered with plastics weighing > 150 g/m² (excluding adhesives)
	8911900	Other chemical and fertiliser minerals

Table 93: Commodities not used in the MSA for magnesite

List of commodities		
PRODCOM	10911033	Preparations used for farm animal feeding (excluding premixtures): pigs
	10911035	Preparations used for farm animal feeding (excluding premixtures): cattle
	10911037	Preparations used for farm animal feeding (excluding premixtures): poultry
	10911039	Preparations used for farm animal feeding (excluding premixtures): n.e.c.

7.12. Appendix 2 – Data sources for magnesium

Table 94: Main stakeholders involved in the MSA for magnesium

List of stakeholders
International Magnesium Association - IMA
RHI Magnesita GmbH
V.I.C.
European Aluminium Association

Table 95: Data sources used in the MSA for magnesium

List of data sources	Year	Title
USGS	2022	Magnesium Statistics and Information
National Center for Biotechnology Information	2022	PubChem Element Properties and Compound Summary
British Geological Survey	2020	World Mineral Production 2016-2020
World Mining Data	2022	Production of Mineral Raw Materials of individual Countries by Minerals
Eurostat Comext	2022	EU trade since 1988 by HS2,4,6 and CN8 (Product Codes: 81041100)
Eurostat Comext	2022	EU trade since 1988 by HS2,4,6 and CN8 (Product Codes: 76012020 + 76012080 = 760120) [DS-645593]
Eurostat PRODCOM	2022	Total production by PRODCOM list (NACE Rev. 2) - annual data [DS-066342]
Eurostat PRODCOM	2022	Total production by PRODCOM list (NACE Rev. 2) - annual data [DS-066342 (Codes: 24421153; 24421154; 24421155; 24453024; 24453026]

List of data sources	Year	Title
North American Die-Casting Association	2021	Magnesium Alloys
European Aluminium Association:	2006	European Aluminium Association: Aluminium Recycling in Europe - The Road to High Quality Products, 2006
Eurostat PRODCOM	2022	Verkaufte Produktion, Exporte und Importe je PRODCOM Liste (NACE Rev. 2) - Jährliche Daten [DS-066341]
IMA	2017	Magnesium Recycling in the EU - Material flow analysis of magnesium (metal) in the EU and a derivation of the recycling rate
Eurostat Comext	2022	EU trade since 1988 by HS2,4,6 and CN8
Webmineral	2022	Webmineral - Dolomite Mineral Data
Eurostat	2022	Feedback help center regarding evolution of trade codes
BGS	n.d.	Commodity profile - MAGNESIUM
expert feedback	2022	Expert feedback at 09/2022 SCRREEN Workshop in Brussels and 03/2023
Expert feedback	2023	Suggestion for parameters for automotive sector / vehicle from Öko-Institut
Airbus	2022	End-of-life Reusing, recycling, rethinking
European Aluminium	2022	Aluminium beverage can recycling rates 2020 - Report of the activities undertaken
EC	2015	MSA Magnesium 2015
Hypthesis on annual growth rate	2023	Annual change rate (model internal estimate)
Efthymiou E.	n.d.	Structural Aluminium Alloys and Sustainability in Building Applications
BGS	2023	Production of magnesium metal, primary

Table 96: Commodities used in the MSA for magnesium

List of commodities		
COMEXT	81043000	Magnesium raspings, turnings and granules, graded according to size; magnesium powders
	81041100	Unwrought magnesium, containing >= 99,8% by weight of magnesium
	760200	Waste and scrap, of aluminium (excl. slags, scale and the like from iron and steel production, containing recoverable aluminium in the form of silicates, ingots or other similar unwrought shapes, of remelted waste and scrap, of aluminium, ashes and residues from aluminium production)
	810420	Magnesium waste and scrap (excl. ash and residues containing magnesium, and raspings, turnings and granules graded according to size)
	81041900	Unwrought magnesium, containing < 99,8% by weight of magnesium
	760120	Unwrought aluminium alloys
	810490	Articles of magnesium, n.e.s.
	843311	Mowers for lawns, parks or sports grounds, powered, with the cutting device rotating in a horizontal plane
	846781	Chainsaws for working in the hand, with self-contained non-electric motor
	8607	Parts of railway or tramway locomotives or rolling stock, n.e.s.
	8802	Powered aircraft "e.g. helicopters and aeroplanes"; spacecraft, incl. satellites, and suborbital and spacecraft launch vehicles

List of commodities		
	87032110	Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only spark-ignition internal combustion reciprocating piston engine of a cylinder capacity <= 1.000 cm³, new (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars, with spark-ignition internal combustion reciprocating piston engine of a cylinder capacity <= 1.000 cm³, new (excl. vehicles for the transport of persons on snow and other specially designed vehicles of subheading 8703.10)(1988-2016)
	87032210	Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.000 cm³ but <= 1.500 cm³, new (excl. vehicles for travelling on snow and similar vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars, with spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.000 cm³ but <= 1.500 cm³, new (excl. those of heading 8702 and vehicles for the transport of persons on snow and similar vehicles of subheading 8703.10)(2000-2016);Motor cars and other motor vehicles principally designed for the transport of persons, including station wagons and racing cars, with spark-ignition internal combustion reciprocating piston engine of a cylinder capacity > 1 000 cc but =< 1.500 cc, new (excl. vehicles for the transport of persons on snow and other specially designed vehicles of subheading no 8703.10)(1988-1988)

List of commodities		
	87032311	Motor caravans with only spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.500 cm³ but <= 3.000 cm³, new(2017-2500);Motors caravans with spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.500 cm³ but <= 3.000 cm³, new(1989-2016)
	87032319	Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.500 cm³ but <= 3.000 cm³, new (excl. those of subheading 8703.10 and motor caravans)(2017-2500);Motor cars and other motor vehicles principally designed for the transport of 1 to 9 persons, incl. station wagons and racing cars, with spark-ignition internal combustion reciprocating piston engine, of a cylinder capacity > 1.500 cm³ but <= 3.000 cm³, new (excl. those of subheading 8703 10 and motor caravans)(1989-2016)
	87032410	Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only spark-ignition internal combustion reciprocating piston engine of a cylinder capacity > 3.000 cm³, new (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars, with spark-ignition internal combustion reciprocating piston engine of a cylinder capacity > 3.000 cm³, new (excl. vehicles for the transport of persons on snow and other specially designed vehicles of subheading 8703.10)(1988-2016)

