

Study on Data for a Raw Material System Analysis: Roadmap and Test of the Fully Operational MSA for Raw Materials

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1. Introduction

1.1 Context of the project

Whereas the supply security of fossil fuels has raised concerns among politicians and economic actors for many years, it is only recently that the growing challenge of securing access to metals and minerals needed for economic production has received the same public attention.

Indeed, many non-energy raw materials are not only essential for the production of a broad range of goods and applications used in everyday life, but also for the development of high tech products and emerging innovations, which are notably necessary for the development of more eco-efficient technologies.

However, very little primary production of these materials occurs within Europe and production of many materials is reliant on a few Third countries, creating a status of dependence on extra-EU supply for Europe and risks of market distortions.

To address this growing concern, the European Commission launched the European Raw Materials Initiative in 2008 and adopted in 2011 a strategy document which sets out targeted measures to secure and improve access to raw materials for the EU, based on a three-pillar approach:

- fair and sustainable supply of raw materials from international markets,
- fostering sustainable supply within the EU,
- boosting resource efficiency and promoting recycling.

These initiatives are part of the Europe 2020 strategy for smart, sustainable and inclusive growth and linked to the 'Innovation Union' flagship initiative, proposed by the European Commission in 2010. This global strategy recognises the importance of an effective innovation policy which covers innovation along the entire supply chain as well as the demand side, including in particular extraction, processing and recycling steps and tackling issues such as eco-design, substitution and resource efficiency.

Nevertheless, for the successful implementation of EU policies in this field, there is a need of:

- identifying the raw materials that are key for the European Economy,
- and having a detailed picture of the flows of these materials in Europe.

This knowledge would help identifying where innovation has the greatest potential, where it should be supported, and what the main leverages are.

Within this context, the European Commission launched in 2010 the *Study on Critical Raw Materials at the EU level* in order to identify the non-energy raw materials considered as critical for Europe, based on their economic importance and their risk of supply interruption. The first edition of this study in 2010 resulted in a list of 14 raw materials. Then, a revision of this study in 2014 resulted in the current list of materials considered as critical for Europe, which includes 20 materials such as: antimony, beryllium, fluorspar, indium, rare earths...

In parallel to these studies aiming at identifying key materials for Europe's economy, the European Commission launched in 2012 the *Study on Data Needs for a Full Raw Materials Flow Analysis*. The objective of this study was to support the European Commission in identifying the information and data needs for a complete raw materials flow analysis at the European level. In particular, the aims of the study were to assess available data with reference to material flows, to examine data gaps and bottlenecks and to make recommendations for a future data strategy covering both the improvement of data availability and quality.

The study focused on information collection for 21 materials or groups of materials from a range of publicly available data bases, public authorities in each Member State, industry associations, companies and commercially available reports. The study pointed out data gaps regarding practically all stages of the life cycle of materials and identified as the main shortcomings the reliance on one-off or non-EU sources with no or irregular updates, the lack of standardized data and some insufficient details in the COMEXT trade statistics. The study also gave recommendations on how to overcome

some of these gaps. Thus, this study underlined the lack and the need of reliable data relating to flows and trends of critical raw materials in the EU. Indeed, a comprehensive data inventory of the materials flows in industry and society would be essential to get the solid ground for informed discussion and decision making on supply of raw materials. Such data on the quantity and quality of raw materials in each life cycle stage would allow more decisions that provide balanced, secure and sustainable supply throughout the entire materials flows.

1.2 Objectives of the project

The main objective of the present project is to respond to the needs of information on non-energy material flows and to assist the European Commission on the development of a full Material System Analysis (MSA) for several key raw materials in the European Union.

For each material, the MSA consists of:

- a map of the flows of material through the EU economy, as raw materials or as parts of basic materials, components or products, in terms of entries into the economy (extraction and import), movements through the economy (production, consumption, export), additions to stock, and end of life,
- with additional information related to security of supply (company concentration, country concentration...), substitutes, future supply and demand changes of materials.

The MSA includes the entire life cycle of materials, including exploration, extraction, processing, manufacturing, use and end of life through either disposal or recovery.

The raw materials studied in this project are listed in the table below. They include:

- the raw materials considered as critical for Europe (indicated with a * in the table),
- lithium, which is currently not included in the list of critical raw materials but which is a borderline case,
- and aggregates. Contrary to other materials studied in this project, aggregates are mostly supplied at a local level and are not considered as critical raw materials. However, the big flows of aggregates in Europe, the important number of small companies involved at the different life cycle steps of these materials and the economic importance of the construction and building sectors in the European economy make of aggregates an interesting case study.

Table 1: Raw Materials studied

List of the 28 raw materials studied, <i>raw materials considered as critical for Europe are indicated with *</i>	
Aggregates	Lithium
Antimony*	Magnesite*
Beryllium*	Magnesium*
Borate*	Natural Graphite*
Chromium*	Niobium*
Cobalt*	Selection of 3 Platinum Group Metals*: Palladium, Platinum and Rhodium
Coking coal*	Phosphate Rock*
Fluorspar*	Selection of 6 heavy Rare Earth Elements* and light Rare Earth Elements*: Europium, Terbium, Neodymium, Dysprosium, Erbium and Yttrium
Gallium*	Silicon Metal*
Germanium*	Tungsten*
Indium*	

This project is the follow-up of the *Study on Data Needs for a Full Raw Materials Flow Analysis* mentioned above and shall implement its recommendations. The main challenges are to fill the data gaps and remove the bottlenecks of the data flows, either by finding data sets or developing appropriate modelling.

More precisely, the project aims to provide:

- a complete overview of existing data sources adapted or workable for MSA in Europe, with a specific examination of the Eurostat data base on trade of goods from the viewpoint of its usability for MSA,
- a detailed methodology on establishing MSA in Europe,
- a complete MSA for the 28 studied materials, with detailed data sources, assumptions and calculations and with main data gaps filled with experts' inputs gathered through direct consultations and organisation of workshops,
- recommendations for the maintenance and update of the MSA.

The outcome of the project will be made available in a database (with secured access) developed by the European Commission that will help identifying key opportunities to secure supply of non-energy resources in Europe.

1.3 Project implementation

This project was launched in January 2014 and finished in September 2015. The work was structured in five tasks:

- task 1: Complete overview and evaluation of data sources,
- task 2: Procedure for the development of MSA in Europe,
- task 3: Experts consultation,
- task 4: Development of MSA for the studied materials in Europe,
- task 5: Recommendations on maintaining and updating the MSA database.

The specific description of each task and the work program are detailed in the following sections.

Task 1 included:

- a review of literature and data sources potentially usable for MSA (including for example geological surveys databases, Eurostat PRODCOM and ComExt databases, industry reports, commercial datasets and reports, life cycle assessment case studies...),
- an evaluation of the identified datasets from the viewpoint of their usability for the MSA of the 28 materials studied in this project (including for example an assessment of their frequency of update, their reliability, their conditions of use in terms of Intellectual Property Rights, their cost...),
- and an identification of the main data gaps.

Task 2 consisted of defining a general methodology for the development of MSA in Europe. This task included in particular:

- securing a consistent use of terms and definitions in the field of MSA,
- defining the common list of parameters and the flow chart constituting the MSA of the different materials studied (parameters describing flows and stocks, characterising criticality of the materials and forecasting future supply and demand),
- defining calculation formulas for some specific parameters,
- establishing a procedure to prioritise and validate existing data sources for MSA,
- establishing a procedure to fill data gaps by techniques of approximation from existing sources or expert consultation,
- developing a structure for storing and displaying information on the MSA in an Excel file (data sources, assumptions, calculations and results) and in a Sankey diagram,
- assessing the possibility to establish future routines to facilitate updates for relevant information.

Task 3 involved the consultation of experts to provide inputs and feedback on the work conducted during the project. Experts' inputs were gathered through direct consultations and organisation of 5 workshops. These workshops involving between 15 and 30 international experts were organised in Brussels in order to review the work achieved by the project team and to validate, complete or modify the preliminary results obtained. One workshop was focused on methodological aspects for establishing MSA and 4 other workshops were dedicated to the development of the MSA of the 28 studied materials. The project team was also regularly in contact with members of other European ongoing projects (Minventory, Minerals4EU...) in order to share information related with MSA of raw

materials in Europe. Finally, the project team also contacted a number of stakeholders in the US and Japan in order to promote international cooperation in the field of MSA and critical materials. The stakeholders were invited to join trilateral discussions with the objective of sharing knowledge and best practices regarding sustainable supply of raw materials.

Task 4 concerned the data collection and processing for the development of the MSA of the 28 studied materials. In addition to desk research of available information, as mentioned above, the project team was regularly in contact with experts in order to collect information and to ensure the consistency of the results. Experts were contacted while the project team was beginning to work on specific materials in order to acquire general knowledge about the life cycle of the materials, validate first information gathered and provide data. Then, experts were invited to participate in workshops to review and validate the work achieved regarding the MSA of these specific materials. Before each workshop, material-specific background documents describing the preliminary results and the data missing were prepared by the project team and sent to experts in order to give them time to review the documents and gather missing information. Task 4 also included the development of the 28 Excel files compiling all the data sources, assumptions, calculations and results of the 28 MSA as well the development of the Sankey diagrams presenting the results.

Task 5 concerned the elaboration of recommendations for the European Commission to maintain and update on a regular basis the database including the 28 MSA achieved during this project. This includes the technical aspects such as the collection, aggregation and verification of data, but also the organisational and administrative aspects of maintaining and updating the database. The recommendations inform about the most efficient manner to organise and manage the different steps of maintaining and updating the MSA database, i.e. data collection, compilation, verification and publication.

2. Methodology

2.1 Definition of a Material System Analysis

According to OECD, a Material System Analysis (MSA) is defined as follows:

“A Material system analysis (MSA) is based on material specific flow accounts. It focuses on selected raw materials or semi-finished goods at various levels of detail and application (e.g. cement, paper, iron and steel, copper, plastics, timber, water) and considers life-cycle-wide inputs and outputs. It applies to materials that raise particular concerns as to the sustainability of their use, the security of their supply to the economy, and/or the environmental consequences of their production and consumption.”

Within the framework of this project, which aims to develop MSA for several key raw materials at the European level, a MSA consists of:

- a map of the flows of material through the European economy (EU28), as raw materials or as parts of basic materials, components or products, in terms of:
 - entries into the economy (extraction and import),
 - movements through the economy (production, consumption, export),
 - additions to stock,
 - and end of life,
- with additional information related to security of supply (governance risk supply, country concentration...), substitutes, future supply and demand changes of materials.

The MSA includes the entire life cycle of materials, including exploration, extraction, processing, manufacturing, use and end of life through either disposal or recovery.

It should be noticed that in this project, the MSA does not take into account the analysis of the environmental consequences of the production and consumption of the materials involved, and in this way its scope is slightly reduced compared to the OECD definition. However, the presented MSA data will no doubt prove to be very useful in policy discussions on reducing Europe’s vulnerability to factors that may limit access to critical materials. Insight in the environmental consequences of options to improve resource efficiency and to secure access to these resources would be of great value, particularly for evaluating prospects for mining, recycling and reduction of landfill, but this aspect is not addressed in this study.

2.2 Scope of the Material System Analysis

The content of the MSA is specified by:

- a list of parameters,
- a flow chart, which can be displayed with detailed and simplified Sankey diagrams,
- and a reference unit.

2.2.1 Parameters of the Material System Analysis

The parameters aim to describe physical flows and stocks along the life cycle of the material, characterise the criticality of the material or forecast future supply and demand.

In order to define the list of parameters to study, the parameters from the *Study on Data Needs for a Full Raw Materials Flow Analysis* (2012, European Commission) were taken as a basis and evaluated one by one. In addition, specific investigations were carried out in order to define which parameters relating to criticality should be included in the MSA.

To this aim, the *Report on Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials* (2014, European Commission) that contains a discussion about aspects

that can influence criticality was analysed. These aspects were subject to review with regard to a possible integration into the MSA framework.

Based on these elements, a first list of parameters was proposed to the European Commission's Services, based on a literature review of the parameters used in previous MFA studies and on the list of parameters proposed in the *Study on Data Needs for a Full Raw Materials Flow Analysis* (2012, European Commission).

The list of proposed parameters was discussed with experts on Critical Raw Materials and MSA methodology. A workshop was held in Brussels with the aim of presenting the proposed methodology and parameters, and allowing experts to suggest improvement options. Table 2 shows the organisations that participated to this workshop on the MSA methodology.

Table 2 : List of organisations participant to the methodology workshop

Organisations participant to the methodology workshop
Euromines
Outotec
Chatham House
Eunomia Research & Consulting Ltd
European Aggregates Association (UEPG)
Federal Institute for Geoscience and Natural Resources (BGR)
Bureau de Recherches Géologiques et Minières (BRGM)
Fraunhofer ISI
CEIS
Eurometaux
Polish Geological Institute
CML Leiden University
EPBA
Euroalliages

According to the experts that attended the workshop, accomplishing the full MSA of each material studied is an ambitious objective, and therefore the focus should be put on the parameters related to physical flows and stocks of materials. Additional parameters related to production and demand trends, criticality and policy objectives would also be useful for the MSA.

Finally, based on the proposition of the project team and the suggestions made by the experts, the list of parameters validated by the European Commission's services to be studied in the MSA includes 52 required parameters and 11 optional parameters divided in 3 groups:

- Group 1 parameters = parameters representing physical flows and stocks of a material (such as reserves in EU, imports to EU of products...),
- Group 2 parameters = parameters relating to policy objectives and criticality (such as governance risk supply, economic importance...),
- Group 3 parameters = parameters relating to future supply and demand change (such as resources in EU, future demand...).

It is underlined that the methodology for the assessment of criticality of materials is currently under revision by the European Commission services. A new methodology and a new list of parameters relating to criticality will be available in 2016. Consequently, it is probable that the group 2 parameters included in this study regarding MSA will be modified when it will be updated in the future.

All the group 1 parameters are required whereas some group 2 and group 3 parameters are optional depending on the availability of data.

All the parameters are defined with a code including:

- a capital letter referring to the life cycle step (A to G, A for Exploration, B for extraction, C for processing, D for manufacture, E for Use, F for Collection and G for Recycling),
- a first number referring to the group of the parameter (1 to 3),
- and an incremental number.

The parameters are described in Table 3.

Table 3: List of parameters included in the MSA. White = required parameter; Grey = optional parameter

Life cycle stage	Type of parameter	Parameter	Description of the parameter
A. Exploration	1 - Parameters representing physical flows and stocks of materials	A.1.1 Reserves in EU	<i>Quantity of the element in the EU reserves</i>
		A.1.2 Reserves in ROW	<i>Quantity of the element in the rest of the world (ROW) reserves</i>
	3 - Parameters relating to future supply and demand change	A.3.1 Resources in EU	<i>Quantity of the element in the EU resources</i>
		A.3.2 Resources in ROW	<i>Quantity of the element in the rest of world (ROW) resources</i>
		A.3.3 Investment in exploration	<i>Current and planned investment in exploration</i>
B. Extraction	1 - Parameters representing physical flows and stocks of materials	B.1.1 Production of primary material as main product in EU sent to processing in EU	<i>Annual quantity of the element in the production of primary material as main product in EU sent to processing in EU Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step in situ).</i>
		B.1.2 Production of primary material as by-product in EU sent to processing in EU	<i>Annual quantity of the element in the production of primary material as by-product in EU sent to processing in EU Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step made in situ).</i>
		B.1.3 Exports from EU of primary material	<i>Annual quantity of the element in the exports from EU of primary material (as main product or by-product) Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step made in situ).</i>
		B.1.4 Extraction waste disposed in situ /tailings in EU	<i>Annual quantity of the element in the extraction waste disposed in situ in EU Extraction waste disposed in situ refers to tailings (waste from extraction and if applicable preliminary step of processing made in situ)</i>
		B.1.5 Stock in tailings in EU	<i>Quantity of the element in tailings in EU</i>
	2 - Parameters relating to policy objectives	B.2.1 Country concentration	<i>Index highlighting the concentration of the countries involved in the extraction of the element. Use the Herfindahl-Hirschman-Index (HHI), given by the sum of the squared market shares of the countries extracting the element. This parameter is calculated based on the methodology described in the Report on Critical Raw Materials for the EU (2014, European Commission) and on updated data gathered within this project.</i>

Life cycle stage	Type of parameter	Parameter	Description of the parameter
		B.2.2 Governance risk supply	<p><i>Index highlighting the concentration of the countries involved in the extraction of the element with regard to their governance stability. Use the modified Herfindahl-Hirschman-Index (HHI), given by the sum of the squared market shares of the countries extracting the element multiplied by their score in the World Governance Index. The result is then weighted by the Substitutability Index and the Recycling Input Rate at world level.</i></p> <p><i>This parameter is calculated based on the methodology described in the Report on Critical Raw Materials for the EU (2014, European Commission) and on updated data gathered within this project</i></p>
		B.2.3 Production of primary material as main product in ROW	<i>Annual quantity of the element in the production of primary material as main product in rest of the world (ROW)</i>
		B.2.4 Production of primary material as by product in ROW	<i>Annual quantity of the element in the production of primary material as by product in rest of the world (ROW)</i>
		B.2.5 Industry structure in EU	<i>SME ratio of companies involved in extraction</i>
		B.3.1 Future supply	<i>Published projections of future extraction</i>
	3 - Parameters relating to future supply and demand change	B.3.2 Typical time required for production of primary material in EU	<p><i>Past typical time range to obtain necessary permits and to begin the production of primary material in the mine, pit or quarry in EU, including a sub-distinction between 2 timeframes:</i></p> <ul style="list-style-type: none"> - <i>The average timeframe for the completion of the administrative process: From the submission by the operator of all the necessary documents to the competent authorities to the formal and official reply of the competent authorities (i.e. permit(s) granted or refused);</i> - <i>The average timeframe to open the mine once the necessary permits have been obtained, including the average timeframe lost because of court proceeding.</i>
		B.3.3 Typical time required for production of primary material in ROW	<p><i>Past typical time range to obtain necessary permits and to begin the production of primary material in the mine, pit or quarry in the rest of the world (ROW), including a sub-distinction between 2 timeframes:</i></p> <ul style="list-style-type: none"> - <i>The average timeframe for the completion of the administrative process: From the submission by the operator of all the necessary documents to the competent authorities to the formal and official reply of the competent authorities (i.e. permit(s) granted or refused);</i> - <i>The average timeframe to open the mine once the necessary permits have been obtained, including the average timeframe lost because of court proceedings.</i>
	C. Processing	1 - Parameters representing physical flows and stocks of materials	C.1.1 Production of processed material in EU sent to manufacture in EU
C.1.2 Exports from EU of processed material			<i>Annual quantity of the element in the exports from EU of processed material</i>

Life cycle stage	Type of parameter	Parameter	Description of the parameter
		C.1.3 Imports to EU of primary material	Annual quantity of the element in the imports to EU of primary material (as main product or by-product) Primary material refers to products at the gate of the mine, pit or quarry (ore or concentrate after a preliminary processing step made in situ).
		C.1.4 Imports to EU of secondary material	Annual quantity of the element in the imports to EU of secondary material
		C.1.5 Processing waste in EU sent for disposal in EU	Annual quantity of the element in the processing waste in EU sent for disposal in EU
		C.1.6 Exports from EU of processing waste	Annual quantity of the element in the exports from EU of processing waste
		C.1.7 Output from the value chain at the processing step	Annual quantity of the element exiting the value chain (as impurities, non functional by-product, dissipation...)
	2 - Parameters relating to policy objectives	C.2.1 Country concentration	Index highlighting the concentration of the countries involved in the processing of the element. Use the Herfindahl-Hirschman-Index (HHI), given by the sum of the squared market shares of the countries processing the element. This parameter is calculated based on the methodology described in the Report on Critical Raw Materials for the EU (2014, European Commission) and on updated data gathered within this project
		C.2.2 Governance risk supply	Index highlighting the concentration of the countries involved in the processing of the element with regard to their governance stability. Use the modified Herfindahl-Hirschman-Index (HHI), given by the sum of the squared market shares of the countries processing the element multiplied by their score in the World Governance Index. The result is then weighted by the Substitutability Index and the Recycling Input Rate at world level. This parameter is calculated based on the methodology described in the Report on Critical Raw Materials for the EU (2014, European Commission) and on updated data gathered within this project
		C.2.3 Industry structure in EU	SME-ratio of companies involved in processing
	3 - Parameters relating to future supply and demand change	C.3.1 Future demand	Published projections of future demand of processed material
	D. Manufacture of end-products	1 - Parameters representing physical flows and stocks of materials	D.1.1 Production of manufactured products in EU sent to use in EU
D.1.2 Exports from EU of manufactured products			Annual quantity of the element in the exports from EU of manufactured products
D.1.3 Imports to EU of processed material			Annual quantity of the element in the imports to EU of processed material
D.1.4 Manufacture waste in EU sent for disposal in			Annual quantity of the element in the manufacture

Life cycle stage	Type of parameter	Parameter	Description of the parameter	
E. Use		EU	waste in EU sent for disposal in EU	
		D.1.5 Manufacture waste in EU sent for reprocessing in EU	Annual quantity of the element in the manufacture waste in EU sent for reprocessing in EU = Annual quantity of the element in the processing inputs of secondary material from manufacture from EU	
		D.1.6 Exports from EU of manufacture waste	Annual quantity of the element in the exports from EU of manufacture waste	
		C.1.7 Output from the value chain at the manufacturing step	Annual quantity of the element exiting the value chain (as impurities, non-functional by-product, dissipation...)	
		2 - Parameters relating to policy objectives	D.2.1 Main uses	Main applications
			D.2.2 Substitutability index	Substitutability Index at world level This parameter takes over the results in the Report on Critical Raw Materials for the EU (2014, European Commission)
	D.2.3 Economic importance		Economic importance of megasectors (ratio of GVA on EU 's GDP) This parameter is calculated based on the methodology described in the Report on Critical Raw Materials for the EU (2014, European Commission) and on updated data gathered within this project	
	D.2.4 Industry structure in EU		SME-ratio of companies involved in manufacture,	
	D.3.1 Future supply		Published projections of future demand of manufactured products, Evolution of megasectors, Opportunities and impacts of new technologies and policies	
	1 - Parameters representing physical flows and stocks of materials	E.1.1 Stock of manufactured products in use in EU	Quantity of the element in the stock of manufactured products in use in EU	
		E.1.2 Stock of manufactured products at end of life in EU	Quantity of the element in the stock of manufactured products at end of life that are kept by users in EU	
		E.1.3 Exports from EU of manufactured products for reuse	Annual quantity of the element in the exports from EU of manufactured products for reuse (products for reuse not considered as waste)	
		E.1.4 Imports to EU of manufactured products	Annual quantity of the element in the imports to EU of manufactured products	
E.1.5 In use dissipation in EU		Annual quantity of the element lost by in use dissipation in EU In use dissipation refers for example to: a loss of zinc due to corrosion of zinc coating on steel, a loss of copper due to spread of copper sulphate as a fungicide (based on UNEP definition)		
E.1.6 Products at end of life in EU collected for treatment		Annual quantity of the element in the manufactured products at end of life (waste) in EU collected for treatment		

Life cycle stage	Type of parameter	Parameter	Description of the parameter
		E.1.7 Annual Addition to in-use stock of manufactured products in EU	<i>Quantity of the element that is annually added to the stock of manufactured products in use in EU</i>
		E.1.8 Annual addition to end-of-life stock of manufactured products in EU	<i>Quantity of the element that is annually added to the stock of manufactured products at end of life that are kept by users in EU</i>
F. Collection	1 - Parameters representing physical flows and stocks of materials	F.1.1 Exports from EU of manufactured products at end of life	<i>Annual quantity of the element in the exports from EU of manufactured products at end of life (waste for treatment)</i>
		F.1.2 Imports to EU of manufactured products at end of life	<i>Annual quantity of the element in the imports to EU of manufactured products at end of life (waste for treatment)</i>
		F.1.3 Manufactured products at end of life in EU sent for disposal in EU	<i>Annual quantity of the element in the manufactured products at end of life (waste) in EU sent for disposal in EU</i>
		F.1.4 Manufactured products at end of life in EU sent for recycling in EU	<i>Annual quantity of the element in the manufactured products at end of life in EU sent for recycling in EU</i>
		F.1.5 Stock in landfill in EU	<i>Quantity of the element in landfill in EU</i>
		F.1.6 Annual addition to stock in landfill in EU	<i>Quantity of the element that is annually added to landfill in EU</i>
G. Recycling	1 - Parameters representing physical flows and stocks of materials	G.1.1 Production of secondary material from post-consumer functional recycling (old scrap) in EU sent to processing in EU	<i>Annual quantity of the element in the production of secondary material from post-consumer functional recycling (old scrap) in EU sent to processing in EU Functional recycling refers to recycling in which the element in a discarded product is separated and sorted to obtain secondary material displacing same primary material (based on UNEP definition)</i>
		G.1.2 Production of secondary material from post-consumer functional recycling (old scrap) in EU sent to manufacture in EU	<i>Annual quantity of the element in the production of secondary material from post-consumer functional recycling (old scrap) in EU sent to manufacture in EU Functional recycling refers to recycling in which the element in a discarded product is separated and sorted to obtain secondary material displacing same primary material (based on UNEP definition)</i>
		G.1.3 Exports from EU of secondary material from post-consumer recycling	<i>Annual quantity of the element in the exports from EU of secondary material from post-consumer functional and non-functional recycling</i>
		G.1.4 Production of secondary material from post-consumer non-functional recycling in EU	<i>Annual quantity of the element in the production of secondary material from post-consumer non-functional recycling in EU Non-functional recycling refers to recycling in which the element in a discarded product is collected and incorporated in a associated large magnitude material stream. This represents the loss of its function as it is generally impossible to recover it from the large magnitude stream (based on UNEP definition)</i>

Life cycle stage	Type of parameter	Parameter	Description of the parameter
		G.1.5 Recycling waste in EU sent for disposal in EU	<i>Annual quantity of the element in the recycling waste in EU sent for disposal in EU</i>
		G.2.1 European Functional Recycling rate	<i>Functional Recycling rate including collection rate and recycling process efficiency rate at EU level. The definition of this parameter is presented in section 5.5, and it is different from that of the parameter "End-of-life Recycling Input Rate" used in the Report on Critical Raw Materials for the EU (2014, European Commission).</i>
	2 - Parameters relating to policy objectives	G.2.2 European Non Functional Recycling rate	<i>Non Functional Recycling rate including collection rate and recycling process efficiency rate at EU level. The definition of this parameter is presented in section 5.5, and it is different from that of the parameter "End-of-life Recycling Input Rate" used in the Report on Critical Raw Materials for the EU (2014, European Commission).</i>
		G.2.3 Industry structure in EU	<i>SME-ratio of companies involved in recycling,</i>
	3 - Parameters relating to future supply and demand change	G.3.1 Future supply	<i>Published projections of future supply of secondary material from post-consumer recycling Model data of anthropogenic stocks</i>

2.2.2 Flow chart and Sankey diagrams of the Material System Analysis

The flow chart of the MSA aims to give a visual presentation of the flow and stock parameters (group 1 parameters).

The flow chart is presented in Figure 1.

Based on this general flow chart, detailed and simplified Sankey diagrams specific to each studied material are developed (see chapter 3 - Results). These Sankey diagram allow:

- to show the results of the flow parameters, with the width of the arrows displayed proportionally to the flow quantity,
- to present the results of the stock parameters, with the value of the stock and the annual addition to this stock.

In this public report, only simplified Sankey diagrams are displayed. The Detailed Sankey diagrams, with all the flows and stocks for each life cycle steps, are confidential.

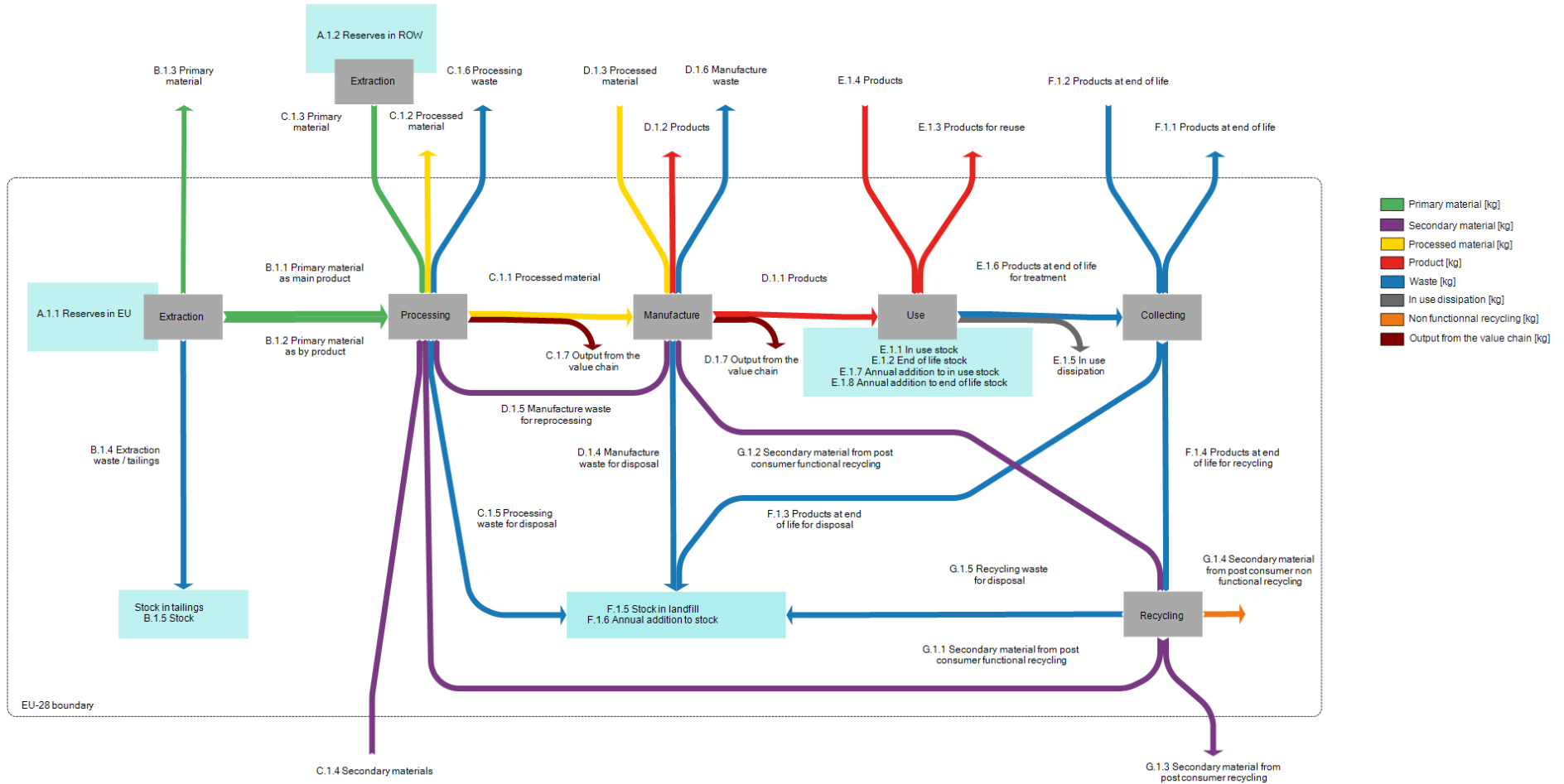
2.2.3 Reference unit of the Material System Analysis

Regarding materials which are defined as chemical elements (Antimony, Beryllium, Germanium...), the reference unit for the physical flows and stocks parameters is generally 1 kg of element (for example 1 kg of Antimony, 1 kg of Beryllium...).

Regarding the other materials (Fluorspar, Borates, Magnesite, graphite, phosphate, aggregates...), the reference unit is defined on a case by case basis and specified in each MSA. For example, the reference unit for the MSA of Fluorspar (CaF_2) is 1 kg of Fluorine (F) and the reference unit for the MSA of aggregates is 1 kg of aggregates.

In addition, it should be noted that the flow parameters aims to quantify physical flows of material between two life cycle steps and not embodied flows. For example for Fluorspar, the MSA aims to quantify the annual quantity of Fluorine in the imports to EU of processed material containing Fluorine, but not in the amount of Fluorspar needed to obtain the imported processed material (embodied consumption of Fluorspar).

Figure 1: Flow chart of the MSA presenting the flow and stock parameters (group 1 parameters)



2.3 Different approaches used for the development of the Material System Analysis

Depending on the life cycle step and the available data sources, two main approaches are used for the calculation of the MSA parameters: the bottom-up approach and the top-down approach.

For both approaches, the study cannot estimate the uncertainty level of the calculations so the resulting figures should be taken with caution in any cases.

2.3.1 Bottom-up approach

The bottom-up approach refers to a calculation of the flow and stock parameters based on data at the product level.

This approach is used when data on products is available and quite exhaustive.

For most of the studied materials, this approach is used at the extraction and processing steps. This is mainly due to the limited number of primary materials and processed materials produced at these steps and the availability of information on these specific flows in databases such as the Eurostat database. In addition, the composition of these primary and processed materials is generally known. Consequently, the quantity of the studied material in the flows of primary and processed materials can generally be calculated using data such as: production sold in EU of primary material X, exports from EU of processed material Y, imports to EU of processed material Z.

However, the bottom-up approach is less used in the manufacture step and in further steps, for 3 main reasons:

- At the manufacture step and downstream, the number of semi-finished products and finished products can be extremely large and it is quite impossible to consider all the flows or even a significant part of the flows of these products.
- There are lots of data gaps regarding the amount of the flows of specific types of semi-finished or finished products in the available databases or in trade associations.
- The material content in specific types of semi-finished or finished products is generally not available. Furthermore, when looking at a specific type of product, the material content may vary a lot depending on the product. Consequently, the calculation of average contents is quite difficult and could give quite unreliable results.

2.3.2 Top-down approach

The top-down approach refers to a calculation of the flow and stock parameters based on data at the EU level.

This approach is used when data for the overall EU production or consumption of a studied material at a specific life cycle step is available and when shares of use of the material per type of sector (or application) are known. With such data, the quantity of the studied material in the output or the input of this specific life cycle step can be calculated, with details per sector.

For most of the studied materials, this approach is used in the manufacture step and in further steps, for the 3 main reasons explained in the previous section: complexity of the value chain at these steps, lack of data regarding the amount of the flows of specific types of products (or waste), lack of data regarding the material content in the products.

However, this top-down approach also requires the use of data at the product level. Indeed, for each sector, it is necessary to know the exports and imports of the studied material, in addition to EU production or consumption. To this aim, it is generally necessary to define a typical product for each sector and to calculate ratios such as export/EU production or imports/EU consumption for each of these typical products thanks to available information in Eurostat databases or trade associations. Then, the assumption is made that these ratios, which are representative of typical products within a sector, are representative of the whole sector. Then, it is possible to estimate the imports, exports and production sold in EU per sector and to deduce the global imports, exports and production sold in EU.

For the use step and waste management steps, additional data relating to typical products per sector are required such as: lifespan of products, annual growth rate of consumptions...Here again, the

assumption is made that these data are representative of the whole sector, which leads to uncertainties.

Finally, the top-down approach may be considered as more exhaustive in terms of quantity of the studied material than the bottom-up approach as the data for each sector is calculated as a share of the total EU production or consumption. However, the traded quantities (exports and imports) and other parameters (such as in use stock) are calculated by using data representative of typical products per sector and not representative of the whole sector, which does not accurately reflect the reality.

2.4 Main data sources and general procedure for the development of the Material System Analysis

A general procedure was defined in order to calculate the different parameters of the MSA based on the main data sources available. This general procedure is based on desk study and expert consultation. However, it is underlined that this general methodology was adapted on a case by case basis for each material, depending on the available data.

The general procedure is described below. The list of data sources used and the main stakeholders who contributed to the development of the MSA for each material are detailed in Annex 2.

2.4.1 Desk study

For the development of a MSA, the first important task is to identify the value chain of the material studied, i.e. all the forms (from ores to end-manufactured products containing the material) that come through the European economy, and in particular the different uses of the material. This value chain is divided into the different life cycle steps.

Then, for each life cycle step, a common approach is carried out in order to identify the relevant data sources, to compile data and to calculate parameters.

The paragraphs below highlight the main data sources used and the main calculation methods applied for the different life cycle steps.

2.4.1.1 Exploration and extraction steps

Data on EU or world resources and reserves are generally provided by BGS Mineral Factsheets or USGS Minerals Yearbook (see Box 1 for a presentation of BGS and USGS data regarding mineral resources and reserves). In the same way, data on EU production of primary material (ores or concentrate) is generally provided by BGS European Mineral Statistics, Eurostat or industrial stakeholders and associations. Those sources may also give inputs to make the distinction between the extraction of the element as main product or as by-product.

The production of primary material per country can be found in USGS mineral commodities summaries or through industrial stakeholders' websites. Those market shares are the starting point for the calculation of the Group 2 parameters, such as country concentration and governance risk supply. For governance risk supply, the WGI index are listed in the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*.

The EU production, imports and exports of primary materials are generally provided in the PRODCOM and ComExt databases of Eurostat (see Box 2 for a presentation of the Eurostat databases PRODCOM and ComExt).

Based on these data sources, the quantity of the studied element in reserves, resources or production of primary material is generally calculated by multiplying the quantity of ore by the average raw material content in the ore and then by the average element content in the raw material (see Figure 2). This is an application of the bottom-up approach presented in section 2.3.1.

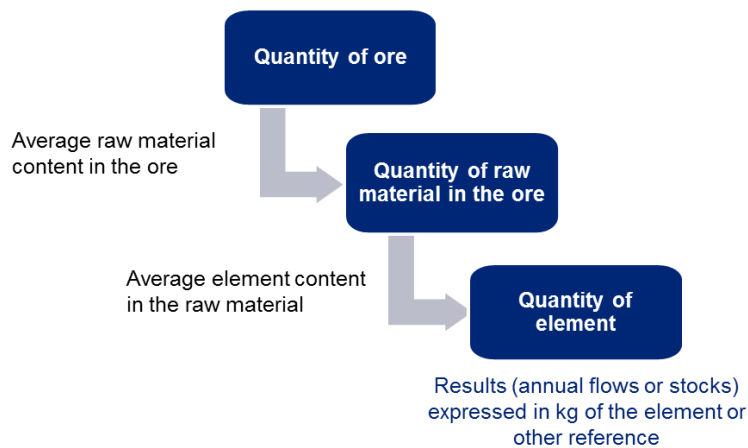


Figure 2: Calculation method for the upstream steps (exploration, extraction and processing)

There is usually little data about the waste generated during the extraction process, although some sources may report the overall efficiency of the mining and processing steps. Consequently, data on extraction waste and stock in tailings have to be estimated by stakeholders in order to fill the data gaps. In the same way, information about the investment in exploration, the time to open a mine or the structure of the extractive industry for each studied material is often missing from literature and databases and it is often necessary to rely on stakeholder estimations.

Regarding future supply of primary material, the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)* often provides data.

In some cases, the MSA is built based on different data sources that use different methodology or definition of flows or materials. This may lead to uncertainties in the results that the lack of homogeneous data obliges to accept. In order to note these uncertainties in the results, a score regarding the quality of the data has been added to each data point, as presented in section 2.6.

Box 1: BGS and USGS as main data sources for exploration and extraction

Geological survey institutions follow up on the exploration and extraction of raw material deposits. They generally group them into reserves (economically exploitable deposits) and resources (known but under current conditions not exploitable deposits). Especially USGS has a long track record of compiling all relevant information about raw material reserves and resources. Differentiated by raw material they observe all known exploration and exploitation activities and provide them in a condensed way on their web page. They are structured by raw material and contain information about country specific situation. The restrictions faced by the geological surveys are connected to availability of information and use of different standards (JORC, PERC...) regarding the definition of reserves and resources. The quality and the scope of data can be different and depend on the collaboration of companies and national governmental bodies.

For example, USGS data does not apply unified classification of resources and products across countries regarding aggregates. This commodity can be found under the following headings for individual countries: Sand and gravel, Sand and gravel: common sand and gravel, Sand and gravel: other sand, gravel and aggregates. However, definition of these material categories is not provided therefore it is not possible to determine to which extent they are identical or overlapping.

Another issue is the availability of the most recent information provided by companies and national institutions around the world. Settled knowledge or early estimates are needed to fulfil the task of reporting actual data.

Besides, BGS publishes the “world mineral data” annually with information for the last four years. This publication comprises data on the worldwide mineral production per commodity and country. Additionally, BGS publishes the “European Minerals Statistics”, which also comprises data on imports and exports of European countries of the different commodities. However, it is not stated whether the exports and imports are Extra-EU or Intra-EU, so the trade data cannot be used, especially if a better source is available (Eurostat for example).

Depending on the differentiation of the life cycle steps of the material under investigation, BGS data

can also be used for parts of the processing or even manufacturing step. One major advantage of the BGS “European Mineral Statistics” as a data source for the MSA is the commodity specific view, which is missing in the COMEXT or PRODCOM classification.

2.4.1.2 Processing step

As in the previous steps, the data on EU production of processed material is generally provided by BGS European Mineral Statistics or the PRODCOM database of Eurostat. Similarly, EU imports and exports of processed material are generally provided by the ComExt database of Eurostat or by industry associations. The content of the element in the processed materials are generally provided as estimates by industry associations. Thus, the calculation of the parameters at the processing step is generally based on a bottom-up approach as described in section 2.3.1.

USGS commodities profiles give inputs regarding the amount of secondary material used in the US economy, whose ratio between primary and secondary input can be extrapolated to EU (on the hypothesis that they are both developed regions), but the distinction between intra-EU or extra-EU imports is not available.

The amount of processed material produced by each country can be found in Market element overview reports written by the French Geological Survey BRGM or through industrial stakeholders' websites. As for the extraction step, those market shares are the starting point for the calculation of the Group 2 parameters, such as country concentration and governance risk supply.

The quantity of element in the waste generated during the processing step is often provided by literature through data on the efficiency or yield of the process.

Information about the structure of the processing industry is often missing from literature and databases and it is often necessary to rely on stakeholder estimations.

Regarding future demand of processed material, the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)* often provides data, but this data needs to be regularly updated to be still usable for future works.

Box 2: ComExt and PRODCOM Eurostat databases

The ComExt¹ database provides statistics on merchandise trade among the EU member states, and between the member states and global partners. ComExt, developed and maintained by Eurostat, is based on the data provided by the statistical agencies of the EU member states.

Trade goods are classified by the 8-digit European Harmonized System (CN8, Combined Nomenclature) as well as NACE (up to 4 digits) and SITC Rev. 3 (up to 5 digits). The CN is an eight-digit subdivision of the Harmonised System (HS), comprising four two-digit levels: HS2, HS4, HS6 and CN8. Trading partners are designated a three-digit or four-digit code.

The PRODCOM² database provides the EU statistics on the production of manufactured goods. The term comes from the French "PRODUCTION COMMUNAUTAIRE" (Community Production) for mining, quarrying and manufacturing: sections B and C of the Statistical Classification of Economy Activity in the European Union (NACE 2).

PRODCOM uses the product codes specified in the PRODCOM List containing about 3900 different types of manufactured products. Products are identified by an 8-digit code. The first four digits are the classification of the producing enterprise given by the Statistical Classification of Economic Activities in the European Community (NACE) and the first six correspond to the CPA. The remaining digits specify the product in more detail.

Most product codes correspond to one or more Combined Nomenclature (CN) codes but some (mostly industrial services) do not.

Although the ComExt and PRODCOM databases contain large amount of data, only some product

¹ <http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do>

² <http://ec.europa.eu/eurostat/web/PRODCOM/data/database>

categories can be directly used for MSA. The reason is that CN and PRODCOM classifications are based on different accounting rules and principles than MSA and are not material-specific. Examples of directly usable CN categories are presented below:

- 25041000: Natural graphite in powder or in flakes,
- 25191000: Natural magnesium carbonate "magnesite",
- 25280000: Borates, natural, and concentrates thereof, whether or not calcined, and natural boric acids containing $\leq 85\%$ of H_3BO_3 calculated on the dry weight (excl. borates separated from natural brine),
- 25292100: Fluorspar containing by weight $\leq 97\%$ calcium fluoride,
- 27011210: Coking coal, whether or not pulverised, non-agglomerated,
- 28046900: Silicon containing $< 99,99\%$ by weight of silicon.

Inconsistencies that hamper use of the ComExt and PRODCOM databases for MSA are articulated further in chapter 4. This chapter also provides some suggestions for adjustments making the ComExt database more usable for MSA.

2.4.1.3 Manufacture

The identification of the main uses and the main finished products containing the studied materials is performed thanks to literature (for example USGS commodity documents, the CRM report, BRGM reports...) and trade associations.

Then, the European production (total or sold in Europe), the imports and the exports of semi-finished products and finished products containing a studied material may be provided by PRODCOM, ComExt or by trade associations, but there lots of data gaps and difficulties.

Indeed, to follow the flows of all the semi-finished products and finished products requires to split the manufacturing step of each type of product containing a studied material into numerous manufacturing steps and requires to take into account a huge number of intermediate flows regarding production, import and export of all these products. To illustrate these difficulties, one can use the example of planes, which are produced with aero jet engines, which are themselves produced with turbine blades. Some blades made in EU are sold in EU or are exported whereas some blades are imported in EU. Aero jet engines produced in EU can be made with blades made in EU but also with imported blades and some of these engines are used in the EU whereas others are exported. Also some jet engines are imported in EU. And then, it is the same at the plane level with planes produced in EU with engines made in EU or not, with blades made in EU or not. Some of these planes are sold in EU or exported, some others are imported.

Thus, the accounting of all these flows is intrinsically difficult but the difficulties are reinforced by the fact that:

- there are lots of data gaps regarding the amount of the flows of specific types of semi-finished or finished products, mainly because of aggregated or missing codes in Eurostat databases or because of confidentiality of data at the level of trade associations,
- the composition of the semi-finished and finished products, and in particular the content in the studied materials, is generally not available.

In order to reduce these difficulties, a simplified approach focused on the finished products and sometimes on one level of semi-finished products can be performed instead. But even with a simplified approach, it is necessary to fill data gaps and to make estimations in order to translate data on production, import or export of products into flows of the material (element) under study as illustrated in Figure 3. Such approach is still difficult to implement and may provide results with high uncertainties.

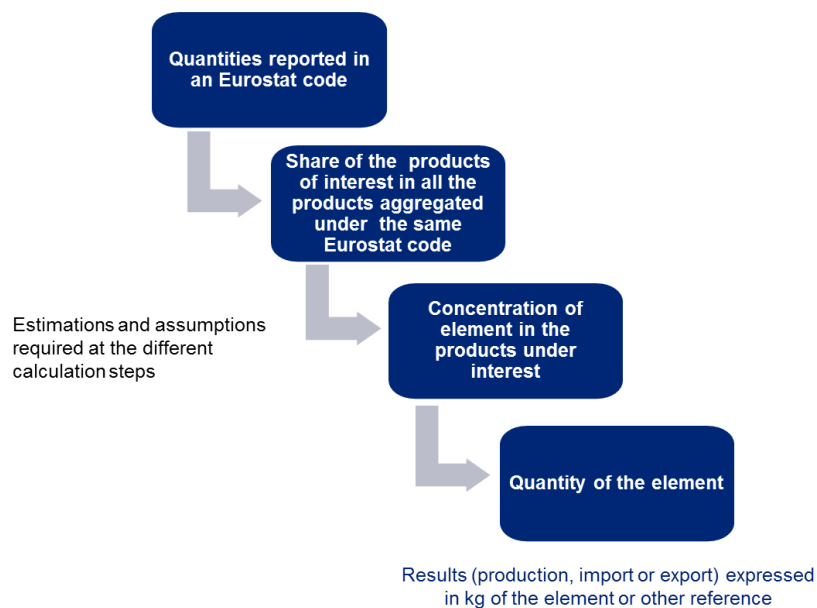


Figure 3: Possible calculation method for the manufacture step (bottom-up approach)

Therefore, the bottom-up approach described above is generally not used and a top-down approach (as described in 2.3.2) is generally preferred at the manufacture step. To do so, it is necessary to have:

- data on total EU production or total EU consumption of the studied material in the finished products,
- and data on the shares of use of the material within the main sectors in EU.