List of commodities		
	87033110	Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only diesel engine of a cylinder capacity <= 1.500 cm³, new (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a cylinder capacity <= 1.500 cm³, new (excl. vehicles for the transport of persons on snow and other specially designed vehicles of subheading 8703.10)(1988-2016)
	87033211	Motor caravans with only diesel engine of a cylinder capacity > 1.500 cm³ but <= 2.500 cm³, new(2017-2500);Motor caravans with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a cylinder capacity > 1.500 cm³ but <= 2.500 cm³, new(1989-2016)
	87033219	Motor cars and other motor vehicles, principally designed for the transport of <10 persons, incl. station wagons, with only diesel engine of a cylinder capacity > 1.500 cm³ but <= 2.500 cm³, new (excl. motor caravans and vehicles for travelling on snow and other specially designed vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles, principally designed for the transport of persons, incl. station wagons, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a cylinder capacity > 1.500 cm³ but <= 2.500 cm³, new (excl. motor caravans and vehicles specially designed for travelling on snow and other special purpose vehicles of subheading 8703.10)(1989-2016)
	87033311	Motor caravans with only diesel engine of a cylinder capacity > 2.500 cm³, new(2017-2500);Motor caravans with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a cylinder capacity > 2.500 cm³, new(1989-2016)

List of commodities		
	87033319	Motor cars and other motor vehicles, principally designed for the transport of <10 persons, incl. station wagons, with only diesel engine of a cylinder capacity > 2.500 cm³, new (excl. motor caravans and vehicles for travelling on snow and other specially designed vehicles of subheading 8703.10)(2017-2500);Motor cars and other motor vehicles, principally designed for the transport of persons, incl. station wagons, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a cylinder capacity > 2.500 cm³, new (excl. motor caravans and vehicles specially designed for travelling on snow and other special purpose vehicles of subheading 8703.10)(1989-2016)
	87039010	Motor cars and other vehicles principally designed for the transport of persons, with electric motors (excl. motor vehicles of heading 8702, vehicles for the transport of persons on snow and other specially designed vehicles of subheading 8703.10)
	87039090	Motor cars and other motor vehicles principally designed for the transport of persons, incl. station wagons and racing cars, with engines other than spark-ignition internal combustion reciprocating piston engine or electric motors (excl. vehicles for the transport of persons on snow and other specially designed vehicles of subheading 8703,10)
	87042110	Motor vehicles for the transport of highly radioactive materials [Euratom], with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t(2022-2500);Motor vehicles for the transport of highly radioactive materials [Euratom], with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t(1988-2021)

List of commodities		
	87042131	Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t, of a cylinder capacity > 2.500 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t, of a cylinder capacity > 2.500 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
	87042191	Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t, of a cylinder capacity <= 2.500 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight <= 5 t, of a cylinder capacity <= 2.500 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)

List of commodities		
	87043131	Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight <= 5 t, of a cylinder capacity > 2.800 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight <= 5 t, of a cylinder capacity > 2.800 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
	87043191	Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight <= 5 t, of a cylinder capacity <= 2.800 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight <= 5 t, of a cylinder capacity <= 2.800 cm³, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
	87049000	Motor vehicles for the transport of goods, with engines other than internal combustion piston engine (excl. dumpers for off-highway use of subheading 8704.10 and special purpose motor vehicles of heading 8705)(2022-2500);Motor vehicles for the transport of goods, with engines other than internal combustion piston engine (excl. dumpers for off-highway use of subheading 8704.10 and special purpose motor vehicles of heading 8705)(1988-2021)

List of commodities		
	87021011	Motor vehicles for the transport of >= 10 persons, incl. driver, with only diesel engine, of a cylinder capacity of > 2.500 cm³, new(2017-2500);Motor vehicles for the transport of >= 10 persons, incl. driver, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine", of a cylinder capacity of > 2.500 cm³, new(1988-2016)
	87021091	Motor vehicles for the transport of >= 10 persons, incl. driver, with only diesel engine, of a cylinder capacity of <= 2.500 cm³, new(2017-2500);Motor vehicles for the transport of >= 10 persons, incl. driver, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine", of a cylinder capacity of <= 2.500 cm³, new(1988-2016)
	87029011	Motor vehicles for the transport of >= 10 persons, incl. driver, with spark-ignition internal combustion piston engine, of a cylinder capacity of > 2.800 cm³, new (excl. with electric motor for propulsion)(2017-2500);Motor vehicles for the transport of >= 10 persons, incl. driver, with spark-ignition internal combustion piston engine, of a cylinder capacity of > 2.800 cm³, new(1988-2016)
	87029031	Motor vehicles for the transport of >= 10 persons, incl. driver, with spark-ignition internal combustion piston engine, of a cylinder capacity of <= 2.800 cm³, new (excl. with electric motor for propulsion)(2017-2500);Motor vehicles for the transport of >= 10 persons, incl. driver, with spark-ignition internal combustion piston engine, of a cylinder capacity of <= 2.800 cm³, new(1988-2016)
	87029090	Motor vehicles for the transport of >= 10 persons, incl. driver, not with internal combustion piston engine or electric motor for propulsion(2017-2500);Motor vehicles for the transport of >= 10 persons, incl. driver, not with internal combustion piston engine(1988-2016)
	87041010	Dumpers for off-highway use, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" or with spark-ignition internal combustion piston engine

List of commodities		
	87041090	Dumpers for off-highway use with engines other than internal combustion piston engine
	87042210	Motor vehicles, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 5 t but <= 20 t, for the transport of highly radioactive materials [Euratom](2022-2500);Motor vehicles, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 5 t but <= 20 t, for the transport of highly radioactive materials [Euratom](1988-2021)
	87042291	Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 5 t but <= 20 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 5 t but <= 20 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
	87042310	Motor vehicles with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 20 t, for the transport of highly radioactive materials [Euratom](2022-2500);Motor vehicles with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 20 t, for the transport of highly radioactive materials [Euratom](1988-2021)

List of commodities		
	87042391	Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 20 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with compression-ignition internal combustion piston engine "diesel or semi-diesel engine" of a gross vehicle weight > 20 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
	87043291	Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight > 5 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(2022-2500);Motor vehicles for the transport of goods, with spark-ignition internal combustion piston engine, of a gross vehicle weight > 5 t, new (excl. dumpers for off-highway use of subheading 8704.10, special purpose motor vehicles of heading 8705 and special motor vehicles for the transport of highly radioactive materials)(1988-2021)
PRODCOM	24453024	Unwrought magnesium, containing >= 99,8% by weight of magnesium
	24421153	Unwrought aluminium alloys in primary form (excluding aluminium powders and flakes)
	24421154	Unwrought aluminium alloys (excluding aluminium powders and flakes)
	24421155	Unwrought aluminium alloys in secondary form (excluding aluminium powders and flakes)
	24422250	Aluminium alloy bars, rods, profiles and hollow profiles (excluding rods and profiles prepared for use in structures)

List of commodities		
	24422350	Aluminium alloy wire (excluding insulated electric wire and cable, twine and cordage reinforced with aluminium wire, stranded wire and cables)
	24422450	Aluminium alloy plates, sheets and strips > 0,2 mm thick
	24422650	Aluminium alloy tubes and pipes (excluding hollow profiles, tubes or pipe fittings, flexible tubing, tubes and pipes prepared for use in structures, machinery or vehicle parts, or the like)
	30303400	Aeroplanes and other aircraft of an unladen weight > 15 000 kg, for civil use
	25291170	Aluminium reservoirs, tanks, vats and similar containers for any material (other than compressed or liquefied gas), of a capacity > 300 litres (excluding fitted with mechanical or thermal equipment)

Table 97: Commodities not used in the MSA for magnesium

List of commodities			Reason why not used
NA			

7.13. Appendix 2 – Data sources for niobium

Table 98: Main stakeholders involved in the MSA for niobium

List of stakeholders
CBMM
V.I.C
Silmet
Strategic Minerals Spain
Treibacher

Table 99: Data sources used in the MSA for niobium

Authors	Year	Title
Cynthia EL Latunussa, Konstantinos Georgitzikis, Cristina Torres de Matos, Milan Grohol, Umberto Eynard, Dominic Wittmer, Lucia Mancini, Manuela Unguru, Claudiu Pavel, Samuel Carrara, Fabrice Mathieux, David Pennington, Gian Andrea Blengini	2020	Study on the EU's list of Critical Raw Materials. Critical Raw Materials Factsheet.
USGS	2021	Mineral Commodity Summaries 2021.
World Mining Data	2022	World Mining Data 2022.

Authors	Year	Title
Eurostat / COMEXT database: International Trade		EU trade since 1988 by HS2-4-6 and CN8 (DS-045409): 261590-Niobium, tantalum or vanadium ores and concentrates 720293-Ferro-niobium 26209920-Slag, ash and residues containing mainly niobium or tantalum 81129221 Niobium "columbium", rhenium, gallium, indium, vanadium and germanium waste and scrap (excl. ashes and residues containing these metals) 81129131-Unwrought niobium "columbium" and rhenium; niobium "columbium" or rhenium powders
	2020	Minerals Yearbook. 2020 tables-only release.
Bakry, M. & Li, J. & Zeng, X.	2022	Evaluation of global niobium flow modeling and its market forecasting
Ladenberger, A., Arvanitidis, N., Jonsson, E., Arvidsson, R., Casanovas, S. & Lauri, L.	2018	Identification and quantification of secondary CRM resources in Europe

Authors	Year	Title
Eurostat / PRODCOM database: Statistics on the production of manufactured goods and international trade	2023	Total Production: 24453064 - Unwrought niobium "columbium" and rhenium; niobium "columbium" or rhenium powders 24203110 - Line pipe, of a kind used for oil or gas pipelines, longitudinally or spirally welded, of an external diameter >406,4 mm, of stainless steel 25112100 - Iron or steel bridges and bridge-sections 24453065 - Articles of niobium "columbium" or rhenium, n.e.s. 29102100 - Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³, 29102230 - Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles), 29102310 - Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles), 29102330 - Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)
USGS	2004	Flow Studies for Recycling Metal Commodities in the United States, Edited by Scott F. Sibley. Circular 1196–A–M. USGS. Niobium by L. D. Cunningham
Eurofer	2022	EUROPEAN STEEL IN FIGURES 2022
Eurostat	2022	Eurostat Statistics explained - Passenger cars in the EU
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
ACEA	2022	THE AUTOMOBILE INDUSTRY POCKET GUIDE 2020/2021
Federal Highway Research Institute Germany	2023	Stahlbau, Korrosionsschutz, Brückenausstattung

Authors	Year	Title
Nia Bell, Rachel Waugh and David Parker	2017	2017 Magnesium Recycling in the EU - Material flow analysis of magnesium (metal) in the EU and a derivation of the recycling rate
Bjorn Fehrm	2017	The aircraft market will double in 20 years
Zhao et al.	2020	Disposal and Recycle Economic Assessment for Aircraft and Engine End-of-life Solution Evaluation
Prescient & Strategic Intelligence	2015	MRI Compatible Patient Monitoring System Market Size, Share, Development, Growth and Demand Forecast to 2020
Steve Rentz	2020	What Does 'End-of-life' Mean for MRI Scanners?