When these data are available, they are the most appropriate data in order to estimate the amount of a studied material within the finished products produced in each sector in Europe or supplied to the final consumer in each sector in Europe. With such data, it is not necessary to make assumptions on the material content of the different products.

Afterwards, a typical finished product is identified for each main sector (for example car for transport sector, laptop for IT sector...). Then, PRODCOM and ComExt databases are generally used in order to calculate ratios such as export/EU production and imports/EU consumption for each typical product. These ratios are considered to be representative of each whole sector. Then, based on these ratios and based on the amount of the studied material produced or consumed in Europe in each sector, it is possible to deduce the production, import and export flows of the studied material in each sector.

The quantity of waste generated during the manufacture and the fate of the waste (disposal, recycling, export...) is often missing and has to be estimated based on yield of processes or expert consultation.

Finally, mass balance equations linking the flows together can be used in order to fill some gaps and to ensure consistency between flows estimated at the processing step, the manufacture and the use step. However, this approach is based flows that depend on assumptions and expert opinion, so it does not reduce the uncertainty of the data produced. The mass balance consistency allow at mathematical equality of input and output flows but does not enhance the robustness of the figures.

With such a top-down approach, it is interesting to note that the development of the MSA is not done chronologically one life cycle step at a time.

Indeed, whereas data on processing are mostly based on inputs of primary material from the extraction step, it is in general preferable to deduce data on manufacture based on output of the manufacture step or inputs of the use step. Indeed, as explained above, estimating data on manufacture based on inputs of processed materials and semi-finished products requires the accounting of a huge number of intermediate flows and would then increase the uncertainties in the results.

The top-down approach at the manufacture step is illustrated in Figure 4. In this figure, the available data is the EU consumption of the studied material at the use step.

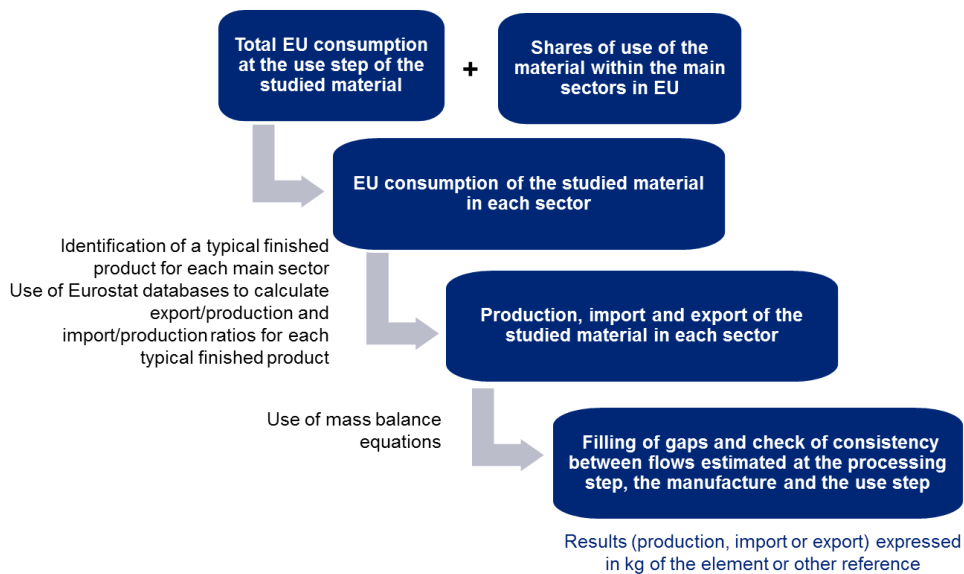


Figure 4: Preferable calculation method for the manufacture step (top-down approach)

The shares of use of the material within the main applications in EU are also the basis for the assessment of the economic importance and the substitutability index, in addition to the data regarding GVA (gross added value) and substitutability of each megasector that are compiled in the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*.

Information about the structure of the manufacturing industry is often missing from literature and databases and it is often necessary to resort to stakeholder estimations.

Regarding future supply or demand of end-products, the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)* often provides data.

2.4.1.4 Use step

The typical finished products identified previously for each main sector containing the studied material are generally also used in order to calculate flow and stock parameters at the use step. For each typical finished product, the following parameters are defined thanks to literature and expert consultation:

- lifespan of the product in Europe,
- rate of product kept by users after end of life in Europe,
- time during which products kept by users after end of life are kept by users in Europe,
- in use dissipation rate of the product in Europe,
- annual growth rate of consumption of the product in Europe,
- rate of products exported for reuse.

Based on these data and the calculation formulas presented in Annex 1, the different flow and stock parameters at the use step are estimated.

With this approach generally implemented, it is important to note that the amount of the studied material in products at end of life collected for treatment is not based on data relating to flows of waste but is estimated based on EU consumption of products and characteristics of products such as lifespan, annual growth of consumption, in use dissipation... This approach ensures mass balance consistency between the parameters at the use step and collecting step and overcomes the problems of data gaps and lack of reliability regarding waste statistics.

However, this approach is based on assumptions regarding characteristics of typical products per sector and may also lead to significant uncertainties.

In the same way, the quantitative assessment of the “in-use stock” of products is also based on EU consumption of products and characteristics of products such as lifespan, annual growth of consumption, in use dissipation, etc. so it is also likely to be uncertain. It must be noted that this stock of products in use represents future stock of raw materials that can be potentially recovered (in idealistic conditions, i.e. both technical and economical) from end-of-life products.

2.4.1.5 Collecting and recycling steps

Data regarding the fate of specific types of product at end of life that are collected for treatment is very scarce.

Generally, the Eurostat data Centre on Waste³ is used for estimating the fate (recycling /exports /incineration /landfill) of some categories of end-of-life products, especially for WEEE. However, this source does not account for all end of life electrical equipment and the fate of the missing portion has to be estimated based on data from published studies of e-waste.

The imports and exports of some categories of hazardous or non-hazardous waste are also provided in the EEA Report on Movements of waste across the EU's internal and external borders, but the accuracy is uncertain as illegal exports occur.

Some Eurostat data is also available for used batteries and vehicles and there are also available reports for steel scrap recycling as an example. Nevertheless, data on many other types of products is not published and has to be estimated from other sources or with assumptions.

Specific data on functional recycling of the element is often difficult to obtain and no general data source is available. However, some literature about the recycling efficiency of some common metals and alloys (steel, aluminium, zinc, etc.) is available and can be used to assess the non-functional recycling of the element.

Once again information about the structure of the recycling industry is often missing, as well as the evolution of the future supply of secondary material.

2.4.2 Expert consultation

In parallel to desk study, the consultation of experts is a key procedure for the development of the MSA, particularly valuable to fill the data gaps and to ensure the reliability of the results.

During this project, experts' inputs were gathered through direct consultations and organisation of 4 workshops dedicated to present and discuss the work on several materials.

The experts were contacted at the beginning of the investigations on each specific material in order to acquire general knowledge about the life cycle of the material, access to additional data sources, fill data gaps, elaborate estimations and hypothesis and validate the information gathered. These discussions were done during the development of the MSA of each material, by email, telephone or physical bi-lateral meetings with the experts contacted.

The figure below (Figure 5) indicates roughly the life cycle steps and parameters for which the inputs from stakeholders have been the most needed (especially parameters in orange and red). If in some cases the stakeholders' feedback enabled to fill data gaps, for some others experts had no data or estimations to provide. It must be noted that this figure has been built based on all the materials as an overview, and is not representative of a single materials.

³ http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselee&lang=en

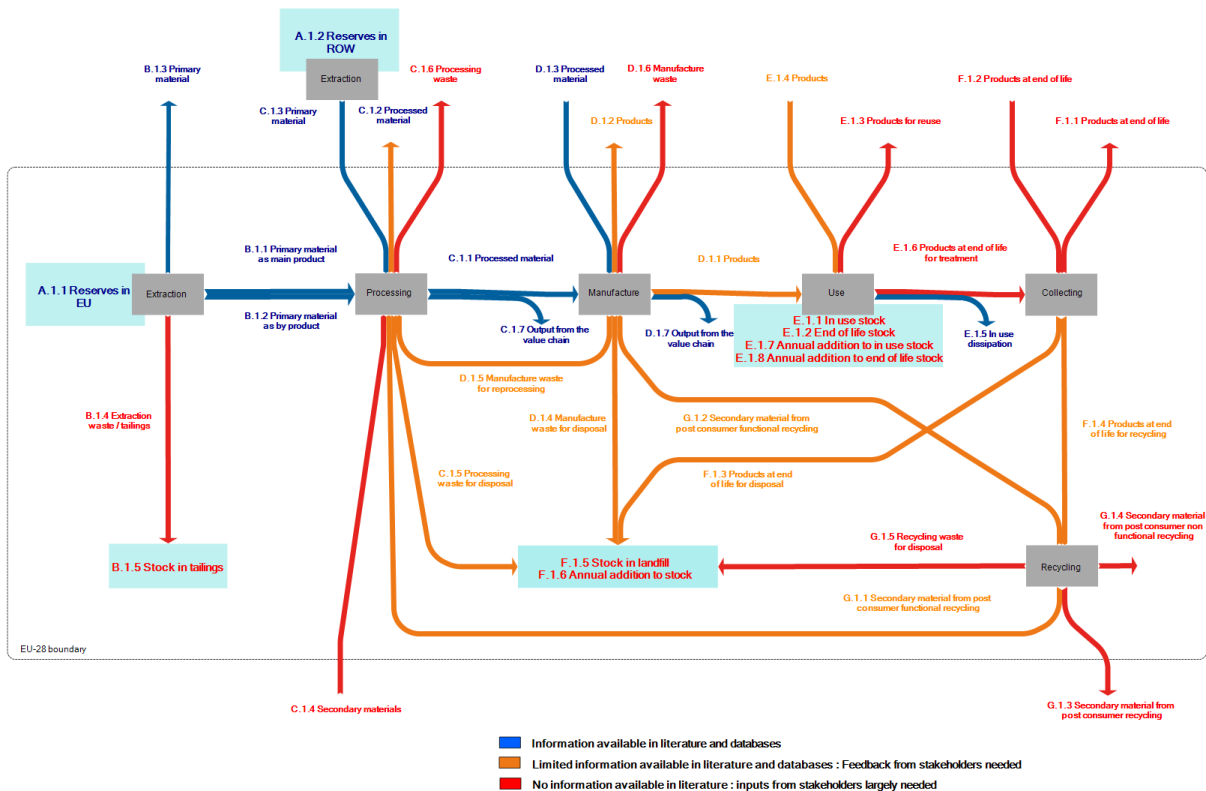


Figure 5 : Overview of the need of stakeholders' input all along the value chain. Blue= most of the time information available in literature, experts input needed mainly for validation; Orange = most of the time limited information available in the literature, experts input needed to fill data gaps or validate estimations; Red = most of the time no information available in the literature, experts input strongly needed to fill data gaps and provide estimations.

The experts contacted for each MSA were also invited to participate in a workshop held in Brussels in order to review, complete, modify or validate the work achieved. Each workshop involved between 15 and 30 international experts, with two to five experts per material. Before each workshop, material-specific background documents describing the preliminary results and the data missing were prepared and sent to experts in order to give them time to review the documents and gather missing information. The results, assumptions and data gaps were discussed during the workshops in order to validate the results or gather suggestions for improvement.

After each workshop, the project team followed-up on the data gaps and issues raised for each material, and prepared a revised version of the results of the MSA according to the suggestions made by the experts. The results were sent to the experts for further revision, comment and validation.

Annex 2 presents the main stakeholders who contributed to the development of each MSA.

Finally, the project team also contacted a number of stakeholders in the US and Japan in order to promote international cooperation in the field of MSA and critical materials. The stakeholders were invited to join trilateral discussions with the objective of sharing knowledge and best practices regarding sustainable supply of raw materials.

2.5 General procedure for the prioritisation of data sources

The general procedure for the development of the MSA, which is described in chapter 2.4, needs to be adapted on a case by case basis for each material, depending on the specificities of its value chain and the available data sources for the different life cycle steps.

Therefore, it is necessary to define a procedure for the prioritisation of the available data sources, according to their suitability for this first MSA and future regular updates.

From a general point of view, priority data sources are those which are publicly available in published reports, quality checked and regularly updated.

However, in most cases these preferred data sources do not exist. Then, a general procedure for the ranking of sources can be proposed at a general level:

- regularly updated information from trade associations or other organisations,
- privately owned information which is purposely provided to MSA or can be purchased at a reasonable price,
- single statistical information by credible institutions which can be extrapolated with the help of available indirect parameters,
- single information by credible institutions which allows a measurement for the moment but cannot easily be extrapolated,
- literature data of different quality grades.

In addition, and as mentioned above, establishing a constant contact with experts in the field of any material and of single important steps in the product chain is a key issue. They are needed to give an opinion about the quality of data and possible new data sources.

2.6 Quality assessment of the results of the Material System Analysis

The reliability of the results provided in this project is one of the main challenges.

The general procedures described above for the development of the MSA and in particular the expert's consultations are essential in order to ensure consistency of the results.

However, the results provided present uncertainties, with magnitudes that may vary depending on the materials, the life cycle steps and the specific parameter analysed.

For example, some studied materials are used in myriads of finished products. Then, it is impossible to be exhaustive and to account for all the uses along the value chain. Therefore, some simplifications are done by focusing on main sectors, and gather together minor uses under the generic appellation "other uses" or "other applications"; and by using typical products for each sector.

In other cases, reliable data needed to calculate some parameters do not exist and it is then required to make some estimation, which could be based on known facts or which could be in the worst case hypothesis without reliable foundation.

In order to address this issue and to give a quality assessment of the results of the MSA, a pragmatic approach was developed.

This approach was defined with the objectives:

- to be very simple to implement, in order not to make more complex the development of the MSA,
- to allow the tracking and the transparent assessment of the robustness of the results provided for each parameter of the MSA,
- to highlight important missing information or results of inferior quality with the purpose to stimulate institutions and stakeholders to close the information gaps by carrying out studies or data gathering activities.

The quality assessment of the results of the MSA is performed as follows:

- For each data used in the MSA, a quality score from 1 to 4 is defined according to the criteria presented in Table 4.
- When the result of a parameter is directly taken from a unique data, the result of the parameter is scored with the same quality score as the data.

Table 4: Quality Score of data used for the calculation of the parameters of the MSA

Source	Criteria	Quality score of data used
Data published or data given from expert (federation, company...)	Direct use of data from a source	4
	Basic extrapolation of data from a source	3
Estimation or Hypothesis	Estimation of data based on known facts	2
	Hypothesis	1

- When a parameter is calculated based on lots of data, a conservative approach is carried out and the result of the parameter is scored with the lower quality score of the different data used, as presented in Table 5.

Table 5: Quality Score of the parameters calculated

Criteria	Quality score of the parameters calculated
Parameter calculated by using only data from sources	4
Parameter calculated by using at least one basic extrapolation of data from a source	3
Parameter calculated by using at least one estimation of data based on known facts	2
Parameter calculated by using at least one hypothesis	1

The DQS of each parameters are displayed in the Excel file and in the Detailed Sankey diagram of each materials, however such confidential documents are not displayed in this public report.

3. Results

3.1 Caveat regarding the results of the Material System Analysis

Before presenting the results, it is important to remember the general objective of the project, which is to develop a Material System Analyses at EU level for 28 materials including those classified as “critical”. This is the first time that such a large number of materials have been considered for MSA at this geographical level and the primary aim is to generate a **global picture of the whole life cycles of the studied materials**.

It is also important to highlight the **numerous difficulties** and the **challenges faced** in responding to this objective.

For example, most of the studied materials are used in many different types of finished products and it is generally impossible to be exhaustive and to account for all the uses along the value chain. Therefore, some simplification was done by establishing cut-off in order to focus on main sectors and by using typical products for each main sector.

Besides, very little data directly usable for the MSA was available and it was often necessary to fill the data gaps by making extrapolations or assumptions based on the limited data available. In particular, each MSA is intended to be representative of a specific recent year. However, for some materials and end uses, there can be significant year to year variation and it was difficult to find data representative of this specific year or to consolidate data from different years.

In addition, the development of a MSA requires that the input and output flows of each life cycle step balance exactly. In order to present consistent results in terms of mass balance, it was necessary to make some adjustments to the values obtained from the different available data sources, each being independent of each other. Nevertheless, these required adjustments may alter the accuracy of the results for some specific flows.

Due to the numerous difficulties encountered and briefly depicted above, it is important to bear in mind that the accuracy of the results is variable depending on the studied materials or parameters. Consequently, **the overall results should be considered as orders of magnitude** and are unlikely to be exactly correct.

Finally, despite these difficulties, it is underlined that **efforts were made in order to deliver results as reliable as possible** within the framework of this project, while **remaining transparent regarding the limitations of these results**.

In particular, efforts were made to work in collaboration with experts in order to review the consistency and accuracy of the work in progress.

Furthermore, many comments were made in the results of the MSA in order to describe the main procedures for the calculation of the parameters (main data sources, main assumptions and limitations) and Data Quality Score (DQS) were determined for each parameter, in order to assess the level of reliability of each result.

Lastly, recommendations were made for the improvement and the update of the MSA in the future.

3.2 Format of the results

3.2.1 Database provided to the European Commission

The MSA of the 28 studied materials are developed and displayed in a secured database of 28 spreadsheets presenting data sources, assumptions, calculations and results.

The 28 spreadsheets are structured identically and include:

- 1 introduction tab [Intro],
- 2 tabs that contain Sankey diagrams [Detailed Sankey Diagram, Simplified Sankey Diagram], which allow to visualize the results for the flows and stocks parameters (group 1 parameters),
- 7 tabs presenting the results of the different parameters (required and optional) per life cycle step [Expl, Extr, Pr, Man, Use, Coll, Rec],
- 1 calculation tab presenting the details of calculation for group 1 parameters (with data sources, assumptions and calculation details) [Calc-flow],
- 1 calculation tab presenting the details of calculation for group 2 and 3 parameters (with data sources, assumptions and calculation details) [Calc-Crit],
- 1 tab of sources presenting all the data sources used [Sources],
- Several additional tabs presenting details of sources and references used for the calculation [World Governance Index, Megasectors].

The 7 tabs presenting the results per life cycle step include the total results of the different parameters and the detailed results per type of primary material, processed materials, finished products or waste depending on the life cycle step.

For each result (total or detailed), the following field exist:

- Name of the studied material (e.g. Beryllium),
- Code and name of the parameter (e.g. C.1.1 Production of processed material in EU sent to manufacture in EU),
- Name of the sub-parameter (e.g. total result, detailed result for Be oxide or detailed result for Be metal),
- Value (e.g. 120 000),
- Unit of the value (e.g. kg of Be),
- Year of reference / Temporal representativeness (e.g. 2012),
- Main data sources used to calculate the parameters (e.g. source 2 and 4, which correspond for example to PRODCOM database and federation X),
- Comments regarding sources and assumptions (e.g. calculated based on trade flows from PRODCOM with data on market shares from federation X),
- Comments regarding the temporal representativeness (e.g. annual growth rate extrapolated from 2003),
- Quality assessment of the result of the parameter (score between 1 and 4).

The database is provided to the European Commission for internal use only.

The 7 tabs presenting the results per life cycle step, the 2 tabs of Sankey diagrams and the tab of sources constitute the information that could be made available in a secured database developed by the European Commission. However, only total results of parameters (without details per type of primary material, processed materials, finished products or waste) would be displayed. Indeed, according to the European Commission, total results of parameters are regarded as sufficient in order to convey meaningful information without raising any confidentiality issues.

3.2.2 Results per material included in this report

In addition to these Excel files and the Detailed Sankey diagrams provided to the European Commission, this report includes a section of results per material. For each material, this section includes:

- a description of the **value chain** with the different forms of the material along the life cycle,
- a **description of the main flows and stocks** in order to provide an overview of the MSA,
- information regarding **data sources, assumptions and reliability of results**,

- and one simplified **Sankey diagram**, which allow to visualize the aggregated results for the flows and stocks parameters (group 1 parameters).

The Sankey diagrams are flow diagrams, in which the width of the arrows is displayed proportionally to the flow quantity. They allow to highlight the major flows within the system.

The **simplified Sankey diagram** depicts the main flows of the material and allows for a rapid understanding of the EU industry by comparing the main input flows or the main output flows.

For better readability and comparison of the Sankey diagrams, all flows associated with a zero value are hidden and colours are identical in both graphs:

- green for primary material,
- yellow for processed material,
- red for finished product,
- purple for secondary material (either going to processing or manufacturing steps),
- blue for waste generated during any of the steps,
- orange for material contained in flows relating to non-functional recycling,
- grey for material dissipated during the use step,
- brown for material contained in output from the value chain (as impurities, non-functional by-product, etc.).

The flows presented in the simplified Sankey diagrams are the following (see section 2.2 for a description of the flow parameters):

Imports	Total	$C.1.3 + C.1.4 + D.1.3 + E.1.4 + F.1.2$
	Primary material	C.1.3
	Secondary material	C.1.4
	Processed material	D.1.3
	Product	E.1.4
	Waste	F.1.2
Exports	Total	$B.1.3 + G.1.3 + C.1.2 + D.1.2 + E.1.3 + C.1.6 + D.1.6 + F.1.1$
	Primary material	B.1.3
	Secondary material	G.1.3
	Processed material	C.1.2
	Product (including for reuse)	$D.1.2 + E.1.3$
	Waste	$C.1.6 + D.1.6 + F.1.1$
Extraction	Primary material (including material exported and extraction waste)	$B.1.1 + B.1.2 + B.1.3 + B.1.4$
Addition to in use and end of life stock	In use and end of life stock	$E.1.7 + E.1.8$
Addition to landfill and tailings	Waste	$F.1.6 + B.1.4$
Losses	Total	$C.1.7 + D.1.7 + E.1.5 + G.1.4$
	Output from the value chain	$C.1.7 + D.1.7$
	In use dissipation	E.1.5
	Non functional recycling	G.1.4
Recycling	Secondary material	$G.1.1 + G.1.2 + D.1.5$

The Sankey diagrams are developed with the software e!Sankey®.

3.3 Results per material

3.3.1 Aggregates

Value Chain

Aggregates are granulate materials obtained from naturally occurring resources. The most common natural aggregates are crushed rocks and sand and gravel, obtained from quarries and pits. Manufactured aggregates are produced from other industries. 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. The figure below presents the value chain of aggregates with the main uses, by type of material and by end-use sector.

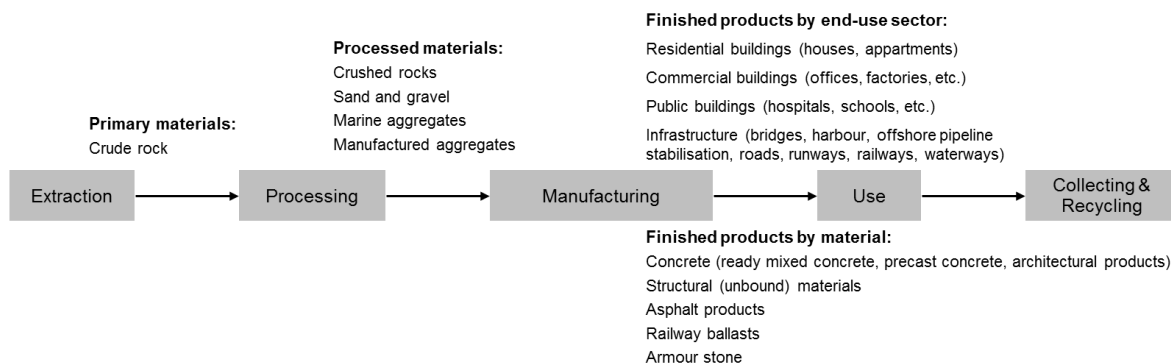


Figure 6: Value chain of aggregates

Description of the main flows and stocks

Flows and stocks are accounted in mass of aggregates and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

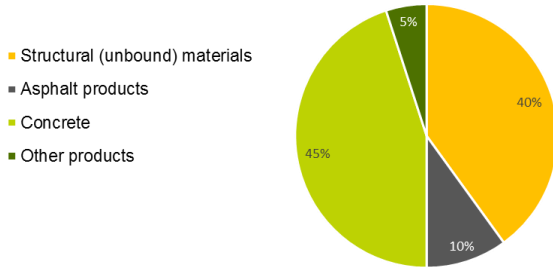
Natural rock is an abundant resource and the associated reserves and resources have not been quantified. Around 2,400 Mt of natural rocks are extracted each year in the EU for a total production around 1,200 Mt of crushed rocks and 1,200 Mt of sand and gravel, marine aggregates and manufactured aggregates. The residues generated during the extraction and processing steps are reused for restoration works of quarries, pits or other extraction sites.