Table 100: Commodities used in the MSA for niobium

List of commodities		
COMEXT	720293	Ferro-niobium
	26209920	Slag, ash and residues containing mainly niobium or tantalum
	81129131	Unwrought niobium "columbium" and rhenium; niobium "columbium" or rhenium powders
PRODCOM	24453064	Unwrought niobium "columbium" and rhenium; niobium "columbium" or rhenium powders
	25112100	Iron or steel bridges and bridge-sections
	24453065	Articles of niobium "columbium" or rhenium, n.e.s.
	24203110	Line pipe, of a kind used for oil or gas pipelines, longitudinally or spirally welded, of an external diameter >406,4 mm, of stainless steel
	29102100	Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³
	29102230	Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	29102310	Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	29102330	Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)

Table 101: Commodities not used in the MSA for niobium

List of commodities			Reason why not used
COMEXT	261590	Niobium, tantalum or vanadium ores and concentrates	Too aggregated to make sense
	81129221	Niobium "columbium", rhenium, gallium, indium, vanadium and germanium waste and scrap (excl. ashes and residues containing these metals)	Too aggregated to make sense
PRODCOM			

7.14. Appendix 2 – Data sources for platinum group metals (PGMs)

Table 102: Main stakeholders involved in the MSA for platinum group metals

List of stakeholders
UMICORE
Johnson Matthey
Heraeus
IPA
Anglo American Platinum
BASF
SFA Oxford

Table 103: Data sources used in the MSA for platinum group metals

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Palladium
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
BRGM	2014	Panorama 2012 du marché des Platinoïdes
Eurostat	2022	Eurostat - Comext database
Eurostat	2022	Eurostat - Prodcom database
Instituto geológico y minero de España	2017	Panorama Minero 2017
Johnson Matthey	2021	PGM Market report
Boliden	2016-2020	Boliden Annual and Sustainability Report

List of data sources	Year	Title
Country Economy	2021	Website
Nornickel	2021	Website
Państwowy Instytut Geologiczny	2015	Predicted metallic resources in Poland presented on the prospective maps at scale 1: 200 000 - Copper, silver, gold, platinum and palladium in the Kupferschiefer ore series
Saidani, M., et al	2019	Closing the loop on platinum from catalytic converters: Contributions from material flow analysis and circularity indicators
Omrani, M., et al.	2020	Platinum group elements study in automobile catalysts and exhaust gas samples
ICCT	2022	European vehicle market statistics
Lisa Tostado	2021	End-Of-Life Vehicles: Final Destination
ACEA	2022	THE AUTOMOBILE INDUSTRY POCKET GUIDE 2020/ 2021
United Nations Environment Programme	2020	Used vehicles and the environment - A global overview of light duty vehicles: Flow, scale and regulation
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
Arcserve	2022	Data storage lifespans: How long will media really last?
Jesse Fredereik	2020	Your car has a weight problem and we need to regulate it
Ozturk, S. et al.	2020	Pacemaker (Medical Device)
Autovista	2022	Petrol-engine decline allows electrified vehicles to close the fuel-type gap in Europe
ACEA	2022	Passenger car registrations in Europe 1990-2021, by country

Table 104: Commodities used in the MSA for platinum group metals

List of commodities		
COMEXT	71101100	Platinum, unwrought or in powder form (with pending questions to experts)
	71102100	Palladium, unwrought or in powder form (with pending questions to experts)
	71103100	Rhodium, unwrought or in powder form (with pending questions to experts)

Table 105: Commodities not used in the MSA for platinum group metals

List of commodities			Reasons why not used
COMEXT	71129200	Waste and scrap of platinum, incl. metal clad with platinum, and other waste and scrap containing platinum or platinum compounds, of a kind used principally for the recovery of precious metal (excl. ash containing platinum or platinum compounds, waste and scrap of platinum melted down into unworked blocks, ingots, or similar forms, and sweepings and ash containing precious metals)	not usable, content unknown
	71101900	Platinum, in semi-manufactured forms	too volatile, not used
	71151000	Catalysts in the form of wire cloth or grill, of platinum	too volatile, not used
	71103900	Rhodium, in semi-manufactured forms	too volatile, not used
PRODCOM	24413010	Unwrought platinum; platinum powders	COMEXT data prefered
	24413055	Platinum, in semi-manufactured forms	COMEXT data prefered

7.15. Appendix 2 – Data sources for rare earth elements (REEs)

Table 106: Main stakeholders involved in the MSA for REE

List of stakeholders
REIA
BRGM
EURARE
Silmet
Treibacher
REMRETEch
LKAB
Geological Survey of Estonia
CEA
EIT Raw Materials
University of Jyvaskyla
Carester
Vacuumschmelze
Treibacher

Table 107: Data sources used in the MSA for REE

Authors	Year	Title
World Mining Data	2022	Federal Ministry of Agriculture, Regions and Tourism of Austria (Ed.): World Mining Data (since 1986)
USGS mineral summaries	2000-2022	USGS (2000-2022). Mineral Commodity Summaries
Eurostat International trade Comext	2022	Eurostat Comext database. EU trade since 1988 by HS2-4-6 and CN8 (DS-045409)
ASTER	2015	Guyonnet D., Planchon M., Rollat A., Escalon V., Tuduri J., Charles N., Vaxelaire S., Dubois D., Fargier H. (2015) Material flow analysis applied to rare earth elements in Europe, Journal of Cleaner Production, Volume 107, 16 November 2015, Pages 215-228
TechMetals Research	2015	The Index
CRM Factsheets	2020	European Commission (2020). Study on the EU's list of Critical Raw Materials (2020): Critical Raw Materials Factsheets (final).