The 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) 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, for each step of the MSA for aggregates.

In the EU, aggregates are directly used in construction works as structural materials (1,000 Mt of aggregates, as presented in Figure 7 – left) or are used to manufacture concrete products (1,000 Mt), asphalt products (200 Mt) or other products such as railway ballasts or armour stone (100 Mt).

The aggregates and construction products containing aggregates are used in infrastructure works (900 Mt), residential buildings (600 Mt), public and commercial buildings (500 Mt each year) (see distribution by end-use sector of the total production/consumption for the EU on Figure 7 – right).

Finished products used in the EU by material



Finished products used in the EU by end-use sector

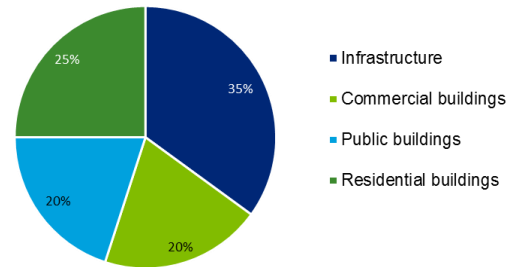


Figure 7: Shares of final uses of aggregates in the EU per type of material (left) and type of end-use sector (right)

Considering the lifespan of buildings and infrastructures and the annual growth in the construction sector, the quantity annually added to stock is around 200 Mt and the stock is evaluated at 114,000 Mt of aggregates.

Around 540 Mt of construction and demolition waste arise per year, of which around 180 Mt are recycled. About 90% of the recycled aggregates are used directly in construction works as structural material, and the rest are used to manufacture other construction products.

Value chain distinguishing steps occurring or not within the EU

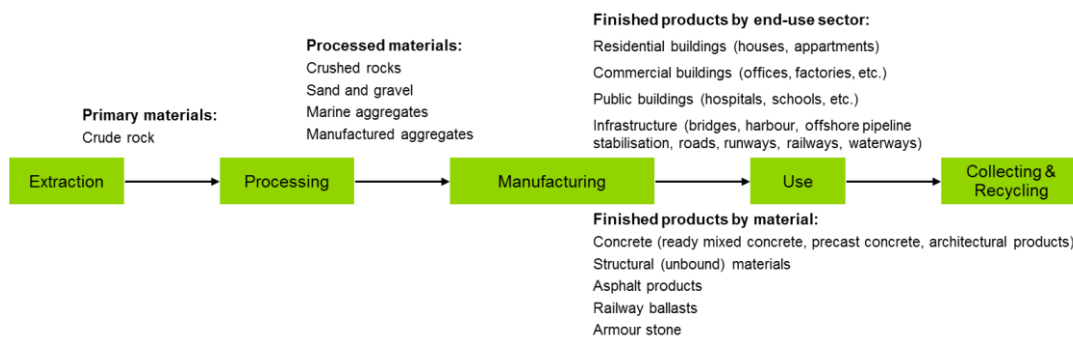


Figure 8: Value chain of aggregates, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

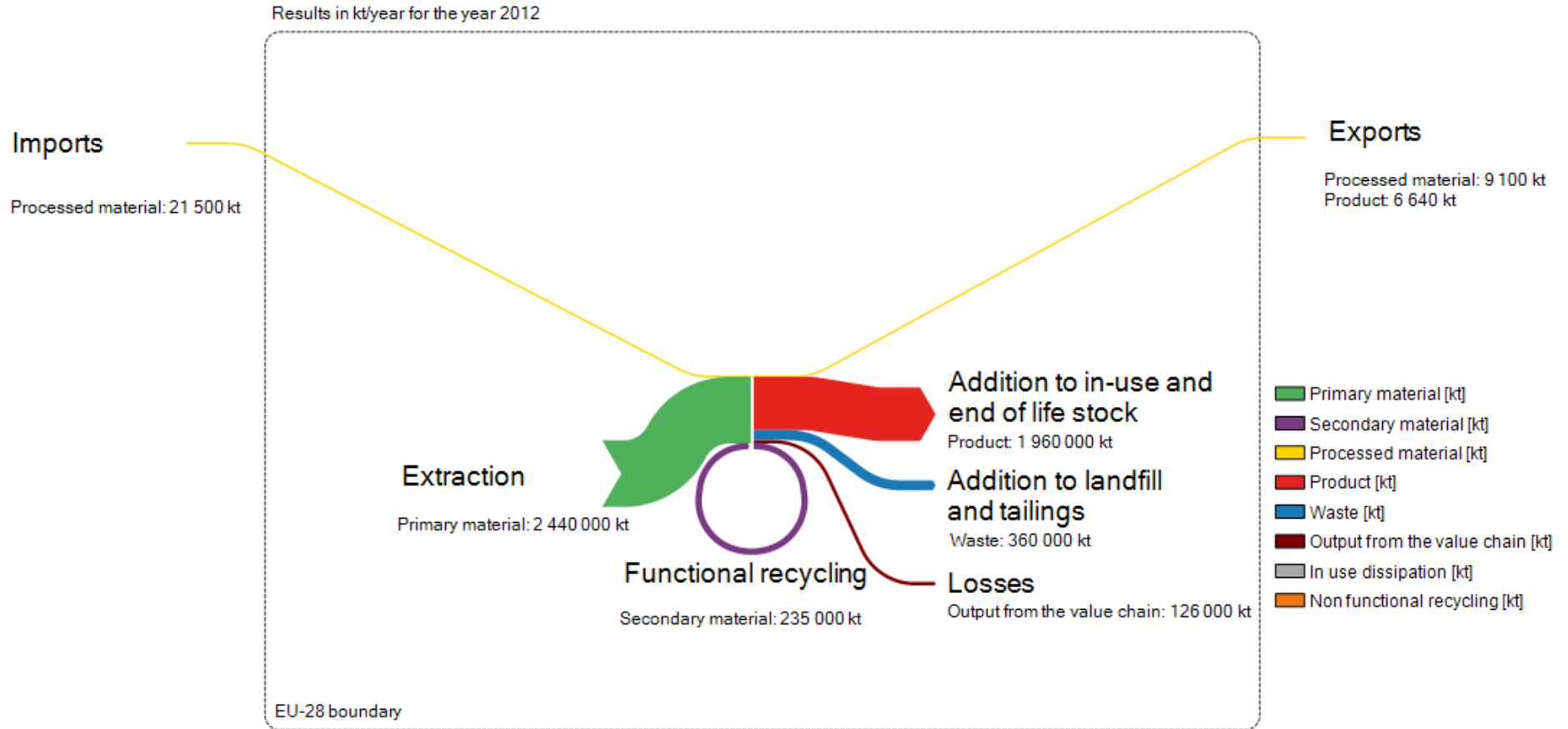
The main sources of data used to develop the MSA are the European Aggregates Association (UEPG), mainly 2012 data for the EU-28, the Eurostat database Comext, and the EU mineral statistics 2008-2012 published by the British Geological Survey (BGS).

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 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 UEPG 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 construction sector is attempted by using the data on aggregates used by each construction sector, an average time residence of aggregates 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 variation of more than 200% between sources. This makes 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 the UEPG was preferred, as recommended by the experts.

Sankey diagram for aggregates

Figure 9: Simplified Sankey diagram for aggregates



3.3.2 Antimony

Value Chain

After extraction, antimony ores & concentrates are processed into antimony metal.

Antimony metal is further processed into semi-finished products such as antimony compounds & chemicals, in particular antimony oxide, and into PbSb alloys. Antimony oxide is used to manufacture flame retarded plastics and rubbers where it is added as a synergist with flame retardants, another semi-finished product in the form of plastic chips (a mixture of substances).

These plastic and rubber intermediate products are then used to manufacture finished products such as textiles, PET containers, electrical equipment and also wire and cables. Antimony alloys are used in vehicle and traction lead-acid batteries and a wide variety of other finished products. Antimony chemicals are used to make a wide range of finished products (as pigments, in vehicle brakes, etc.). However, Sb chemicals account for a small amount of antimony and have been neglected in this MSA.

The figure below presents the value chain of antimony with the main uses.

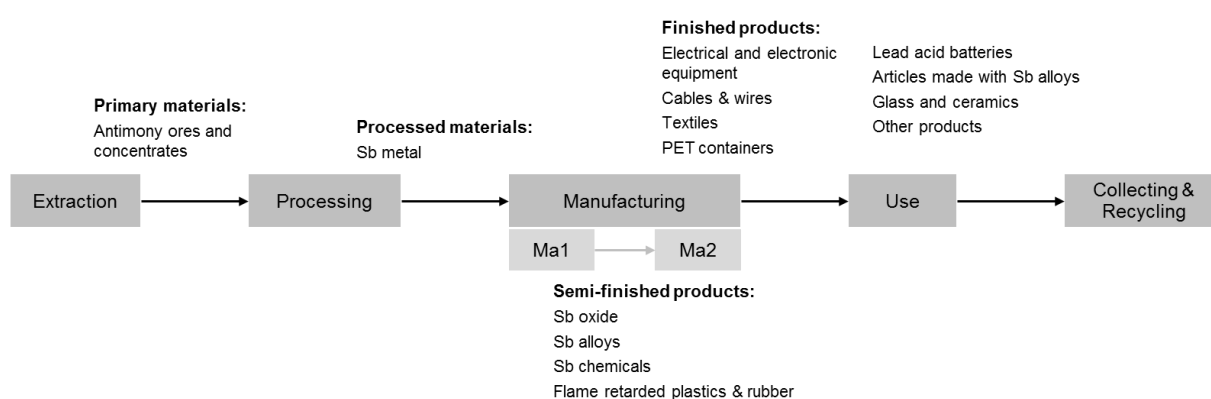


Figure 10: Value chain of antimony

Description of the main flows and stocks

Flows and stocks are accounted in mass of antimony (Sb) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Antimony occurs in minerals in the EU but is no longer mined in the EU countries. There are several plans to open mines in Spain and Italy with reserves totalling 147 kt. World reserves are estimated at 3,400 kt of antimony and the world annual production is around 163 kt of antimony, mostly in China.

Antimony ores are generally processed into metal by the mining companies (i.e. outside of the EU). Some antimony metal (50 t of Sb) is processed in the EU from antimony ores and concentrates that are imported; and about 11 kt of antimony metal is recovered from secondary material (waste, scrap and ashes residues containing antimony).

The European industry imports large quantities of antimony metal (16 kt of Sb) to process antimony oxides, chemicals and alloys. The large majority of these semi-finished materials are sold in the EU and less than 30% are exported.

About 9 kt of antimony in semi-finished materials are imported and used to manufacture various finished products which are sold in the European market or exported in quite similar proportion (see Figure 11 – left). Very small amounts of waste are generated from the manufacturing step.

Imports of finished products amount to 12 kt of antimony, which is less than the antimony content in the European production sold in the EU (around 15 kt of Sb). Antimony consumption growth in the EU has been fairly small in recent years as finished products containing antimony are mature products (see Figure 11 – right). The total in-use stock of antimony in the EU yields about 135 kt of antimony,

with an annual addition to stock of 3.7 kt of antimony. Those stock values have not been assessed by calculation based on growth rates but using expert data.

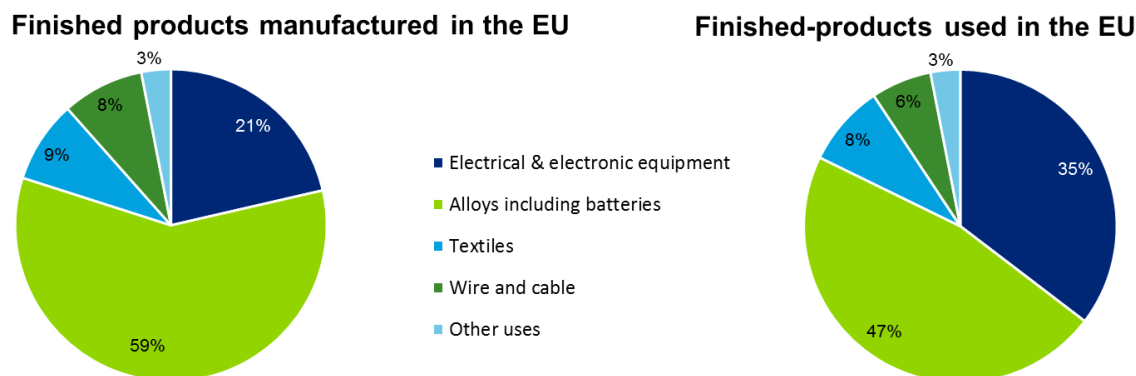


Figure 11: Shares of finished products containing antimony manufactured in the EU (left) and shares of finished products containing antimony used in the EU (right)

About 23 kt of antimony goes every year in the waste management step, and only a small proportion (less than 20%) is disposed. Antimony contained in lead-acid batteries (12 kt) is functionally recycled. For the other applications, antimony contained in the waste is non-functionally recycled.

Value chain distinguishing steps occurring or not within the EU

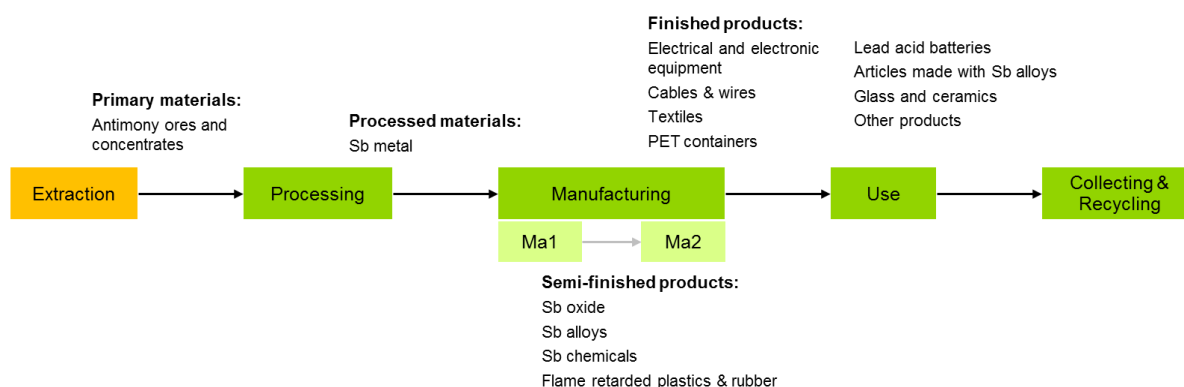


Figure 12: Value chain of antimony, steps in green occur in the EU, steps in orange occur only outside of the EU

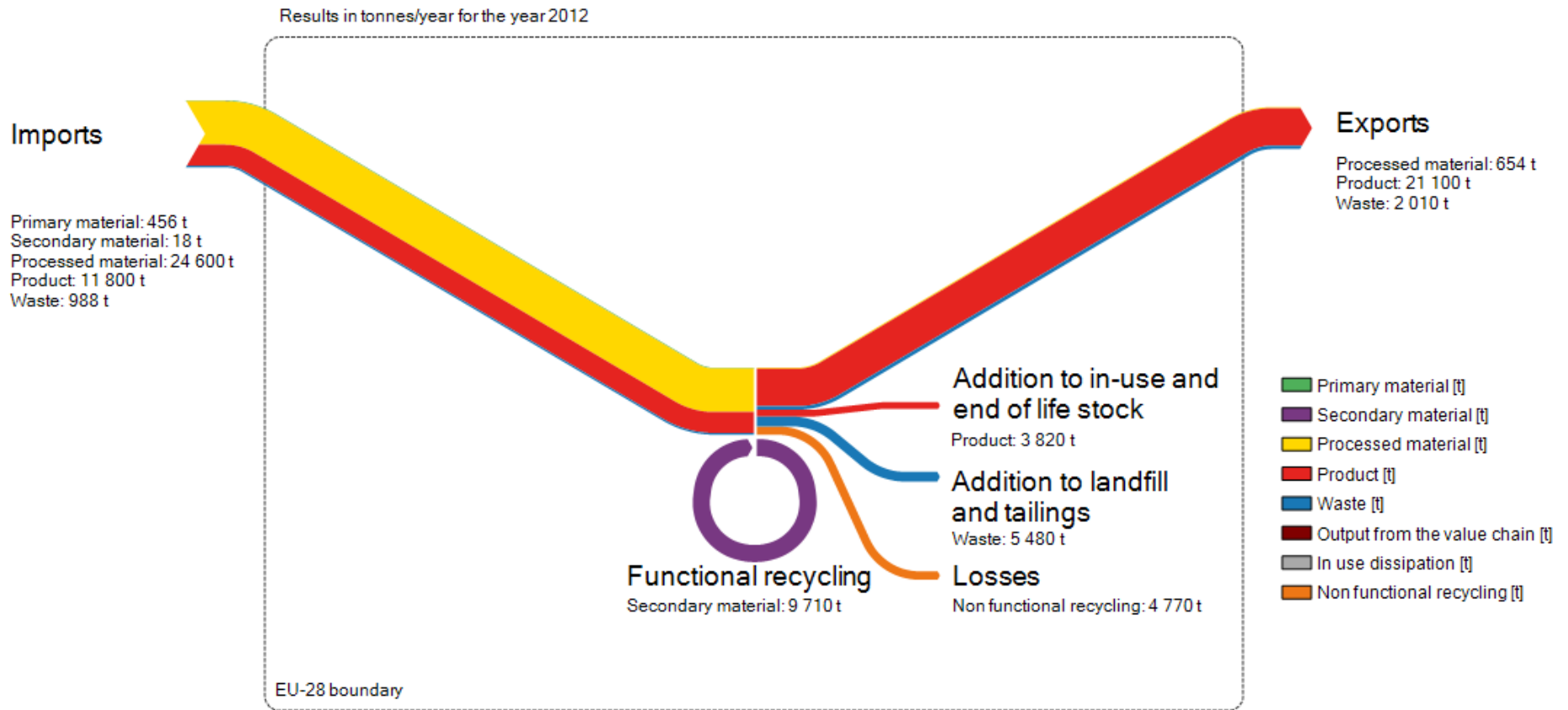
Data sources, assumptions and reliability of results

Useful data was provided by several organisations, in particular by the International Antimony Association who provided valuable data on the EU production, imports and exports of raw materials (metal and chemicals), data on process yields and wastage rates and information on the use of antimony in alloys. Data on downstream uses was obtained from Plastics Europe and from a variety of published data sources including Eurostat.

Data on wastes was obtained from Eurostat for waste electrical equipment and batteries, but the data for electrical equipment is not accurate as a large proportion of waste is unaccounted for and so the actual quantities were estimated by using data from surveys to determine the actual fate of these products. The main data omission however is for products made with alloys containing antimony (apart from batteries where good data is available) and downstream products such as textiles and cables. Flows of these products have had to be estimated by using data from a variety of sources and it was necessary to make several assumptions.

Sankey diagram for antimony

Figure 13: Simplified Sankey diagram for antimony



3.3.3 Beryllium

Value Chain

After extraction, beryllium ore is processed into beryllium oxides and hydroxides, master alloys, beryllium unwrought and powders. These processed materials are converted into semi-finished products consisting mainly of ceramics, alloys and metals. Then, these semi-finished products are used in finished products in various applications such as electronic equipment, road transport, moulds for industry, etc.

The figure below presents the value chain of beryllium with the main uses.

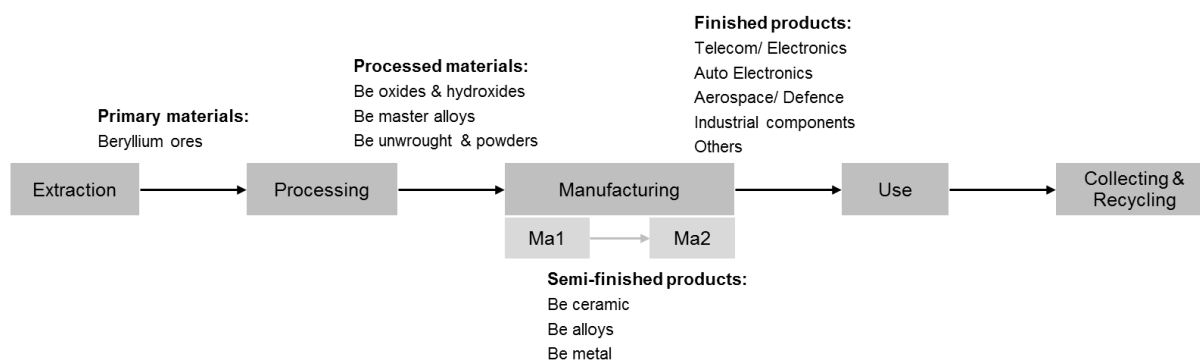


Figure 14: Value chain of beryllium

Description of the main flows and stocks in the EU

Flows and stocks are accounted in mass of beryllium (Be) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of beryllium take place outside of the EU.

There are no reserves of beryllium in the EU and consequently there is no production of beryllium ore. World reserves are estimated as 23,400 t of beryllium content and the world annual production is around 320 t of beryllium content, mainly in the US, China, Brazil and South Africa.

There are no imports of beryllium ore in the EU and this primary material is totally processed outside the EU. The EU entirely depends on imports of processed and semi-finished products, mainly under the form of beryllium master alloys and alloys (around 40 t of Be per year) and beryllium metal (around 10 t of Be per year).

The European industry uses these materials to manufacture various finished products (see Figure 15 – left) which are sold in the EU market and exported in nearly equivalent proportions (around 16 t of beryllium in finished products sold in the EU and around 13 t exported). During this manufacture step, the European industry generates a lot of scrap (22 t of Be, around half of the beryllium input) which is totally sent back to suppliers outside of the EU for recycling.

The beryllium contained in the imports of finished products amount 123 t per year, which is 8 times higher than the beryllium content in the domestic production sold in the EU. These imports represent the largest part of the EU final consumption, which is around 139 t of Be per year (see Figure 15 – right).

Considering the lifespan of the finished products containing beryllium and the annual growth of consumption of these products, a quantity nearly equal to 1/3 of the quantity of beryllium put on the European market is annually added to stock (annual addition to stock around 44 t of Be, stock estimated at 1000 t of Be). The other 2/3 is sent to waste management.

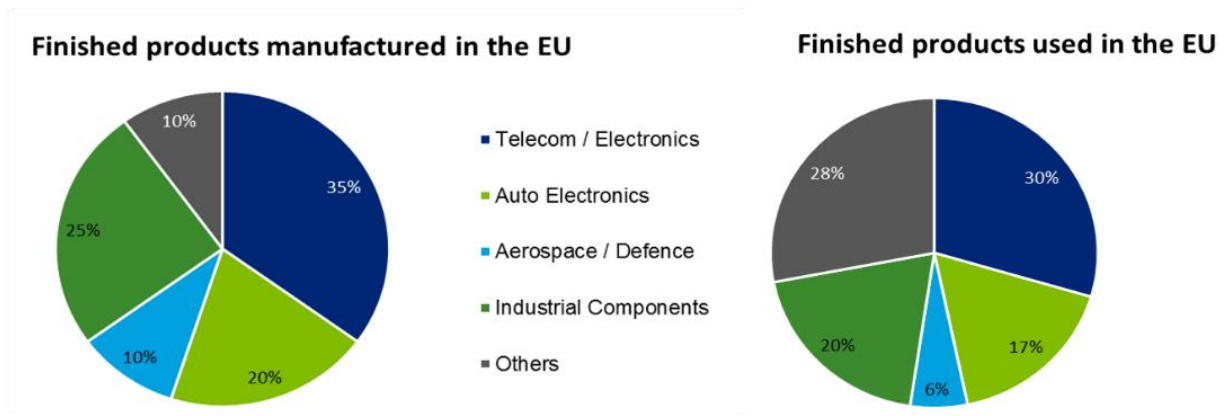


Figure 15: Shares of finished products containing beryllium manufactured in the EU (left) and shares of finished products containing beryllium used in the EU (right)

The beryllium contained in the waste ends up in landfill or is recycled with a large magnitude material stream. However, there is no post-consumer functional recycling of beryllium in the EU and in the world (no recovery of beryllium from old scrap displacing primary production of beryllium). The stock accumulated in landfill in the EU over the last 20 years is estimated around 610 t of beryllium content.