SCRREEN CRM & MSA workshops	2022	Expert advices and validation
Eurostat Prodcom	2022	Eurostat ProdCom database. Sold production, exports and imports by PRODCOM list (NACE Rev. 2) - annual data
Per Kalvig	2022	Rare Earth Elements (REE) - Geology, technologies, and forecasts - MiMa rapport 2022/1
Roskill	2021	Rare Earths: Outlook to 2030 - Twentieth Edition
EURARE	2017	European REE market survey - Task 1.1.2
Solvay	2022	Internet Website Solvay France - La Rochelle plant
Deloitte	2015	Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials
Alain Rollat	2022	Interview with expert Alain Rollat, Carester and ex-Solvay, november 2022
ERECON	2014	Strengthening the European Rare Earths supply-chain
ACEA	2022	THE AUTOMOBILE INDUSTRY P O C K E T G U I D E 2 0 2 0 / 2 0 2 1
Eurostat	2022	Eurostat Statistics explained - Passenger cars in the EU
Sadeghi et al.	2020	A simple, efficient and selective process for recycling La (and Al) from fluid cracking catalysts using an environmentally friendly strategy
Tostado Lisa	2021	End-Of-Life Vehicles: Final Destination
United Nations Environment Programme	2020	Used vehicles and the environment - A global overview of light duty vehicles: Flow, scale and regulation
NSG Group	2022	Waste and Circular Economy
Glass Alliance Europe	2021	Industries
Close the glass loop	2021	RECORD COLLECTION OF GLASS CONTAINERS FOR RECYCLING HITS 78% IN THE EU
Treibascher	2022	Personal communication, Anton Auer, 25/01/23
Wu et al.	2021	Review of rare-earths recovery from polishing powder waste
ADEME	2021	Automotive: key figures 2019

Hartmut Stahl, Georg Mehlhart, Martin Gsell, Jürgen Sutter, Peter Dolega, Yifaat Baron, Clara Löw (Oeko-Institut e.V.) Thomas Neumann (Ramboll) Judith Oliva, Francesca Montevecchi (Umweltbundesamt Wien)	2020	Assessment of options to improve particular aspects of the EU regulatory framework on batteries
Yifaat Baron	2023	Expert interview
Data Intelo	2022	Global Polishing Powder Market by Type (High Ce Type, Middle Ce Type, Low Ce Type), By Application (Crystal, Display Panels, Flat Glass, Optical Glass, Consumer Electronics, Others) And By Region (North America, Latin America, Europe, Asia Pacific and Middle East & Africa), Forecast From 2022 To 2030
Recylum	2022	COMMENT NOS LAMPES SONT-ELLES RECYCLÉES ?
Ecosystem	2021	Où en est le recyclage des ampoules LED ?
Plastics Europe	2022	The Circular Economy for Plastics. A European Overview.
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
Eurofer	2022	EUROPEAN STEEL IN FIGURES 2022
Ceramic world	2021	Ceramic world review 2021 S. 26
Dr. Nabeel Mancheri	2022	REIA's Input for the EU Raw Materials Act
Eurostat	2022	Eurostat Statistics explained - Passenger cars in the EU
Jesse Frederik	2020	Your car has a weight problem and we need to regulate it
Chen et al.	2020	A recovery strategy of Sm, Co for waste SmCo magnets by fatty acid based ionic liquids
Opportimes	2023	Top 10 industrial robot exporters in the world
International Federation of Robotics	2022	Robot sales surge in Europe, Asia and the Americas
Sun Vision Display	2020	The Lifespan of Digital Display Technologies

USINESS WIRE-Research and Markets	2016	Global LED Backlight Display Driver ICs Market 2016-2020 - Expected to Grow at CAGR of 8.24% - Research and Markets

Table 108: Commodities used in the MSA for REE

List of commodities		
COMEXT	28461000	Cerium compounds
	28469010	Compounds of lanthanum, praseodymium, neodymium or samarium, inorganic or organic
	28469020	Compounds of europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium or yttrium, inorganic or organic
	28469090	Compounds of mixtures of rare-earth metals, yttrium and scandium, inorganic or organic
	28053020	Cerium, lanthanum, praseodymium, neodymium and samarium, of a purity by weight of >=95% (excl. intermixtures and interalloys)
	28053030	Europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and yttrium, of a purity by weight of >=95% (excl. intermixtures and interalloys)
	28053010	Intermixtures or interalloys of rare-earth metals, scandium and yttrium
	28053080	Rare-earth metals, scandium and yttrium, of a purity by weight of <95% (excl. intermixtures and interalloys)
	32065000	Inorganic products of a kind used as luminophores, whether or not chemically defined
	85051100	Permanent magnets of metal and articles intended to become permanent magnets after magnetization (excl. chucks, clamps and similar holding devices)
	85051990	Permanent magnets and articles intended to become permanent magnets after magnetization, of materials other than metal or agglomerated ferrite
PRODCOM	20136510	Compounds, inorganic or organic, of rare-earth metals or of mixtures of these metals. Cerium compounds
	20136520	Compounds, inorganic or organic, of rare-earth metals or of mixtures of these metals. Compounds of lanthanum, praseodymium, neodymium, samarium

List of commodities		
	20136550	Compounds, inorganic or organic, of rare-earth metals or of mixtures of these metals. Compounds of europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium or yttrium
	20136585	Compounds, inorganic or organic, of rare-earth metals or of mixtures of these metals. Compounds of mixtures of metals
	27202340	Nickel-metal hydride accumulators (excl. spent)
	27401510	Fluorescent hot cathode discharge lamps, with double ended cap (excluding ultraviolet lamps)
	27401530	Fluorescent hot cathode discharge lamps (excluding ultraviolet lamps, with double ended cap)
	25992995	Permanent magnets and articles intended to become permanent magnets, of metal
	20302130	Prepared pigments, opacifiers, colours and similar preparations for ceramics, enamelling or glass

Table 109: Commodities not used in the MSA for REE

List of commodities			Reason why not used
COMEXT	28469000	Compounds, inorganic or organic, of rare-earth metals, of yttrium or of scandium or of mixtures of these metals (excl. cerium)	Empty since 2016
	28053090	Rare-earth metals, scandium and yttrium (excl. intermixtures or interalloys)	Empty since 2016
	85078020	Accumulators other than lead-acid: nickel-cadmium, nickel-iron, nickel-metal hydride, lithium-ion for laptops	Prodcom code used instead
	85393110	Discharge lamps, fluorescent, hot cathode, with double ended cap	Prodcom code used instead
	85393190	Discharge lamps, fluorescent, hot cathode (excl. with double ended cap)	Prodcom code used instead