Value chain distinguishing steps occurring or not within the EU

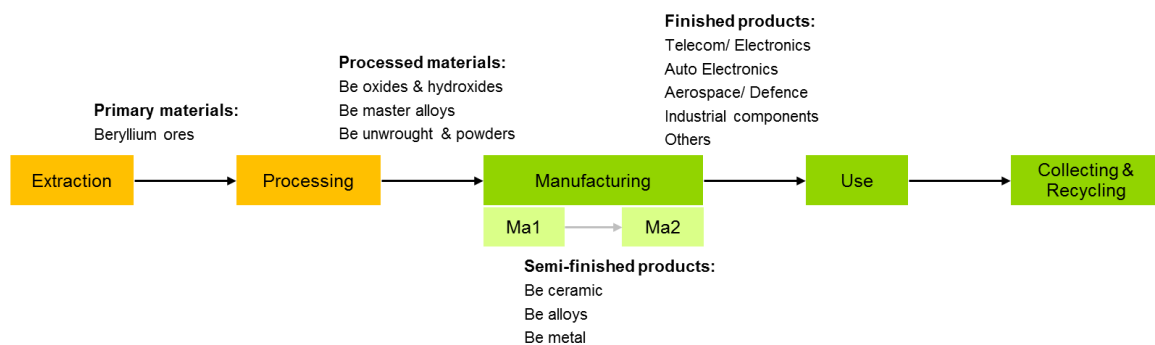


Figure 16: Value chain of beryllium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

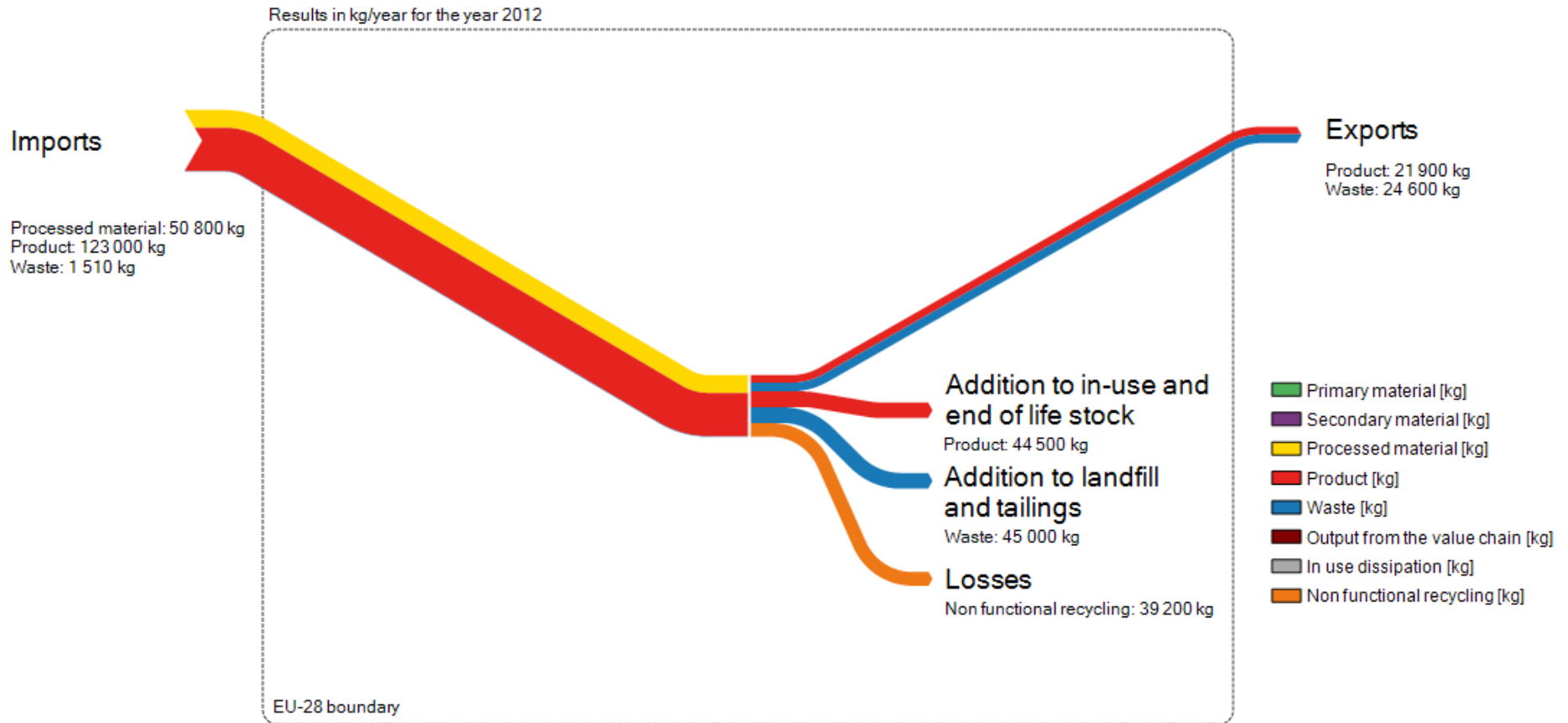
The main source of data for the elaboration of this MSA is the Beryllium Science & Technology association (BeST, International association of beryllium professionals), which provided all data from exploration to first steps of manufacture, as well as data on uses and recycling. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing and recycling.

From the manufacture to the recycling steps, the flows are calculated conservatively based on two main data points: the beryllium input into the European industry at the manufacture step (around 50 t according to BeST) and the beryllium input into the European market at the use step (around 139 t, including imports of finished products, according to Materion).

Based on these two data points, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows in the manufacture, use, collecting and recycling steps. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in the EU of various finished products. In order to fill some 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 level of reliability of results for the steps manufacture, use and collecting is lower than for the other steps.

Sankey diagram for beryllium

Figure 17: Simplified Sankey diagram for beryllium



3.3.4 Borate

Value Chain

Borates are inorganic salts of boron with major deposits found in Turkey and California. Over 150 borate minerals are known; however, four of these minerals represent 90% of the minerals used in industry: the sodium borates tincal and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite. For most applications (high purity sodium borate or boric acid), borates require refining as the ores are not of sufficient quality.

Over three quarters of borates are used in glass and fibreglass applications, ceramics and agriculture (fertilisers). They also have several applications within the construction and chemicals industries. The figure below presents the value chain of borate with its main uses.

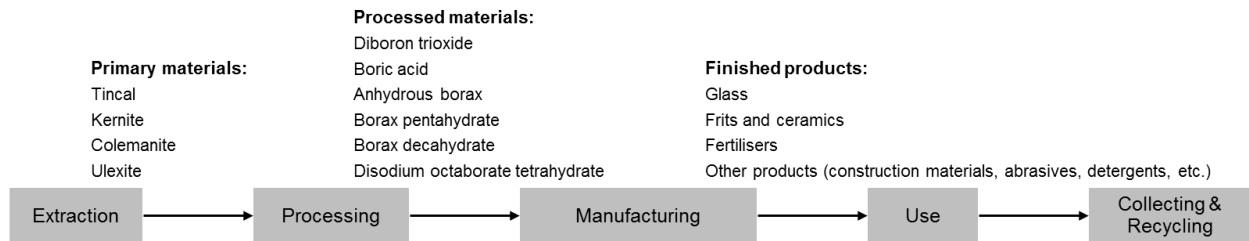


Figure 18: Value chain of borate

Description of the main flows and stocks

Flows and stocks are accounted in mass of boron (B) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

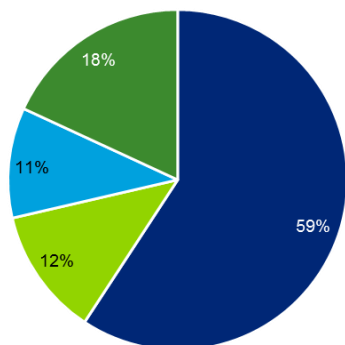
There are no reserves of borate minerals in the EU; the reserves in the rest of the world are estimated at about 65 million tonnes. The largest producer of borate minerals is Turkey followed by the USA, Russia, Argentina and Chile. There is no extraction nor processing of borate minerals in the EU; the European industry is therefore totally dependent on imports.

Imports of primary borates in the EU represent 16 kt in boron content, directly used in manufacturing step. Imports of processed borates in the EU (such as diboron trioxide, boric acid, borax and disodium octaborate tetrahydrate) amount for 60 kt. Most of these volumes is embodied into glass which is mainly sent for use in the EU (40 kt) rather than exported (5 kt in boron content). A part is generated as manufacturing waste (7 t). The second single most common use of borates includes frits and ceramics (7 kt sent to use in the EU, 2 kt exported and 2 t converted to waste) followed by fertilisers (5 kt sent to use and 3 kt exported, for 11 t converted to waste). Other products such as construction materials, abrasives, catalysts, coatings, detergents, etc. account for further 10 kt sent to use, 3 kt exported and 1 t converted to waste. In order to cover the EU demand, about 12 kt of boron are imported in finished products, mainly in glass and fertilisers.

The EU stock of boron in use amounts 180 kt. The largest stocks of boron are related to frits and ceramics (98 kt in boron content) followed by glass (46 kt), other products (35 kt) and fertilisers (1 kt in boron content). The amount of boron in stock reflects the lifespan of particular finished products, which was the longest for frits and ceramics.

The annual amount of boron in end of life products collected for treatment is about 66 kt: respectively 45 kt for glass, 13 kt for frits and ceramics and 7 kt for other products. Only less than 1 kt of boron from fertilisers is collected for treatment, as most of it is dissipated into the environment. More than half of boron in the collected products at end of life is sent for recycling – i.e. 34 kt. The annual amount of products heading for disposal is about 30 kt in boron content, therefore there is a significant stock of boron in landfill accumulated over years.

Finished products manufactured in the EU



Finished products used in the EU

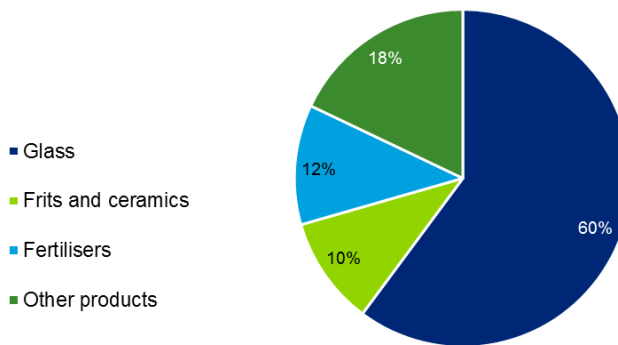


Figure 19: Shares of finished-products containing boron (B) manufactured in the EU and shares of finished-products containing boron (B) used in the EU (taking into account exports and imports of products)

Secondary materials result mostly from non-functional recycling. Borosilicate glass is currently not separated from boron-free container and flat glass. It means that boron in waste borosilicate glass is likely to end up in the manufacture of new glass containers or glass wool and it does not replace primary boron in the new production of borosilicate glass. Moreover, waste from ceramics is mostly used as a construction material.

The annual amount of boron from non-functional recycling reach 21 kt from glass applications, 10 kt from frits and ceramics and 3 kt from other products. About 0.5 kt of boron is a result of recycling of biogenic waste flows such as food waste, manure and common sludge. This can be considered as functional recycling because such secondary material in fertiliser replaces boron from industrial fertilisers.

Value chain distinguishing steps occurring or not within the EU

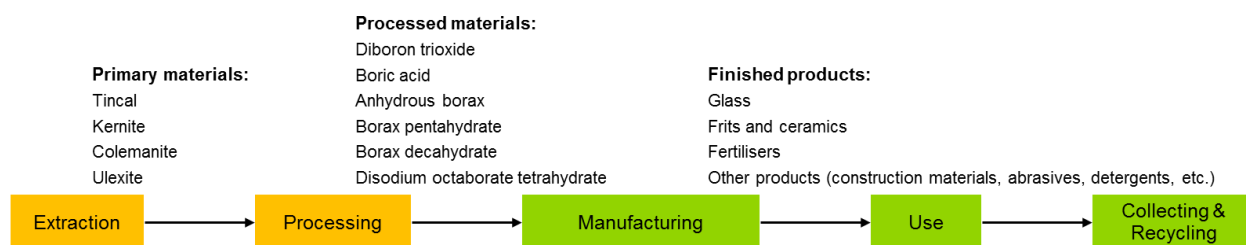


Figure 20: Value chain of borates, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The main data sources for borate case study includes Eurostat Comext, Prodcom and waste databases, International Fertiliser Industry Association, USGS and Ecoinvent database for the calculation of processing and manufacturing waste flows. However the suitability of Ecoinvent database for this purpose should be further re-assessed. An important input presents the information from the Industrial Minerals Association – Europe and Etimine experts who provided data on imports of borate minerals and processed borates and on their use in production of glass, frits and ceramics, fertilisers and other products.

Overall data for exploration to manufacturing steps can be considered quite reliable with the exception of the manufacturing of other products where some assumption are made on the share of exports among the total EU production of those products. For the use phase, most of the indicators are calculated with the use of equations developed within the project. This requires a lot of assumptions to be made on lifespan,

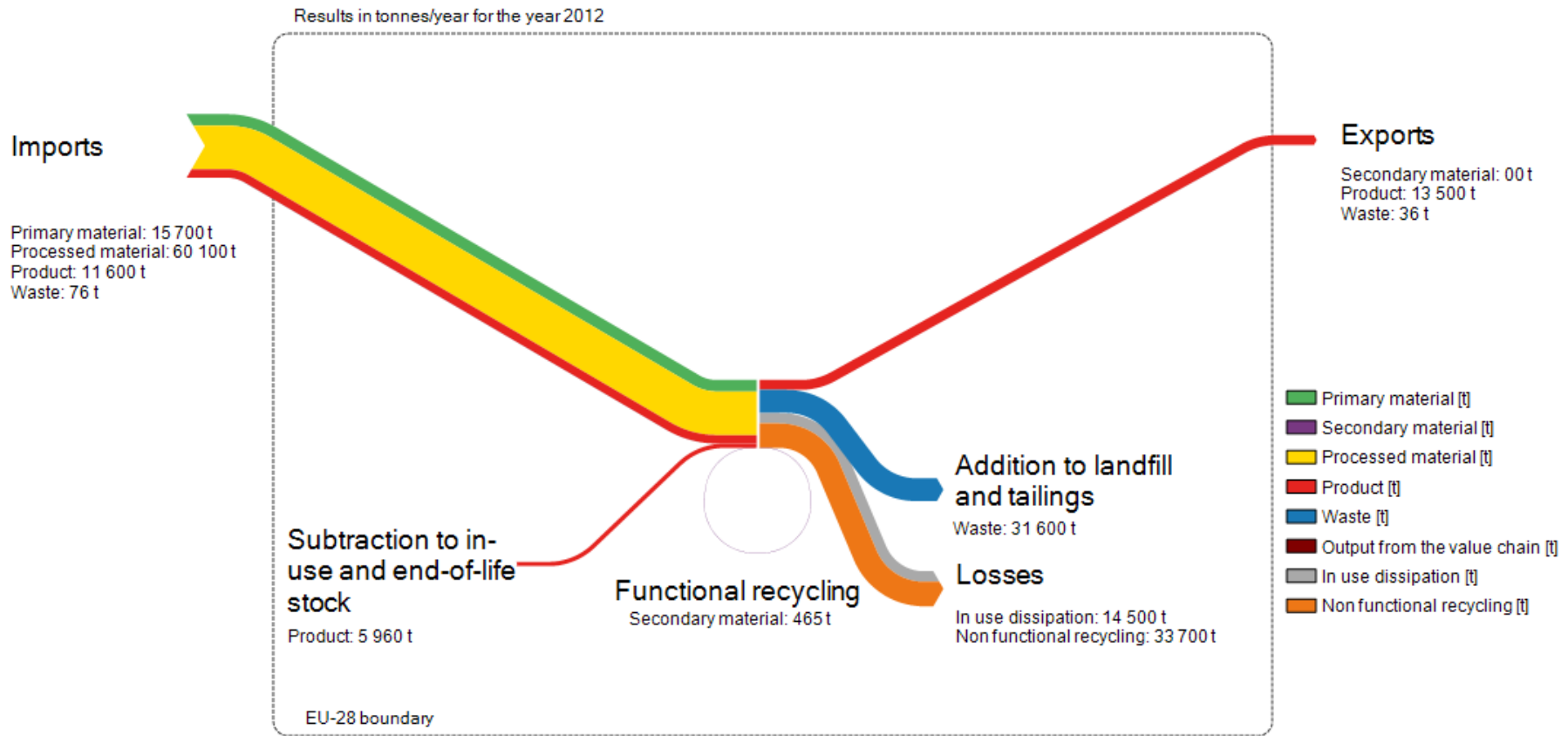
dissipation rate or the rate of particular products kept by users after end of life. Due to this fact the parameters in use step are subjects to quite high uncertainties.

Eurostat waste statistics contains various data usable for the collecting step, in particular regarding glass and biogenic flows (including food and vegetal waste, manure and common sludge). The biogenic flows represent the recycling of borates from fertilisers; their inclusion in the MSA requires estimation of their B content. It was assumed that the Eurostat data on recycling is more precise than data on disposal. Thus the latter parameter for glass and biogenic flows is calculated as the amount collected for treatment minus recycled materials and the balance of foreign trade. Based on expert information on frits and ceramics, it was considered that the recycling rate is similar to that of construction materials while for other products we assumed the same recycling rate as for glass. In general it can be concluded that uncertainties related to parameters in collecting step are similar as those related to the use step.

Little information was found on efficiency of recycling and share of functional/non-functional recycling. These factors therefore have been estimated with the help of experts which results in high uncertainties related to parameters of the recycling step.

Sankey diagram for borates

Figure 21: Simplified Sankey diagram of borates



Nota bene: Due to negative annual rate of consumption of some products containing borates, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow “Subtraction to in-use and end-of-life stock” in the Sankey diagram, which is an input from the EU market to the EU waste management

3.3.5 Chromium

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, “chrome green”) 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).

The 2 figures below present the value chain of chromium with the main intermediates and uses.

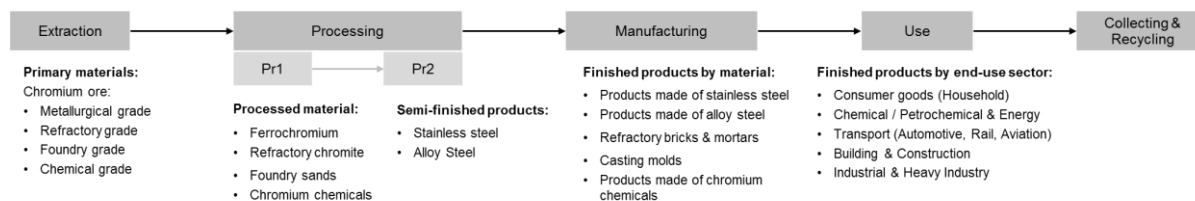


Figure 22: Value chain of chromium

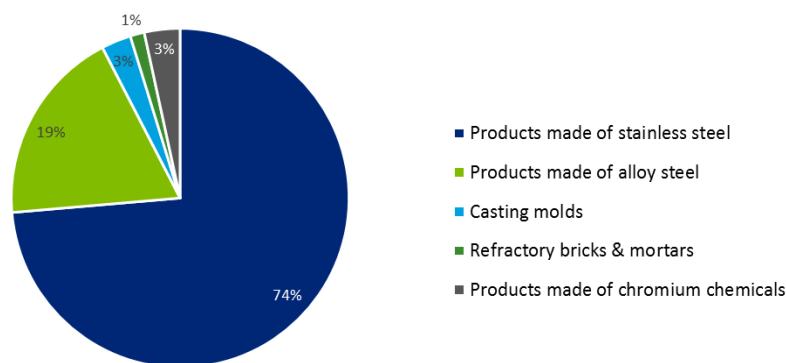


Figure 23: Chromium used in the EU industry for manufacture of finished products per type of material

Description of the main flows and stocks

Flows and stocks are accounted in mass of chromium (Cr) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Significant reserves of chromium in the EU are located in Finland only, with about 9,000 kt in chromium content. In comparison, world reserves are estimated as 140,000 kt in chromium content.

The first stages of the value chain mainly take place outside the EU. The annual EU production of chromium ore is of 280 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 9,000 kt, mainly in South Africa (47%), Kazakhstan (18%) and India (10%).

Imports of chromium ores represent a minor part (94 kt in chromium content) of the total ores used in the EU (370 kt in chromium content). Regarding the semi-processed material ferrochromium (used to process stainless steel and alloy steel), the majority of the 275 kt produced in the EU is sold for further processing in the EU (203 kt), while imports of ferrochromium reach 700 kt in chromium content (mainly from South Africa, i.e. around 60% of the imports of ferrochromium).

The total EU production of crude stainless steel and alloy steel represents around 1,700 kt of chromium, with an input of 780 kt of chromium as scrap (470 kt as old scrap from recycling in the EU and imports of secondary material; 310 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 170 kt of chromium in scrap are generated from the processing of steel in primary forms (“home” scrap), and directly remelted into new steel; 130 kt are generated as “new” scrap from the manufacturing of finished products. Around 380 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 (90 kt in chromium content).

The European industry uses semi-finished products made of stainless steel and alloy steel to manufacture various finished products (see Figure 24 – left) which are either sold in the European market (1,000 kt) or exported (140 kt in chromium content, i.e. 12% of the total EU production of finished products made of steel). 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).

The production of refractory bricks and mortars amounts 18 kt in chromium content and the production of molds for casting amounts 37 kt in chromium content.

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 (37 kt in chromium content) and semi-finished products from chromium chemicals (10 kt). However, these are key products for the European industry (for economic and technological reasons), due to their use in the aviation and energy sector. About 50% of these products are exported with a high added value.

Imports of finished products amount to 110 kt in chromium content, i.e. 9% of domestic consumption in the EU. Distribution by end-use sector of all finished products is shown in Figure 24 – right.

Finished products manufactured in the EU

Finished products used in the EU



Figure 24: Shares of finished-products containing chromium manufactured in the EU and shares of finished-products containing chromium used in the EU (taking into account exports and imports of products)

Considering the lifespan of the finished products containing chromium and the annual growth of the stainless steel market in Europe, about 40% of the chromium put on the EU market is annually added to the in-use stock of chromium (460 kt in chromium content) and almost 60% is collected in products at end-of-life (710 kt). The stock of products in-use is about 24,000 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. non-functional recycling). The overall functional recycling rate is of 48% and the non-functional rate is of 24%. The stock accumulated in landfill over the last 20 years is calculated in the MSA at around 3,000 kt in chromium content.