PRODCOM	20122450	Other colouring matter; pigments and preparations based on inorganic or mineral colouring matter; inorganic products of a kind used as luminophores	Not usable
	20132300	Alkali or alkaline-earth metals; rare-earth metals, scandium and yttrium; mercury	Not usable

7.16. Appendix 2 – Data sources for silicon metal

Table 110: Main stakeholders involved in the MSA for silicon metal

List of stakeholders
BRGM
EUROALLIAGES
Wacker Silicones/Wacker Chemie
European Aluminium Association
PV Cycle
CES - Silicones Europe / CEFIC
University of Oslo

Table 111: Data sources used in the MSA for silicon metal

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary – Silicon metal
SCRREEN	2018	Deliverable 3.3: Challenges of locating, mining and extracting CRM resources
Eurostat	2022	Eurostat - Comext database
Eurostat	2022	Eurostat - Prodcom database
BRGM and COMES	2020	Criticality assessment - Silicon metal
SCRREEN	2016	DELIVERABLE 3.2: Identification and quantification of secondary CRM resources in Europe
SCRREEN	2016	DELIVERABLE 4.2: Production technologies of CRM secondary resources

List of data sources	Year	Title
BGS	2022	World Mineral Production 2016-2020
L'Élémentarium	2022	Fiche complète Silicium
SCRREEN	2018	DELIVERABLE 4.1: Production Technologies of CRM from Primary Resources
EC	2020	Study on the EU's list of Critical Raw Materials
BRGM	2019	Flux de silicium dans les filières de transformation du silicium métal en 2019
ADEME	2020	Rapport annuel du registre des déchets d'équipements électriques et électroniques
Institute of Fluid Dynamics at HZDR	2013	Waste that is brimming with energy
SOREN	2021	Rapport d'activité 2021
Fraunhofer Institute for Solar Energy Systems	2022	Photovoltaics Report
IEA PVPS	2021	Trends in photovoltaic applications
Lisa Tostado	2021	End-Of-Life Vehicles: Final Destination
Eurostat	2019	Total recycling and reuse rate of end-of-life vehicles, 2008–2019 (% of weight of vehicles)
BRGM	2020	Le silicium : un élément chimique très abondant, un affinage stratégique
ADEME	2021	Automotive: key figures 2019
European Commission	2018	Circular Footprint Formula – Default values (Annexe C)

List of data sources	Year	Title
Eurostat	2023	EU Buildings Factsheets
GSM Arena	2019	Counterclockwise: As 5G arrives we track the 3G and 4G adoption
JRC	2020	Analysis of durability, reusability and reparability. Application to washing machines and dishwashers

Table 112: Commodities used in the MSA for silicon metal

List of commodities		
COMEXT	25061000	Quartz (excl. Quartz sands)
	28046900	Silicon containing < 99,99% by weight of silicon
	28046100	Silicon containing >= 99,99% by weight of silicon
PRODCOM	20132150	Silicon
	20132170	Silicon. Containing by weight not less than 99,99 % of silicon
	20132160	Silicon. Other than containing by weight not less than 99,99 % of silicon
	27321200	Insulated coaxial cables and other coaxial electric conductors for data and control purposes whether or not fitted with connectors
	22214150	Plates, sheets, film, foil and strip of cellular polyurethanes
	20421630	Shampoos
	29102100	Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³
	29102230	Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)

List of commodities		
	29102310	Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	29102330	Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)
	25121050	Other paints and varnishes based on synthetic polymers n.e.c.
	25121050	Aluminium doors, thresholds for doors, windows and their frames

Table 113: Commodities not used in the MSA for silicon metal

List of commodities		
COMEXT	25062100	Crude or roughly trimmed quartzite
	38180010	Silicon doped for use in electronics, in the form of discs, wafers, cylinders, rods or similar forms, whether or not polished or with a uniform epitaxial coating (excl. elements that have been further processed, e.g. by selective diffusion)
PRODCOM	27321200	Bituminous mixtures based on natural and artificial aggregate and bitumen or natural asphalt as a binder
	26112240	Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc
	26201100	Laptop PCs and palm-top organisers
	20165700	Silicones, in primary forms
	20421700	Hair preparations (excluding shampoos, permanent waving and hair straightening preparations, lacquers)

7.17. Appendix 2 – Data sources for strontium

Table 114: Main stakeholders involved in the MSA for strontium

List of stakeholders
Canteras Industrial S.A.
Kandelium
Transparency Market Research (TMR)

Table 115: Data sources used in the MSA for strontium

List of data sources	Year	Title
USGS	2022	Strontium Statistics and Information
Minerals4EU	2014	EUROPEAN MINERALS YEARBOOK - DATA FOR Strontium
BGS	2022	World Mineral Production 2016-2020
National Center for Biotechnology Information	2022	PubChem Element Properties and Compound Summary
Transparency Market Research	2022	Strontium Market: Europe Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2016-2024
Minas de Montevive	2016	Producto
EUROSTAT COMEXT	2022	EU trade since 1988 by HS2-4-6 and CN8 [DS-045409__custom_3242651]
EUROSTAT PRODCOM	2022	Sold production, exports and imports [DS-056120__custom_3246701]
Eurostat	2022	Feedback help center

List of data sources	Year	Title
Expert feedback	2023	Feedback during MSA Workshop in Brussels in February 2023
Instituto Geológico y Minero de España (IGME)	2020	Panorama Minero 2018-2020
Cámara Oficial de Comercio, Industria, Servicios y Navegación de España	2023	Spanish foreign trade statistics database
Kandelium	2023	Personal communication via mail 28/03/2023
Öko-Institut	2023	Suggestion for parameters for vehicles sector by Öko-Institut
Secretaría de economía de Mexico	2022	Perfil de Mercado de la Celestita

Table 116: Commodities used in the MSA for strontium

List of commodities		
PRODCOM	25992995	Permanent ferrite magnets are made of hard ferrites such as strontium ferrite, barium ferrite, or cobalt ferrite
	20302150	Vitrifiable enamels and glazes, engobes (slips) and similar preparations for ceramics, enamelling or glass
	20511300	Fireworks
	20122450	Other colouring matter; pigments and preparations based on inorganic or mineral colouring matter; inorganic products of a kind used as luminophores