Value chain distinguishing steps occurring or not within the EU

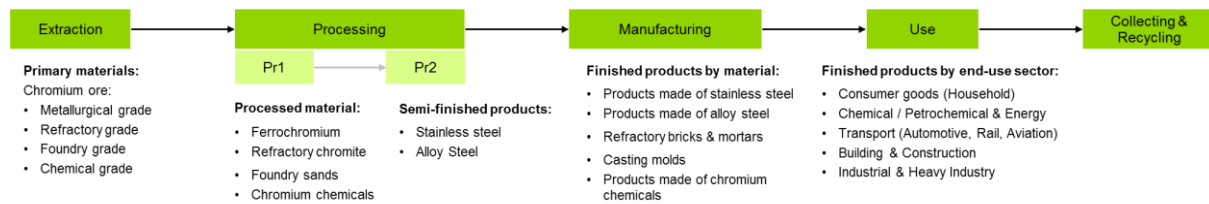


Figure 25: Value chain of chromium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

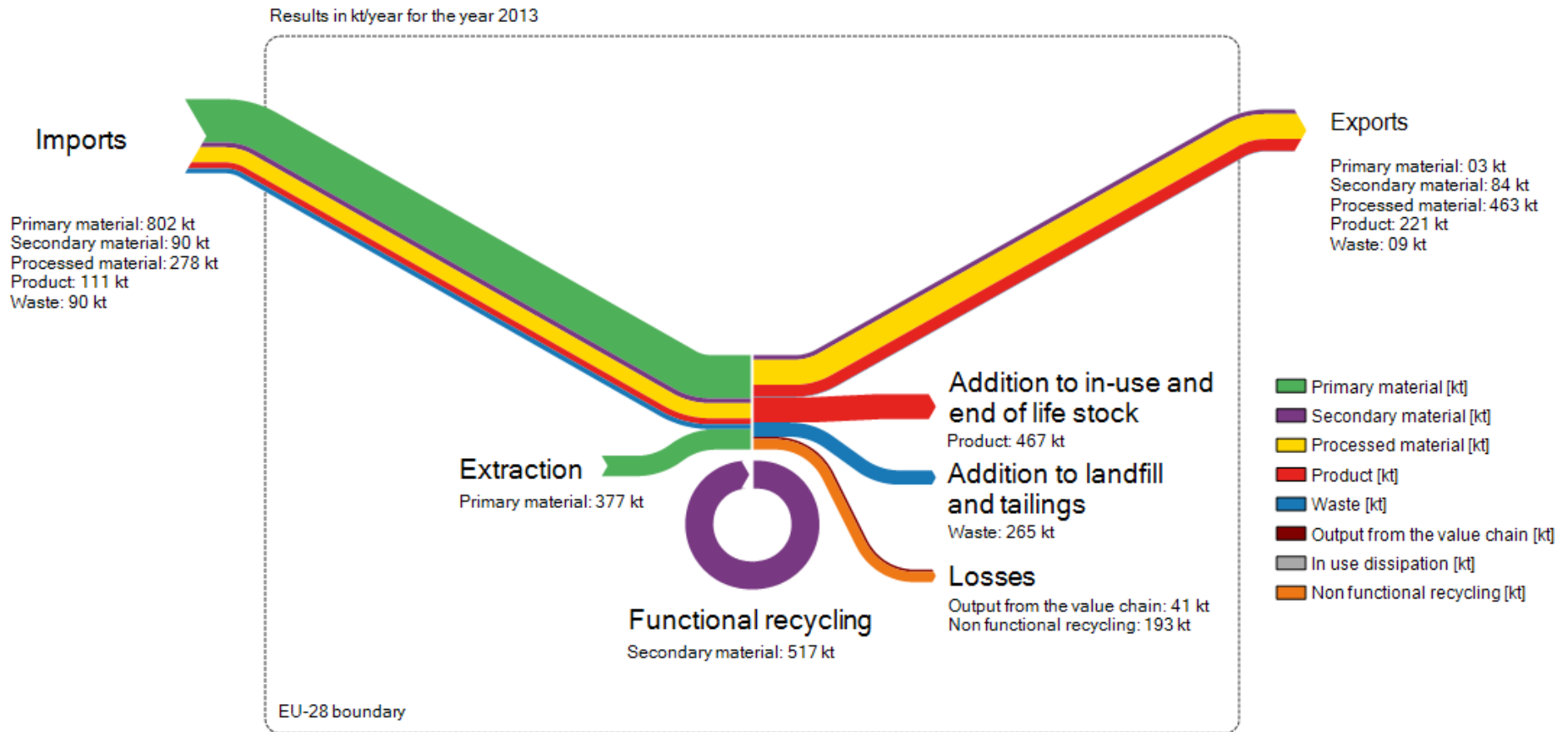
The main sources of data for the elaboration of this MSA are Eurostat, ICDA, ISSF, SMR and Lanxess. Hence, the results can be considered as quite robust for all steps exploration, extraction, processing, and manufacture.

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. Eurostat PRODCOM is a relevant data source for production volumes sold in EU. But its level of detail and the coverage often is not sufficient for this MSA. Particularly for crude stainless steel and products of chromium chemicals data from ISSF respectively from chemical and chromium metal industry experts are used.

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-use, 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.

Sankey diagram for chromium

Figure 26: Simplified Sankey diagram for chromium



3.3.6 Cobalt

Value chain

Cobalt is a transition metal not abundant in the Earth's crust. Cobalt is obtained from mineral ores, often as a by-product of nickel and copper, and it is usually concentrated at the extraction site before being traded. According to the Cobalt Development Institute (CDI), about 50% of cobalt production originates from nickel ores, 44% from copper ores and 6% from primary cobalt production. The main ores of cobalt are cobaltite, erythrite, glaucodot, and skutterudite.

The concentrated ores of cobalt are refined through various processes into a variety of forms: intermediate cobalt production (e.g. cobalt-containing mattes and crude metal, cobalt hydroxide, crude cobalt oxide, cobalt sulphate); and refined cobalt production (e.g. cathodes, briquettes, ingots, granules, and powder) and cobalt chemicals (e.g. cobalt chloride, cobalt oxide, cobalt hydroxide, cobalt salts).

The present analysis includes all cobalt substances used in the EU economy. Cobalt is used in chemical compounds in rechargeable batteries for electric vehicles, laptops, phones, medical devices, cordless tools, in pharmaceutical applications and biogas refining, among others. Metallurgical applications of cobalt are such as superalloys for aeronautic applications, wear/corrosion resistant alloys, prosthetics, medical, dental alloys, high speed steels, hard metals for metal tooling (e.g. diamond tools, drills and cutting tools, grinding tools, hot rolls, rotary cutters, can tooling, metal forming tools), and magnets. Cobalt is also used in catalysts for petroleum refining or polyester precursors. Specific cobalt substances are deliberately used for specific end-uses in order to provide very specific performance and end-user product characteristics.

The figure below presents the value chain of cobalt and its main uses.

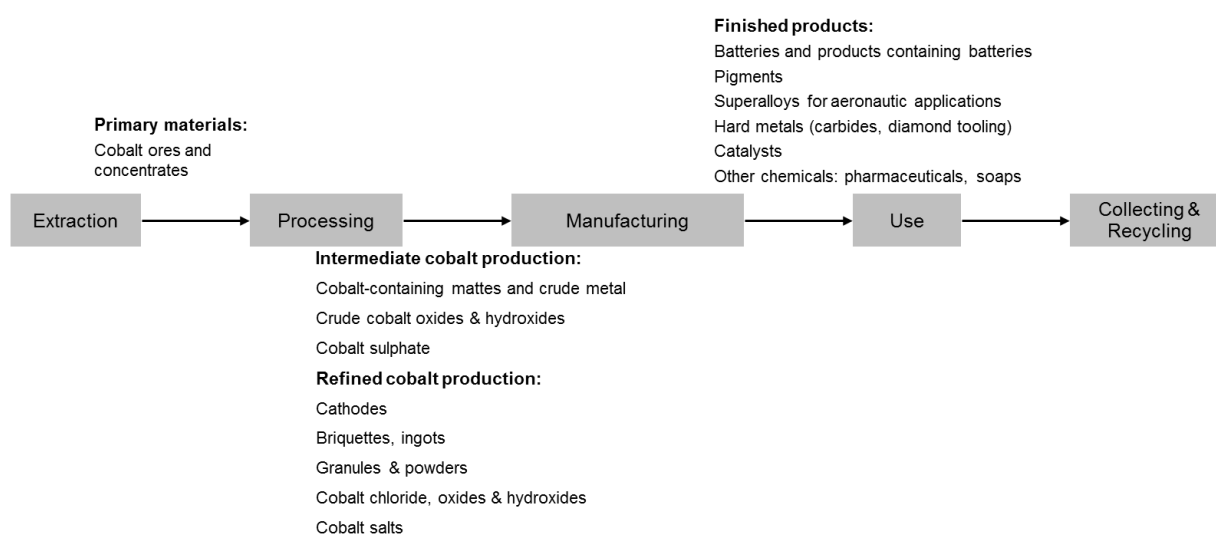


Figure 27: Value chain of cobalt

Description of the main flows and stocks

Flows and stocks are accounted in mass of cobalt (Co) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

World resources of cobalt are estimated around 25,000 Mt of cobalt, with around 7,200 Mt of cobalt reserves worldwide. Additional over 120 million tonnes could exist in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans. The resources and reserves in the EU are not quantified.

The world annual production of cobalt concentrate (i.e. before refining) is around 130,000 kt, and the main producer country is the Democratic Republic of Congo, accounting for 67% of the global

production. China, Zambia and Australia produce respectively 5%, 4% and 4% of the cobalt concentrates worldwide.

In the EU, 1.4 kt of cobalt concentrates are extracted per year in Finland. A total of around 15 kt of cobalt are refined in Finland, Belgium and France per year from imports of cobalt ore concentrates extracted in other countries outside the EU. Therefore, imports of primary materials to the EU amount about 13 kt in cobalt content per year, and imports of refined materials are around 0.6 kt per year.

With these cobalt substances produced in the EU and imported, the European industry manufacture various finished products containing around 11 kt of cobalt and consisting mainly in superalloys and hard metals (see Figure 28 – left). These products are mostly sold in the European market (around 8.4 kt of cobalt in products sold in the EU and 2.4 kt of cobalt in products exported). Some of these cobalt substances exported may be used to manufacture finished products that are imported to the EU in the use phase. Most of the waste generated at the manufacturing step is recovered and reprocessed in the facility in which it was produced.

Imports of finished products amount around 11 kt of cobalt content, batteries and products containing batteries representing almost 90% of the cobalt content in these imports. The European final consumption of products containing cobalt is around 20 kt per year (see Figure 28 – right).

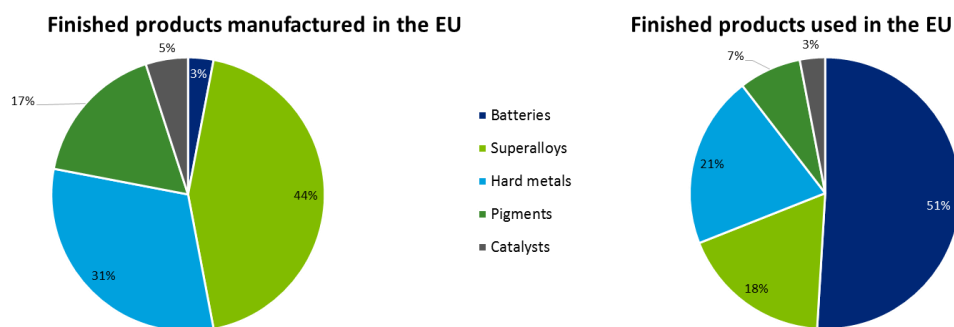


Figure 28: Shares of finished products containing cobalt manufactured in the EU (left) and shares of finished products containing cobalt used in the EU (right)

Considering the estimations of the lifespan and the annual growth of consumption of the finished products containing cobalt, the quantity annually added to stock is around 2.4 kt of cobalt. Around 2.3 kt of cobalt are exported in products for reuse and around 13.8 kt are collected for waste management.

Batteries for electric vehicles and superalloys for aeronautic applications are recycled in significant proportion at their end of life. However, batteries for consumer electronics, hard metals for metal tooling, and catalysts are collected and recycled in lower proportion at their end of life, and there is no functional recycling of cobalt in pigments and other chemicals for pharmaceutical applications. As a result, a total amount of around 6;3 kt of cobalt is recycled per year in the EU.

Value chain distinguishing steps occurring or not within the EU

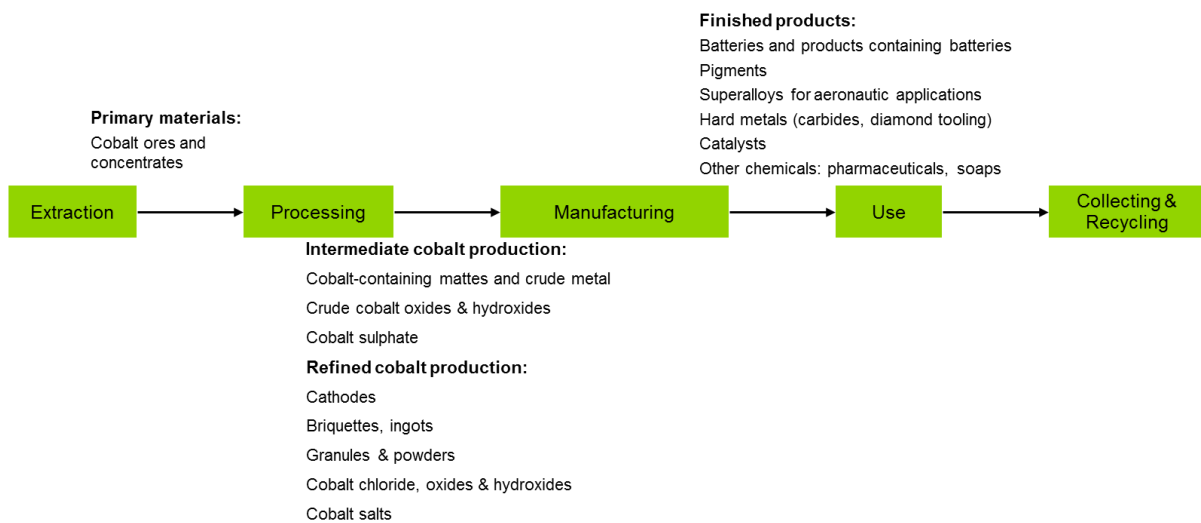


Figure 29: Value chain of cobalt, steps in green occur in the EU, steps in orange occur only outside of the EU

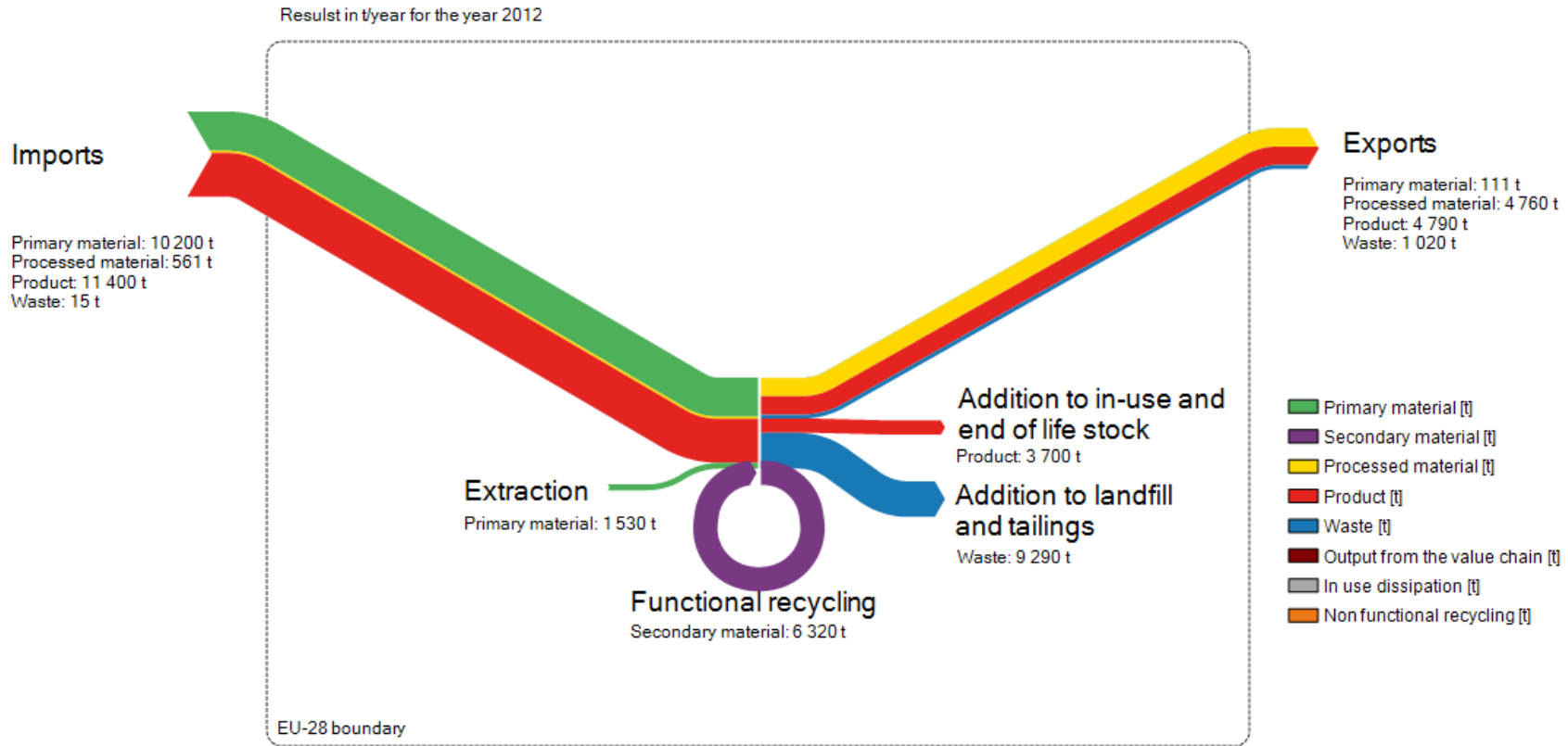
Data sources, assumptions and reliability of results

The main data sources for the development of the MSA of cobalt are the Cobalt Development Institute, the British Geological Survey, the US Geological Survey, the Bureau de Recherches Géologiques et Minières, and the Eurostat PRODCOM database. Some data on the recycling of cobalt and lifetimes of cobalt-bearing products are provided in Harper (2011) and Shedd (2004).

From the manufacturing step to the recycling step, the flows and stocks of cobalt are highly estimative and calculated based on trade statistics of finished products, average lifespan of products, collecting and recycling practices, etc. This approach and the lack of data lead to a low robustness of the results for the steps of use, collecting and recycling.

Sankey diagram for cobalt

Figure 30: Simplified Sankey diagram for cobalt



3.3.7 Coking Coal

Value Chain

Coking coal is a low-ash, low-sulphur bituminous coal. After mining 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 in 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 further processed to produce carbon electrodes as well. The figure below presents the value chain of coking coal with the main uses.

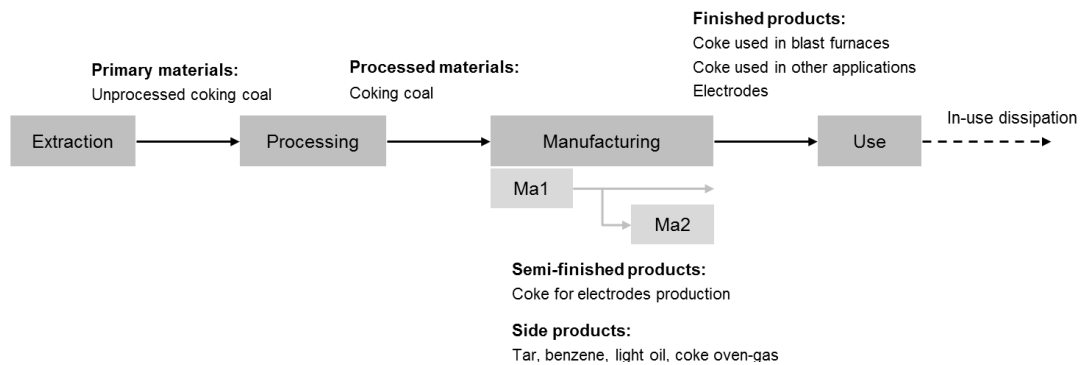


Figure 31: Value chain of coking coal

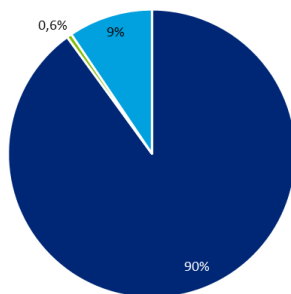
Description of the main flows and stocks

Flows and stocks are accounted in mass of carbon (C) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

World reserves of coking coal are estimated as 80,000 Mt of C content, whereas the reserves in the EU are assumed to be little more than 2,000 Mt of C content. World annual production is around 750 Mt of C content, mainly in China, Australia, USA, Russia and India.

There are no imports of unprocessed coking coal into the EU since processing takes place closely to the mines. The European production of coal is about 18 Mt in C content per year. One half is mined in Poland, whereas Germany and the Czech Republic contribute to roughly one quarter each. Most of the coal mined and processed in the EU is sent to manufacture in the EU; around 1 % is exported.

Finished products manufactured in the EU



Finished products used in the EU

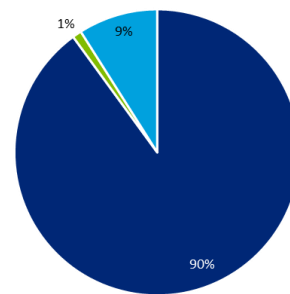


Figure 32: Shares of finished products containing coking coal manufactured in the EU and shares of finished products containing coking coal used in the EU (taking into account exports and imports of products)

For the processing of coke, additional 30 Mt of C content in processed coking coal are imported to the EU, mostly from the USA, Australia, Russia and Canada. The total European annual coke production is about 37 Mt in C content (see Figure 32 – left). In this process, about 8 Mt of C in side products (pitch, tar, oil, and coke-oven gas) are produced and fed to the chemical industry for further processing. A small share (~1%) of the produced coke is sent to another processing step for electrodes production. Most of the coke manufactured in the EU is sold for use in the EU rather than exported (exports of finished products represent 2.4 Mt of C content). Imports of coke in manufactured products are equivalent to exports, with about 1.8 Mt in C content to be used in the EU.

As displayed on Figure 32 – right, more than 90% of coke is used in blast furnaces both for heating and as a reduction medium for the production of pig iron from iron ores. Only about 1 % is used in electrodes 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, coke is entirely dissipated as it is oxidised to CO₂.

Value chain distinguishing steps occurring or not within the EU

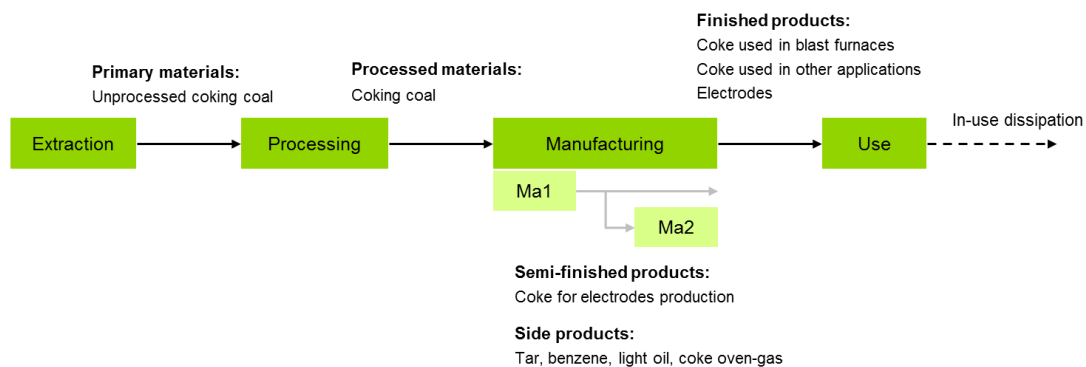


Figure 33: Value chain of coking coal, steps in green occur in the EU, steps in orange occur only outside of the EU

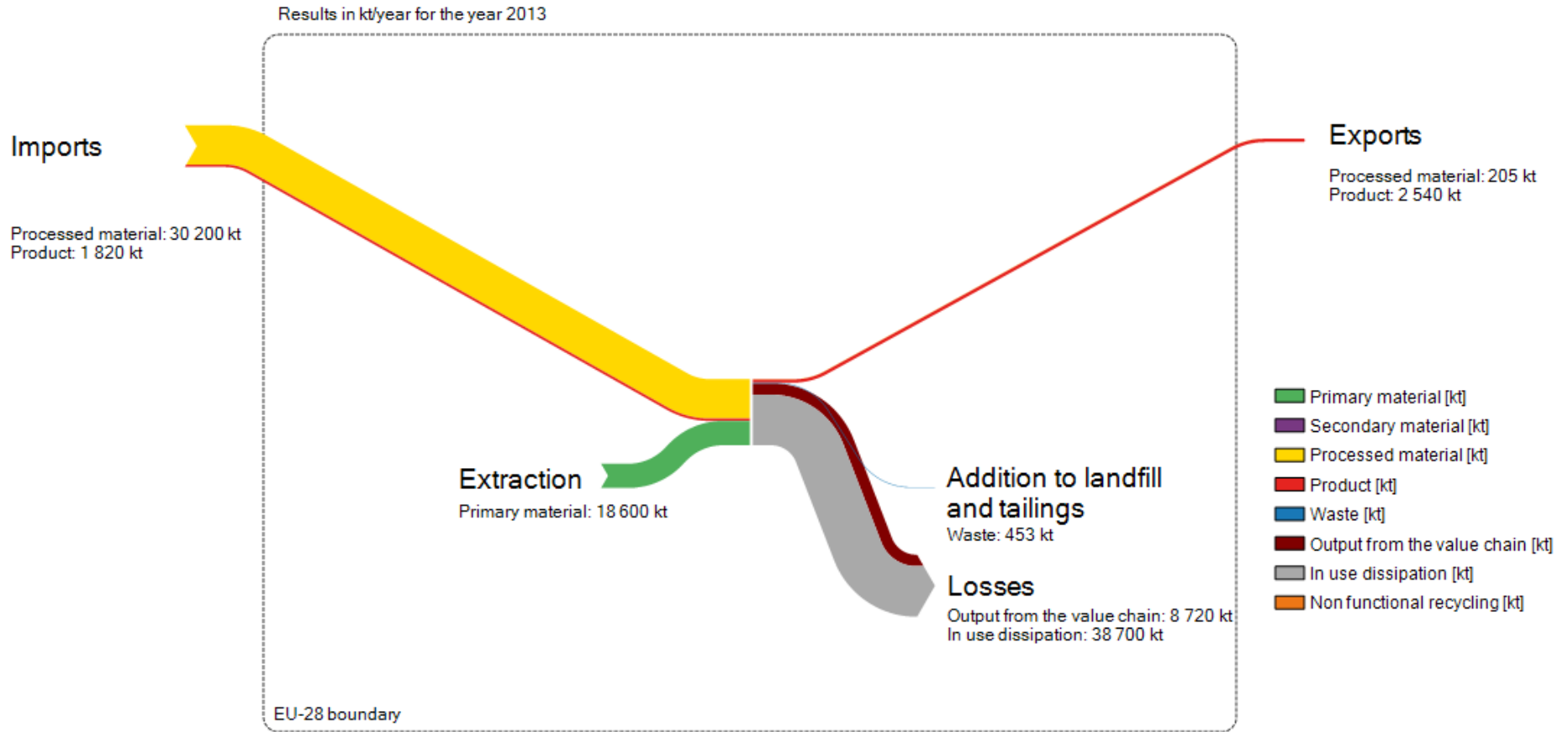
Data sources, assumptions and reliability of results

For the steps of exploration, extraction, and processing literature data from BGR and the Austrian Ministry of Science, Technology and Commerce, was used. 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 (PRODCOM and COMEXT) and statistics from the Verein der Kohleimporteure. Details on the manufacturing processes and of side products were obtained from BAT reference documents as well as from experts and publications from industry and industry associations (e.g. Euromines, EURACOAL, EUROFER). 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 considered to be still 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.

Sankey diagram for coking coal

Figure 34: Simplified Sankey diagram for coking coal



3.3.8 Fluorspar

Value Chain

After extraction, fluorspar ore is directly transformed into fluorspar acid grade (AG) and metallurgical grade (MG). Those primary materials are then processed into hydrogen fluoride (HF), cryolite and aluminium fluoride (AlF₃). Fluorspar MG is also used in iron and steel making, but is not incorporated in the iron and steel products.

The processed material HF is converted into semi-finished products such as fluorocarbons, fluoropolymers, fluoroaromatics and uranium hexafluoride (UF₆, used in nuclear energy production) or is directly converted into finished products such as inorganic fluorine compounds. HF is also used for etching and pickling of metals and for alkylation process in oil refining but for these 2 applications there is no F element in the final products. In the same way, cryolite and aluminium fluoride are used for aluminium processing but are not incorporated in aluminium alloys. Fluorocarbons, fluoropolymers and fluoroaromatics are used in finished products in various applications such as cable insulation, fire protection, refrigerants, pharmaceuticals, etc.

The figure below presents the value chain of fluorspar with the main uses.

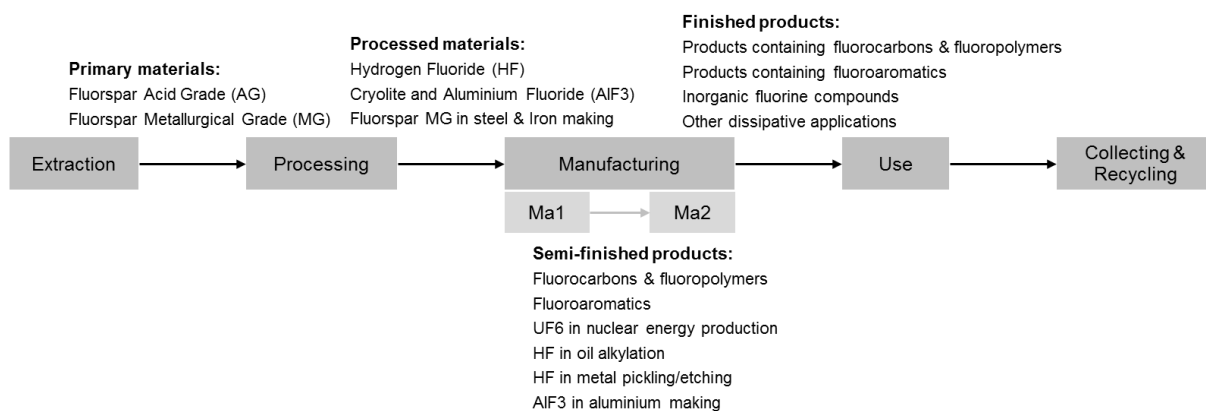


Figure 35: Value chain of fluorspar

Description of the main flows and stocks

Flows and stocks are accounted in mass of fluorine (F) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

World reserves of fluorspar are estimated as 117,000 kt of F and the world annual production of primary material is around 3,000 kt in F content, mainly in China and Mexico. Reserves of fluorspar in the EU amount to 650 kt in F content. The European production of primary material is around 108 kt of F and is entirely in the form of fluorspar AG (no production of fluorspar MG in the EU). The EU production mainly takes place in the UK, Spain, Germany and Bulgaria. 87 kt of F contained in this primary material are sent to processing in the EU and 21 kt are exported. Fluorspar AG and MG are also largely imported in the EU, respectively 140 kt and 96 kt of F content.

The European production of processed material amounts 210 kt of F, with 175 kt in the form of HF and 35 kt in the form of cryolite and aluminium fluoride. Most of this processed material is sold in the EU (185 kt of F), the rest is exported (26 kt of F). There is an important internal recycling of F in the manufacturing industry, as well as important losses from the value chain due to the formation of by-products (that can be valorised). Therefore waste generated during the production of HF, cryolite and aluminium fluoride, as well as iron and steel products, and disposed in landfill is negligible (less than 1 kt of F, including less than 20 t for the production of HF).

Imports of processed materials and semi-finished products are around 81 kt of F and represent around 30% of the F supply for European manufacturers. Imports mainly consist in fluorocarbons and fluoropolymers. With the processed materials and the semi-finished products produced in the EU and imported, as well as the secondary material coming from post-consumer recycling, the European

industry manufactures various finished products containing around 189 kt of F. A third is sold in the EU (around 64 kt of F) and the rest is exported (around 125 kt of F). The important amount of waste generated is due to the use of HF, cryolite and aluminium fluoride in industrial processes (etching and pickling of metals, alkylation process in oil refining, aluminium making) (see Figure 36 – left).

Imports of finished products amount 64 kt of F, which is equivalent to the F content in the domestic production of finished products sold in the EU. The European final consumption of products containing F is around 130 kt of F per year (see Figure 36 – right).

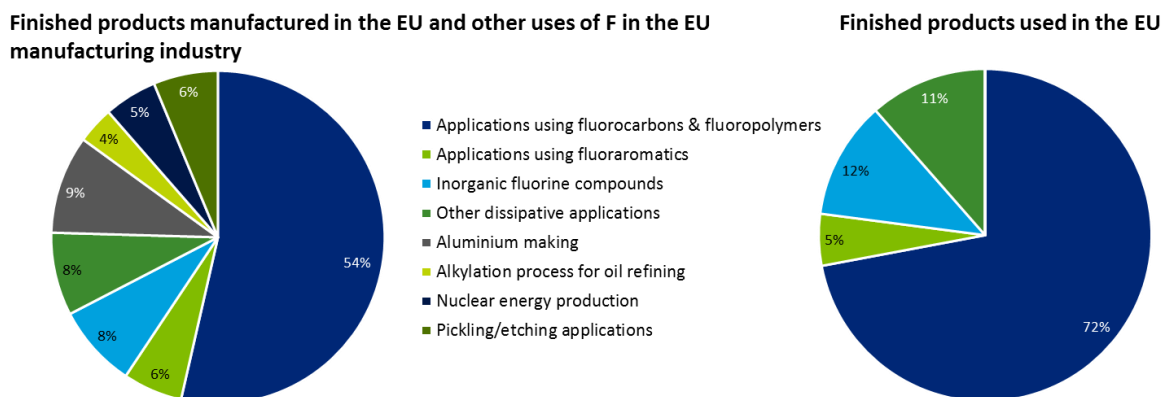


Figure 36: Shares of finished products containing fluorine manufactured in the EU and other uses of fluorine in the European manufacturing industry (left) and shares of finished products containing fluorine used in the EU (right)

Considering the lifespan of the finished products containing F and the negative annual growth of consumption of these products, about 50 kt of F are destocked annually from the in-use and end-of-life stocks of products (which amount around 1.8 Mt of F). Quite the same amount is lost due to dissipative use. Then, around 130 kt of F are sent to waste management.

The F contained in the waste mainly ends up in landfill. The stock of F accumulated in landfill in the EU over the last 20 years is estimated around 5.6 Mt. Only a very small part of the F contained in the waste is effectively recycled (around 5 kt of F). The secondary material produced from this post-consumer functional recycling is sent to the manufacturing step.

Value chain distinguishing steps occurring or not within the EU

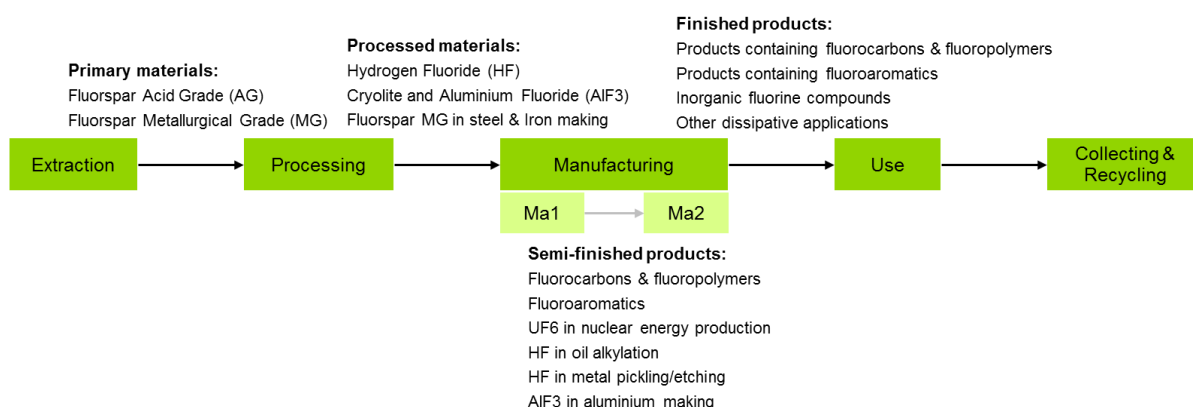


Figure 37: Value chain of fluorspar, step in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

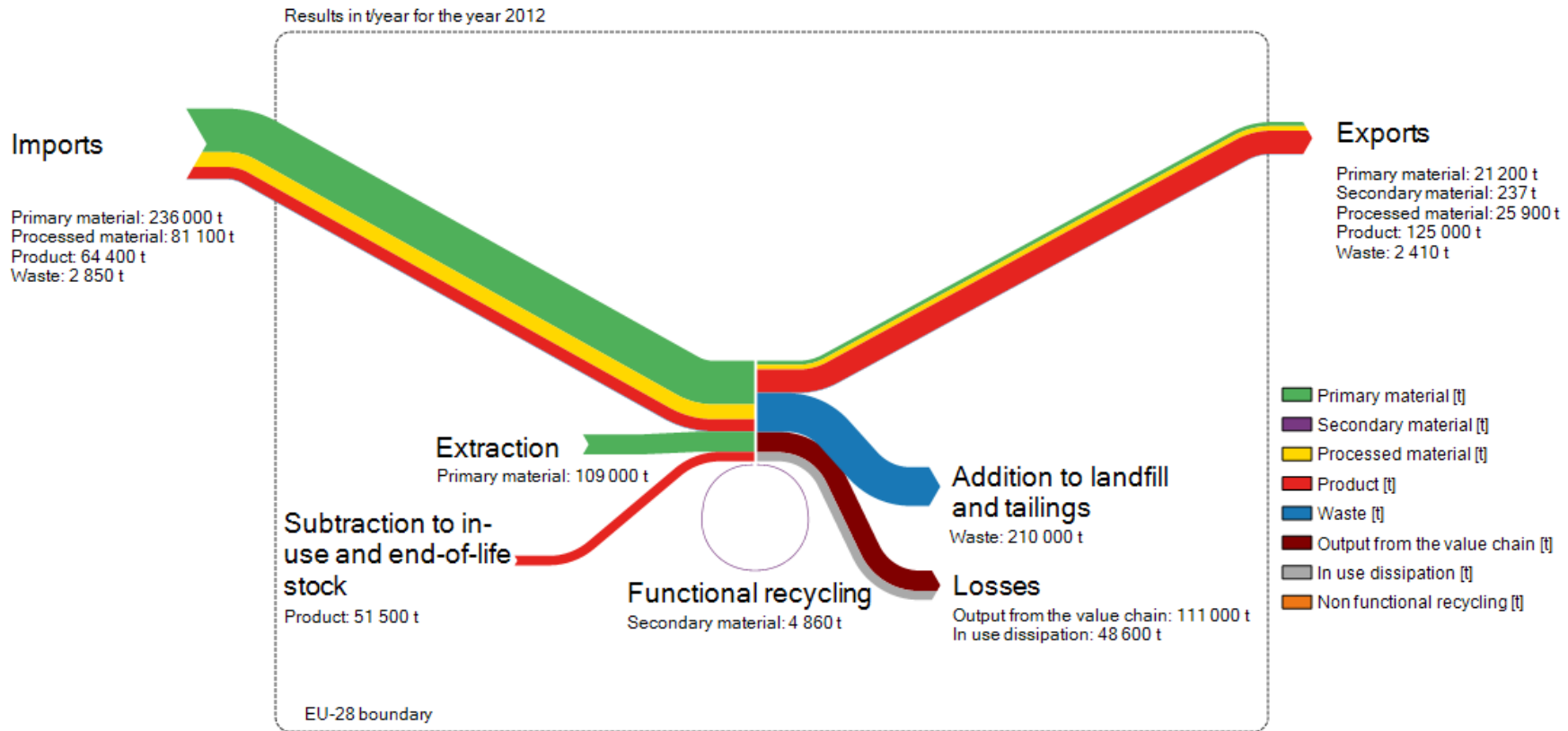
The main sources of data used for the development of this MSA are experts: an expert from LMT Services provided data for exploration and extraction steps, whereas experts from CEFIC and Dupont provided data on manufacturing and use steps, as well as data on generation of waste. Hence, the results for the upstream steps can be considered as a quite robust.

From the manufacturing to the recycling steps, the flows are calculated based on one main data point: the repartition of uses of HF in the EU manufacturing industry, provided by Dupont.

Based on this data, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows in the manufacturing, use, collecting and recycling steps. This exercise requires a number of other data sources to characterize each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports/imports and production sold in the EU of various finished products (using the PRODCOM and ComExt Eurostat databases). In order to fill some data gaps, other hypotheses were made, particularly in terms of quantity of waste generated during the processing and manufacturing step. For these reasons, the level of reliability of results for the steps manufacturing, use, collecting and recycling is lower than for the upstream steps.

Sankey diagram for fluorspar

Figure 38: Simplified Sankey diagram for fluorspar



Nota bene: Due to negative annual rate of consumption of some products containing fluorspar, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow “Subtraction to in-use and end-of-life stock” in the Sankey diagram, which is an input from the EU market to the EU waste management

3.3.9 Gallium

Value Chain

Bauxite ores are the main source of gallium, accounting for more than 95% of worldwide production of primary gallium. However, only 10% of the aluminium industry extract gallium from bauxite ores; most of the gallium is thus contained in tailings or sent to landfill as waste from aluminium extraction.

Primary gallium is obtained from bauxite ores and further processed into refined gallium. The main semi-finished products are wafers of GaAs and GaN, as well as strategic gallium compounds (GaIn, GaO, etc.). GaAs wafers can be used in civil and military applications, for semiconductor or sensor uses. GaN wafers are mostly used in optoelectronic applications. Other applications include permanent magnets and finished products based on various gallium compounds. The figure below presents the value chain of gallium and its main uses.

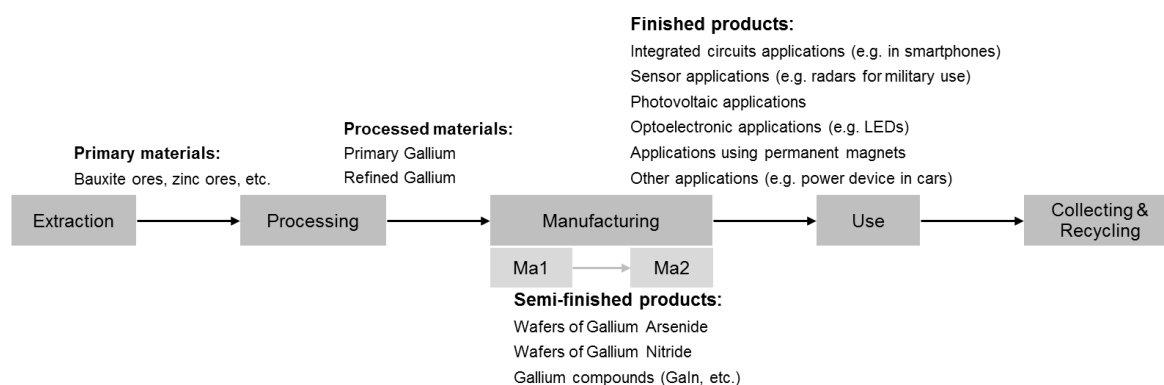


Figure 39: Value chain of gallium

Description of the main flows and stocks

Flows and stocks are accounted in mass of gallium (Ga) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Resources of gallium in the EU contained in bauxite ores are of 19.8 kt of gallium, compared to 1,000 kt of gallium worldwide. In addition, considerable amounts of gallium are thought to be contained in zinc resources. No information was found on reserves of gallium, however please note that various references do not properly distinguish reserves and resources.

Around 8 t of Ga content is extracted and sold in the EU as bauxite ores (compared to 86 t of gallium contained in extracted bauxite ores not used in gallium industry, i.e. disposed in tailings); 40 t of gallium content is imported in the EU as bauxite ores for the gallium industry (compared to more than 700 t of gallium imported in bauxite ores not used in gallium industry i.e. sent for disposal in the EU). Production sold of processed material (mainly refined gallium) in the EU is around 30 t; in comparison, consumption of processed material in manufacturing is of 64 t of gallium content (including imports of refined gallium).

The majority of the refined gallium is used to manufacture GaAs wafers; around 5% are used respectively in the manufacturing of GaN wafers and various strategic gallium compounds. However, only sensor applications for military uses and applications using permanent magnets are thought to be manufactured in the EU. Thus the entire production of GaN wafers and most of the GaAs and gallium compounds are exported from the EU to manufacture finished products outside of the EU, e.g. in smartphones or photovoltaic panels (see Figure 40 - left).

The consumption of gallium in finished applications in the EU is estimated at 57 t; the distribution between applications is presented in Figure 40 - right. It appears that 42 t of those 57 t of gallium content are imported. Imports in the EU of applications using permanent magnets represent 30% of the consumption in the EU for these applications; imports of sensor applications are estimated at 10% of the EU consumption.

Considering the lifespan and annual growth of consumption of each final application, the quantity annually added to stocks is equivalent to 30 t of gallium content, with in-use stock and end-of-life stocks up to 280 t of gallium. There is no in-use dissipation in these applications, thus the collected volume of products at end-of life for treatment is of 27 t of gallium content.

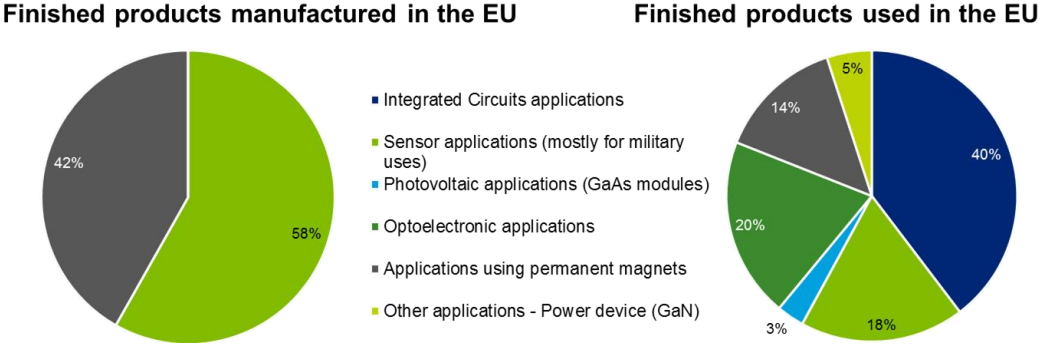


Figure 40: Shares of finished products containing gallium manufactured in the EU (left) and shares of finished products containing gallium used in the EU (right)

Recycling of gallium at end-of-life does not currently exist worldwide. However secondary material from new scrap (i.e. manufacturing waste sent to reprocessing) accounts for 40% of the production of processed material in the EU (i.e. 32 t of gallium); among which a small part is imported in EU. By comparison, annual addition to stock in landfill represents 50 t of gallium content (calculated sum of waste flows generated from processing until recycling, excluding gallium contained in bauxite ores not sent to gallium industry, i.e. 700 t of gallium in imports of bauxite ores in the EU).

Value chain distinguishing steps occurring or not within the EU

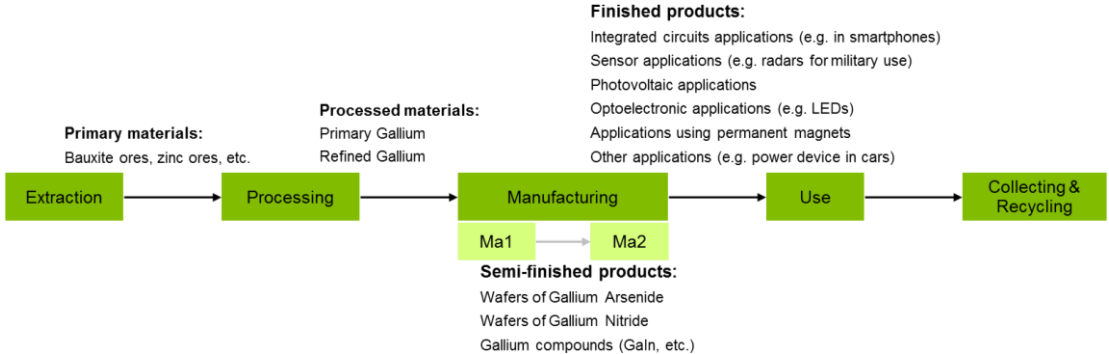


Figure 41: Value chain of gallium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

As explained above regarding the reserves and resources, no information was found on gallium reserves in the EU and worldwide. However multiple references (in particular USGS) do not adequately distinguish between the two definitions, potentially impacting other sources.