List of commodities		
	27401510	Fluorescent hot cathode discharge lamps, with double ended cap
Spanish Foreign trade statistics database	28051910	Strontium metal
	28342980	Strontium nitrate

Table 117: Commodities not used in the MSA for strontium

List of commodities			Reasons why not used
COMEXT	28051910	Strontium and barium	excluded by experts
	28369200	Strontium carbonate	Too high values reported
	28164000	Oxides, hydroxides and peroxides, of strontium or barium	Not relevant

7.18. Appendix 2 – Data sources for titanium

Table 118: Main stakeholders involved in the MSA for titanium

List of stakeholders
ASD Association
Thyssenkrupp Materials
European Defence Agency
Geological Survey of Norway
V.I.C
ifri French Institute of International Relations
Tronox Corporation

Table 119: Data sources used in the MSA for titanium

Authors	Year	Title
Cynthia EL Latunussa, Konstantinos Georgitzikis, Cristina Torres de Matos, Milan Grohol, Umberto Eynard, Dominic Wittmer, Lucia Mancini, Manuela Unguru, Claudiu Pavel, Samuel Carrara, Fabrice Mathieux, David Pennington, Gian Andrea Blengini	2020	Study on the EU's list of Critical Raw Materials. Critical Raw Materials Factsheet.
World Mining Data	2022	World Mining Data 2022.
USGS	2017	Mineral Commodity Summaries 2017.
USGS	2018	Mineral Commodity Summaries 2018.
USGS	2019	Mineral Commodity Summaries 2019.
USGS	2020	Mineral Commodity Summaries 2020.
USGS	2021	Mineral Commodity Summaries 2021.

Authors	Year	Title
Eurostat / COMEXT database: International Trade		EU trade since 1988 by HS2-4-6 and CN8 (DS-045409): 26140000-Titanium ores & concentrates 28230000-Titanium oxides 26209960-Slag, ash and residue containing mainly titanium 720291-Ferro-titanium and ferro-silico-titanium 81081090-Titanium waste and scrap (excl. ash and residues containing titanium 81082000- Unwrought titanium, titanium powders
Eurostat / PRODCOM database: Statistics on the production of manufactured goods and international trade		Sold production, exports and imports (DS-056120): 07291930-Titanium ores and concentrates 20121150-Titanium oxides 24101255-Ferro-titanium and ferro-silico-titanium
Eurostat / PRODCOM database: Statistics on the production of manufactured goods and international trade		Total production (DS-056121) 20122415 - Pigments and preparations based on titanium dioxide containing >= 80 % by weight of titanium dioxide 32061100 - Pigments and preparations based on titanium dioxide of a kind used for colouring any material or produce colorant preparations, containing >= 80% by weight of titanium dioxide calculated on the dry matter (excl. preparations of heading 3207, 3208, 3209, 3210, 3212, 3213 and 3215)
World Mineral Statistics Data		
Lewicka, E., Guzik, K. & Galos, K.	2021	On the Possibilities of Critical Raw Materials Production from EU’s Primary Sources.
Frank Marscheider-Weidemann, Sabine Langkau, Elisabeth Eberling, Lorenz Erdmann, Michael Haendel, Michael Krail, Antonia Loibl, Christoph Neef, Marius Neuwirth, Leon Rostek, Saeideh Shirinzadeh, Denis Stijepic, Luis Tercero Espinoza	2021	DERA Rohstoffinformationen. Rohstoffe für Zukunftstechnologien.
	2022	Validation Workshop on Critical Raw Materials.

Authors	Year	Title
Christoph Lindner, Jan Schmitt, Julia Hein	2020	Stoffstrombild Kunststoffe in Deutschland 2019.
	2019	Titandioxid in Kunststoffen.
	2022	The Circular Economy for Plastics. A European Overview.
	2018	Plastic waste and recycling in the EU: facts and figures.
Laurel G. Woodruff, George M. Bedinger, and Nadine M. Piatak	2017	Critical Mineral Resources of the United States - Economic and Environmental Geology and Prospects for Future Supply: Titanium.
UN Comtrade database		Codes: 810820 Titanium unwrought; powders 810830 Titanium waste and scrap
S. Samal	2016	Synthesis and Characterization of Titanium Slag from Ilmenite by Thermal Plasma Processing
Zixian Gao, Gongjin Cheng, He Yang, Xiangxin Xue, and Jongchol Ri	2019	Preparation of Ferrotitanium Using Ilmenite with Different Reduction Degrees
Rauf Hurman Eric	2014	Production of Ferroalloys
El Khalloufi, M., Drevelle, O., & Soucy, G.	2021	Titanium: An Overview of Resources and Production Methods. 11(12), 1425.
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
Daniel Mitrovic	2022	Discussion with the expert
USGS	2022	Mineral Commodity Summaries 2022.
	2022	Validation Workshop on MSA
ACEA	2022	THE AUTOMOBILE INDUSTRY POCKET GUIDE 2020 /2021
Pierre-François Louvigne	2021	Etude de veille sur le marché du titane 2018 – 2020
Eurostat	2022	Eurostat Statistics explained - Passenger cars in the EU
United Nations Environment Programme	2020	Used vehicles and the environment - A global overview of light duty vehicles: Flow, scale and regulation

Authors	Year	Title
Zhao et al.	2020	Disposal and Recycle Economic Assessment for Aircraft and Engine End-of-life Solution Evaluation
Bjorn Fehrm	2017	The aircraft market will double in 20 years
Eurostat	2022	Eurostat Statistics explained - Passenger cars in the EU
Plastics Europe	2022	Plastics - the Facts 2021 An analysis of European plastics production, demand and waste data
Yifaat Baron	2023	Expert interview
envivas.puls	2023	Titanimplantate: Was sind die Vorteile gegenüber Keramik?
Helios Klinikum Pirna	2023	Künstliches Gelenk für die Ewigkeit? – Klinikum informiert über Haltbarkeit und Wechselmöglich-keiten von Hüft- und Knieendoprothesen
Observatory of end-of-life vehicles	2021	Automotive: key figures 2019
Minerals4EU	2018	EUROPEAN MINERALS YEARBOOK - DATA FOR Titanium
Conversio	2019	Titandioxid in Kunststoffen
	2023	Validation Workshop on MSA
Sabra, G.	2022	The Application of the United Nations Framework Classification for Resources to Piampaludo’s Titanium Deposits in Liguria, Italy (Master’s Degree Thesis, Politecnico di Torino).
Jesse Frederik	2020	Your car has a weight problem and we need to regulate it

Authors	Year	Title
Eurostat Prodcom	2022	ProdCom - Sold production, exports and imports - 29102100 - Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³, 29102230 - Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles), 29102310 - Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles), 29102330 - Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)
Nia Bell, Rachel Waugh and David Parker	2017	Magnesium Recycling in the EU - Material flow analysis of magnesium (metal) in the EU and a derivation of the recycling rate

Table 120: Commodities used in the MSA for titanium

List of commodities		
COMEXT	26140000	Titanium ores & concentrates
	26209960	Slag, ash and residue containing mainly titanium
	81082000	Unwrought titanium, titanium powders
	720291	Ferro-titanium and ferro-silico-titanium
	81081090	Titanium waste and scrap (excl. ash and residues containing titanium
PRODCOM	20122415	Pigments and preparations based on titanium dioxide containing >= 80 % by weight of titanium dioxide
	32061100	Pigments and preparations based on titanium dioxide of a kind used for colouring any material or produce colorant preparations, containing >= 80% by weight of titanium dioxide calculated on the dry matter (excl. preparations of heading 3207, 3208, 3209, 3210, 3212, 3213 and 3215)
	29102100	Vehicles with only spark-ignition engine of a cylinder capacity <= 1 500 cm³

	29102230	Motor vehicles with only petrol engine > 1 500 cm³ (including motor caravans of a capacity > 3 000 cm³) (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	29102310	Motor vehicles with only diesel or semi-diesel engine <= 1 500 cm³ (excluding vehicles for transporting >= 10 persons, snowmobiles, golf cars and similar vehicles)
	29102330	Motor vehicles with only diesel or semi-diesel engine > 1 500 cm³ but <= 2 500 cm³ (excluding vehicles for transporting >= 10 persons, motor caravans, snowmobiles, golf cars and similar vehicles)
	24453043	Titanium and articles thereof (excluding waste and scrap), n.e.c.

Table 121: Commodities not used in the MSA for titanium

List of commodities			Reason why not used
COMEXT	28332930	Sulphates of cobalt and of titanium	Too aggregated
	28499050	Carbides of aluminium, of chromium, of molybdenum, of vanadium, of tantalum, and of titanium, whether or not chemically defined	Too aggregated
PRODCOM	20121150	Titanium oxides	Stage at the value chain / Ti content not clear

7.19. Appendix 2 – Data sources for tungsten

Table 122: Main stakeholders involved in the MSA for tungsten

List of stakeholders
ITIA
Wolfram
H.C. Starck
Voestalpine

Table 123: Data sources used in the MSA for tungsten

List of data sources	Year	Title
USGS	2022	Mineral Commodity Summary - Tungsten
International Organizing Committee for the World Mining Congresses	2022	World Mining data 2022
BGS	2022	World Mineral Production 2016-2020
BGS	2011	Tungsten Mineral profile
Eurostat	2022	Eurostat - Comext database
Eurostat	2022	Eurostat - Prodcom database
Han Z., Golev G., Edraki M.	2021	A Review of Tungsten Resources and Potential Extraction from Mine Waste
ITIA	2011	Website
ITIA	2020	Recycling of tungsten: Current share, economic limitations, technologies and future potential
Leal-Ayala, D. et al.	2015	Mapping the global flow of tungsten to identify key material efficiency and supply security opportunities

List of data sources	Year	Title
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA	2022	ESTADÍSTICA MINERA DE ESPAÑA 2020
DERA	2014	DERA Rohstoffrisikobewertung – Wolfram
MSA 2015	2015	Material System Analysis of 28 raw materials
Rewimet	2021	Recyclingsteckbrief
Business Wire	2022	Global Tungsten Market Analytics Report 2022
Grand View Research	2020	Europe Homogeneous Precious Metal Catalyst Market Size, Share & Trends Report
Zhao et al.	2020	Disposal and Recycle Economic Assessment for Aircraft and Engine End-of-life Solution Evaluation
Choi et al.	2018	Extraction of tungsten and vanadium from spent selective catalytic reduction catalyst for stationary application by pressure leaching process
Harper et al.	2008	Illuminating Tungsten's Life Cycle in the United States: 1975−2000
Bjorn Fehrm	2017	The aircraft market will double in 20 years
Hool A. et al	2022	How companies improve critical raw material circularity: 5 use cases
Nia Bell, Rachel Waugh and David Parker	2017	Magnesium Recycling in the EU - Material flow analysis of magnesium (metal) in the EU and a derivation of the recycling rate
Zhao et al.	2020	Disposal and Recycle Economic Assessment for Aircraft and Engine End-of-life Solution Evaluation

Table 124: Commodities used in the MSA for tungsten

List of commodities		
COMEXT	26110000	Tungsten ores and concentrates
	28259040	Tungsten oxides and hydroxides
	28418000	Tungstate wolframates
	28499030	Carbides of tungsten, whether or not chemically defined
	72028000	Ferro-tungsten and ferro-silico-tungsten
	81011000	Tungsten powders
	81019700	Tungsten waste and scrap
PRODCOM	7291915	Tungsten ores and concentrates
	20121975	Tungsten oxides and hydroxides (Total production instead of sold production)
	20135115	Tungstate wolframates
	20136410	Carbides of tungsten, whether or not chemically defined
	24101245	Ferro-tungsten and ferro-silico-tungsten
	24453013	Tungsten powders

Table 125: Commodities not used in the MSA for tungsten

List of commodities			Reason why not used
NA			

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ET-05-24-214-EN-N

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