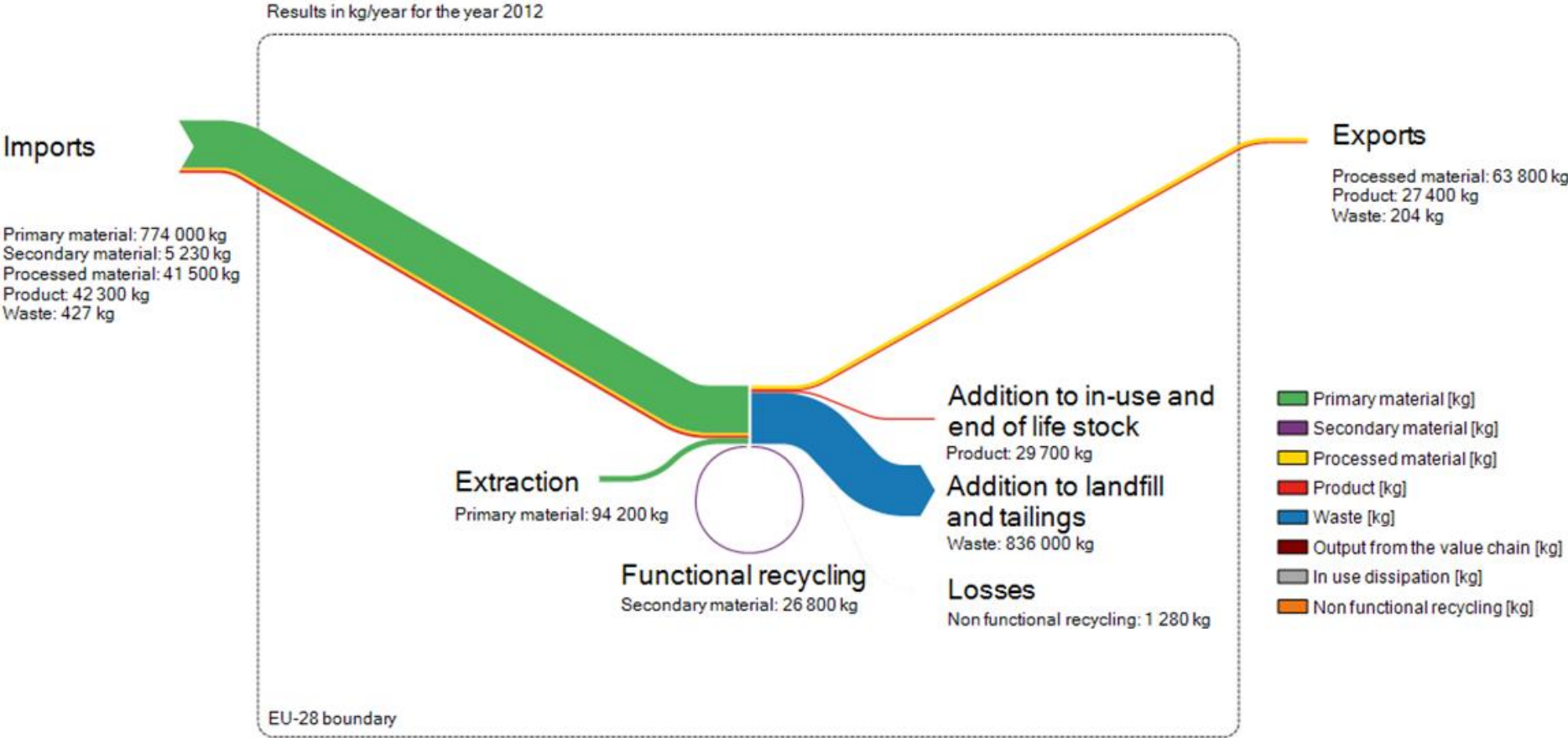
Eurostat database is used for the extraction and processing steps; the aggregated data was confirmed by various expertise during the workshop (Freiberger Compound Materials, Indium Corporation, Soitec). The information calculated in these two steps is therefore considered as reliable.

On the contrary, few quantitative data can be found for on manufacturing and following steps, although the importance of gallium as a strategic compound is well established. Various hypothesis are made regarding the use of processed material in manufacturing. Similarly, the EU consumption of Ga in finished products is estimated based on a share of the EU GDP among worldwide GDP. Distribution between finished applications is provided by a Chinese manufacturer (though Indium Corporation expertise). Multiple finished products are similar to other MSAs, in particular REEs and Germanium. Data from those MSAs was therefore used, when relevant. On the overall, data from manufacturing until collection step is highly unreliable. Because there is no recycling of gallium from products at end-of-life, the reliability of information for this step is good.

As explained before, the MFA accounts for all flows of gallium between the EU and the rest of the world. However because not all gallium is valued in the gallium industry, a large amount of material is imported through the alumina industry and not used in the EU but sent to landfill. These flows represent up to 90% of the total volumes of gallium traded between the EU and the rest of the world, as presented on the Sankey diagrams below. For better readability, two additional Sankey diagrams are presented below, with a specific focus on the gallium industry, i.e. excluding gallium contained in bauxite ores for alumina industry (see Figure 42 and Figure 43).

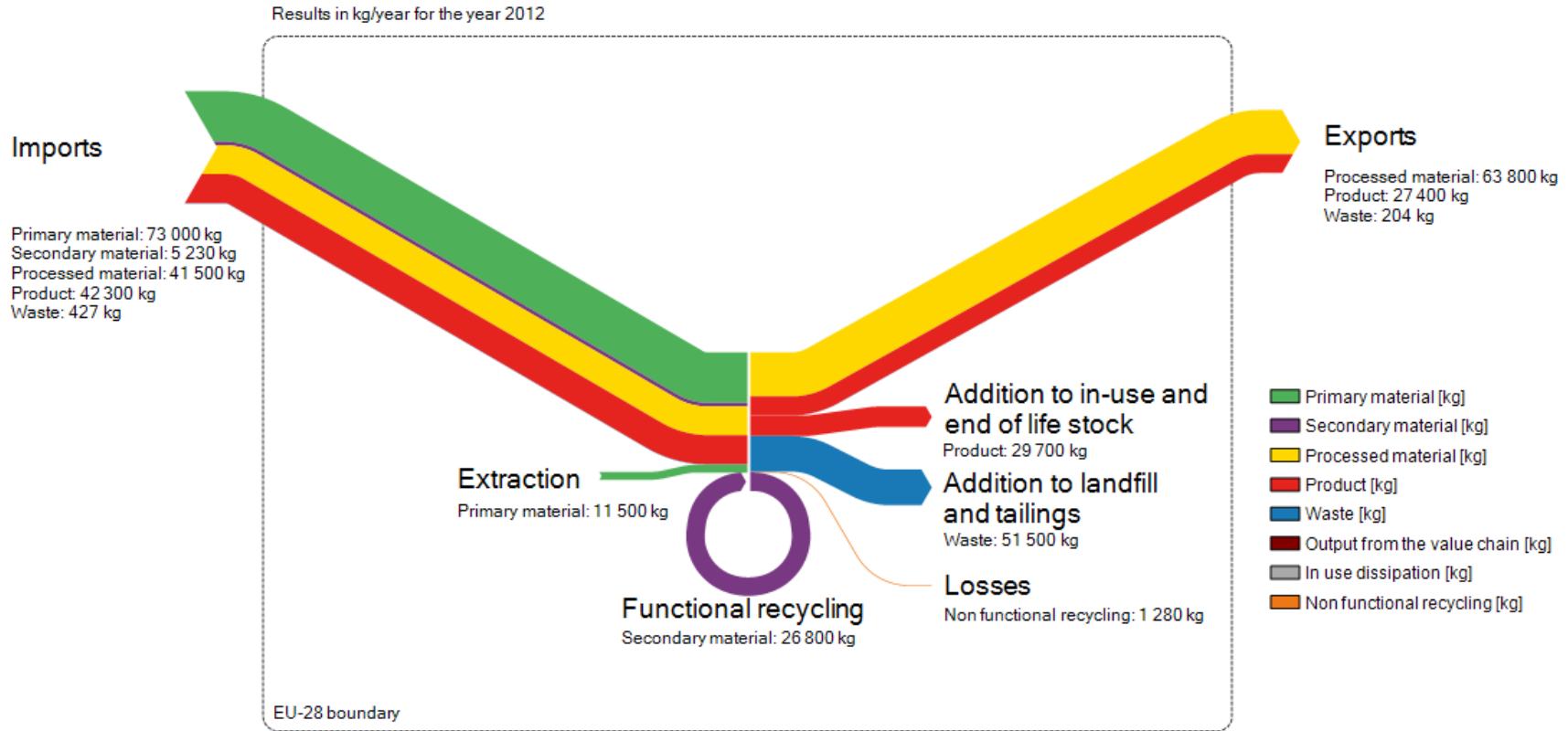
Sankey diagram for gallium

Figure 42: Simplified Sankey diagram for gallium



Sankey diagram for gallium – additional diagrams with a focus on gallium industry (excluding gallium not used in gallium industry)

Figure 43: Simplified Sankey diagram for gallium – focus on gallium industry



3.3.10 Germanium

Value Chain

Germanium is contained in zinc ores and coal ashes. This primary material is processed into germanium concentrates and then crude germanium dioxide (GeO_2). Crude GeO_2 is then converted into germanium tetrachloride (GeCl_4) and high grade GeO_2 . GeCl_4 is also partly used to produce high grade GeO_2 . A fraction of high grade GeO_2 is then transformed into Ge metal.

Those processed materials are used to manufacture various finished products: GeCl_4 is mainly used to manufacture optical fibers, high grade GeO_2 is transformed into PET catalyst and Ge metal serves in several applications such as IR optics, wafers for satellites solar cells, IT applications, etc.

The figure below presents the value chain of germanium with the main uses.

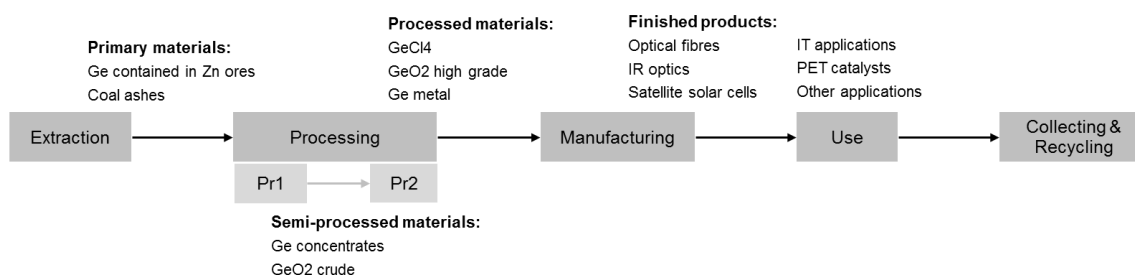


Figure 44: Value chain of germanium

Description of the main flows and stocks

Flows and stocks are accounted in mass of germanium (Ge) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

There are no reserves of germanium in the EU and consequently there is no production of germanium, neither from zinc ores nor from coal ashes. World reserves of germanium are estimated as 8,600 t of Ge content and the world annual production is around 760 t of Ge. Most of the germanium is extracted from zinc ores as a byproduct, mainly in China, the United States, Australia and India. It is important to note that only a small fraction (around 12%) of the germanium contained in the zinc ore extracted worldwide is effectively recovered and further used in the value chain of germanium. The main fraction is not valued and is considered as lost (in tailings, as impurities in zinc products, etc.).

At the processing step, the EU imports 35 t of g contained in zinc ores and 15 t of Ge contained in crude GeO_2 . However, only 15 t of the germanium contained in zinc ores are processed and 20 t are disposed (no recovery of the germanium as a by-product of zinc). The European processing industry is also supplied with around 15 t of germanium in scrap coming from the European manufacturing industry.

With these materials, the EU industry processed high grade GeO_2 , GeCl_4 and Ge metal. The total production amounts around 45 t in germanium content, with around 35 t sold in the EU, compared to about 10 t in exports from the EU. It can be noticed that high grade GeO_2 is entirely exported as there is no manufacturing nor consumption of PET catalysts in the EU.

Imports of processed materials are estimated as 17 t in germanium content, with around 5 t in the form of GeCl_4 and around 12 t in the form of Ge metal. With the processed materials produced in the EU and imported (around 52 t of Ge), as well as small quantities of secondary material coming from post-consumer recycling (around 1 t of Ge), the EU industry manufactures various finished products, containing up to 26 t of Ge (see Figure 45 – left). The important volumes of waste generated during the manufacture step (about half of the Ge input) are mostly sent back to reprocessing in the EU or exported.

Imports of finished products amount around 11 t in germanium content, which is equivalent to the Ge content in the domestic production of finished products sold in the EU. The European final consumption of products containing germanium is around 23 t of Ge per year (see Figure 45 – right).

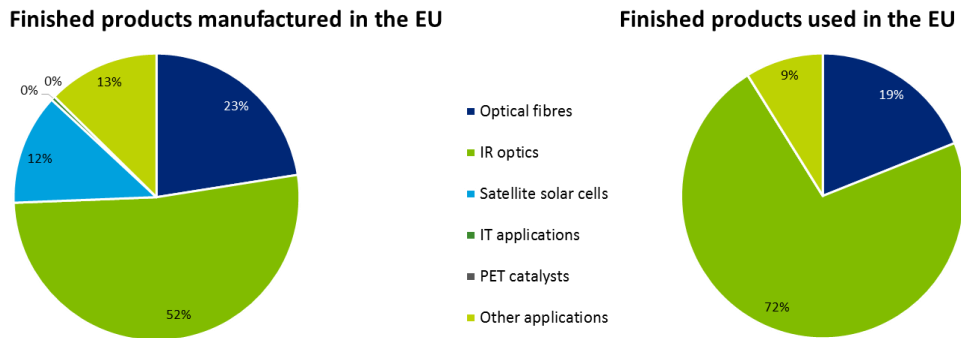


Figure 45: Shares of finished products containing germanium used in manufacture in the EU (left) and shares of finished products containing germanium used in the EU (right)

Considering the lifespan of the finished products containing Ge and the annual growth of consumption of these products, around 5 t of germanium is annually added to the in-use and end-of-life stocks of products (which amount for 147 t of Ge). Around 8 t in germanium content are exported in products for reuse and around 10 t of Ge are sent for waste management.

About 7 t of the germanium contained in the waste are sent to landfill, whereas 2 t are dissipated through non-functional recycling and 1 t is effectively recycled. Secondary material produced from this post-consumer functional recycling is sent to the manufacture step. The stock accumulated in landfill in the EU over the last 20 years is estimated around 440 t of Ge (calculation based on total waste generated from processing until recycling step).

Value chain distinguishing steps occurring or not within the EU

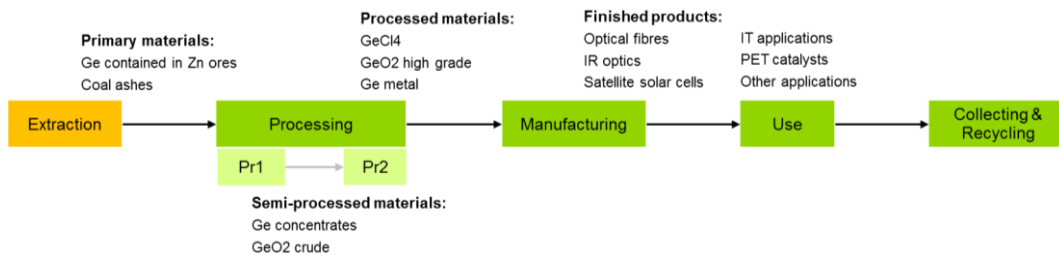


Figure 46: Value chain of germanium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

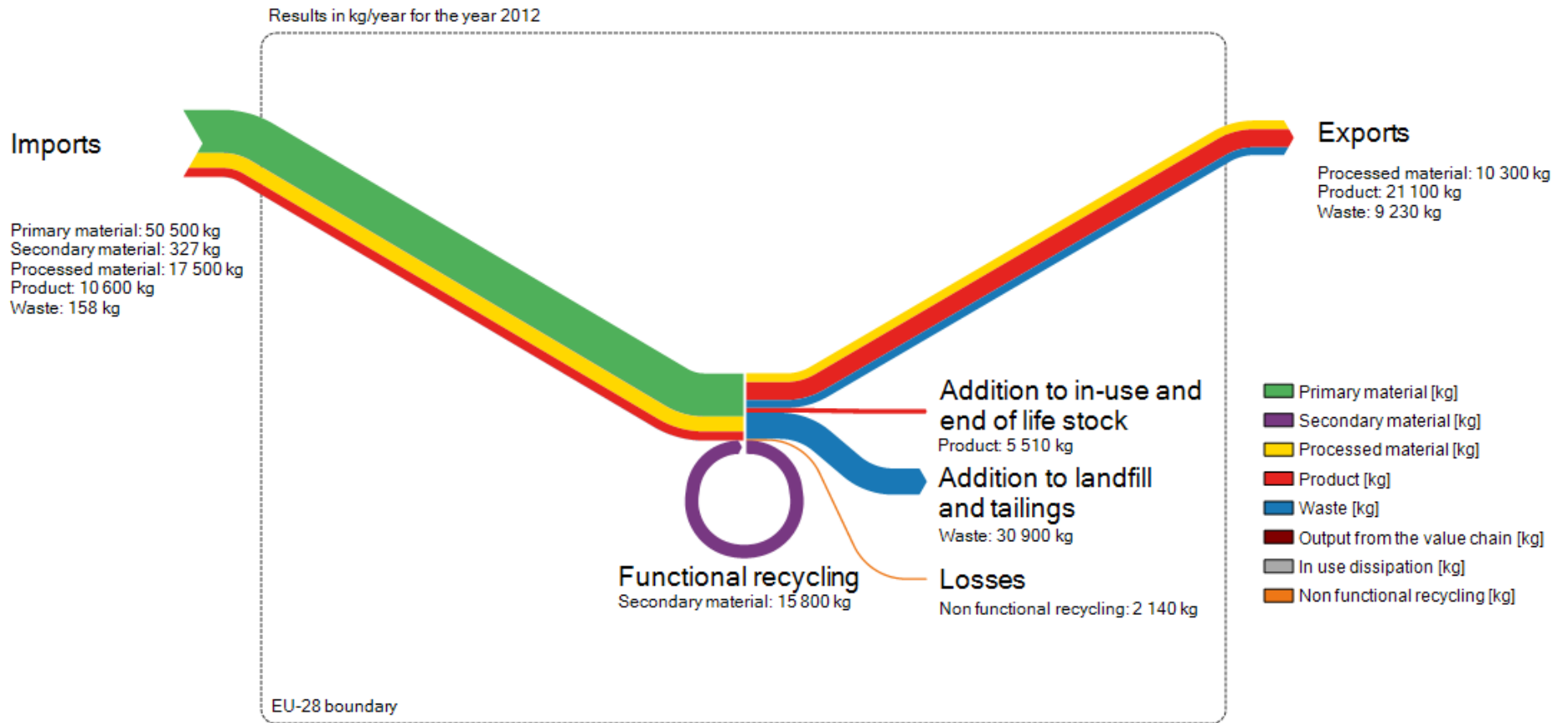
The main sources of data for the development of this MSA are experts from OMG Finland, Indium Corporation and Zinc & Lead Study Group, who provided data for exploration, processing and manufacturing steps, as well as data on generation of waste. BRGM and USGS reports, the RPA study and the European study on the List of Critical Raw Materials were also used and provided data on exploration and extraction steps. Hence, the results of the MSA can be considered as a quite robust for the upstream steps.

From the manufacturing to the recycling steps, the flows are calculated conservatively based on the input flows of respective processed materials and shares of uses given by BRGM (adapted for the EU).

Based on this data, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows in the manufacturing, use, collecting and recycling steps. This exercise requires a number of other data sources to characterize each of the different uses and their representative products (e.g. ratio between exports/imports and production sold in the EU of various finished products provided by Eurostat databases for example, data on lifespan, annual growth of use in each sector, collection rate of end-of-life products, recycling efficiency). In order to fill some data gaps, other hypotheses are made, particularly for finished products at end of life kept by users. For these reasons, the level of reliability of results for the steps use, collecting and recycling is lower than for the upstream steps.

Sankey diagram for germanium

Figure 47: Simplified Sankey diagram for germanium



3.3.11 Indium

Value Chain

Indium occurs mainly at low concentrations in zinc ores, although small amounts also occur with copper and lead ores. There are many zinc refineries globally, but only about 25% are capable of extracting indium; one of these is in the EU, in France. In refineries that cannot recover indium from zinc ores, indium is lost as waste and as an impurity in zinc metal. Several EU manufacturers have refineries that recover small amounts of indium from secondary materials.

Zinc refineries produce indium metal as a by-product. Indium is used to make a variety of chemicals and alloys, but the largest use globally is the manufacture of indium tin oxide (ITO), which is used to manufacture displays, mainly in Asia. The ITO coating process uses a relatively small proportion of the input ITO material; the rest is collected and functionally recycled.

Indium metal is used in the EU to make alkaline batteries, architectural and automotive glass with ITO coatings, thin-film photovoltaics, solders and other alloys and for research. Most uses of indium are in electrical and electronic equipment as displays, semiconductors (e.g. light emitting diodes), solders, etc. Electrical equipment is manufactured in the EU mainly using imported components. At end of life, electrical equipment is either non-functionally recycled, exported or disposed of in the EU.

The figure below presents the value chain of indium with the main uses.

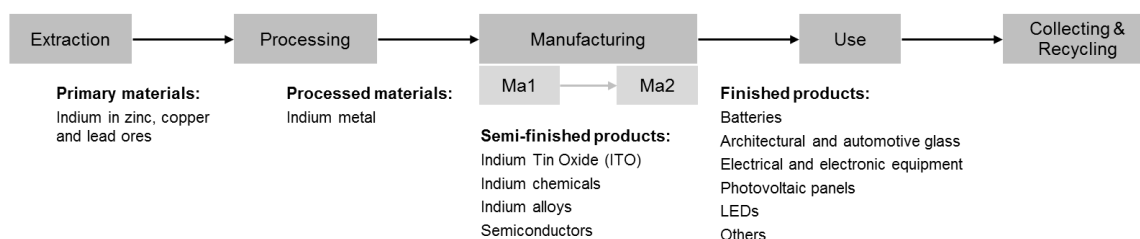


Figure 48: Value chain of indium

Description of the main flows and stocks

Flows and stocks are accounted in mass of indium (In) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

There are no known reserves of indium in the EU but it does occur in zinc ores which are mined in the EU. Estimates of world reserves vary and range from 18,800 to 50,000 t in indium content. World annual production varies annually and is quoted by different sources to be from around 550 t to 800 t of primary indium and about 800 t to 1000 t of secondary indium is also produced, mainly from ITO recycling.

Indium is produced globally from zinc (the main source), lead and copper ores and indium can be recovered in the EU from zinc, lead and copper refinery by-products. Zinc ores are mined in the EU; only one zinc refinery in the EU is capable of recovery of indium as metal, with around 45 t in indium content produced. Most of indium metal is sold on the EU market (32 t) rather than exported (less than 13 t in indium content). Imports of processed material in the EU represent more than 21 t. The EU consumption of indium metal is estimated to be about 54 t.

Trade of indium in semi-finished products between the EU and the rest of the world are important, with exports of 33 t (mainly as chemicals) and imports of 40 t in indium content (mainly as electronic compounds). The European industry uses those semi-finished products and materials to manufacture various finished products (see Figure 19: – left) which are either sold in the EU market (about 38 t) or exported (about 52 t in indium content).

Imports of finished products amount to 81 t per year of indium content; the proportions of indium in products used in the EU are shown in Figure 19: f– right.

The use of indium, particularly in electronics, has grown considerably in recent years. The amount going into stock (59 t of indium in products in use) is similar to the amount reaching end of life (60 t in

indium content). The use of indium in photovoltaics and in architectural glass started fairly recently; there is no such product at end of life due to their long lifetime.

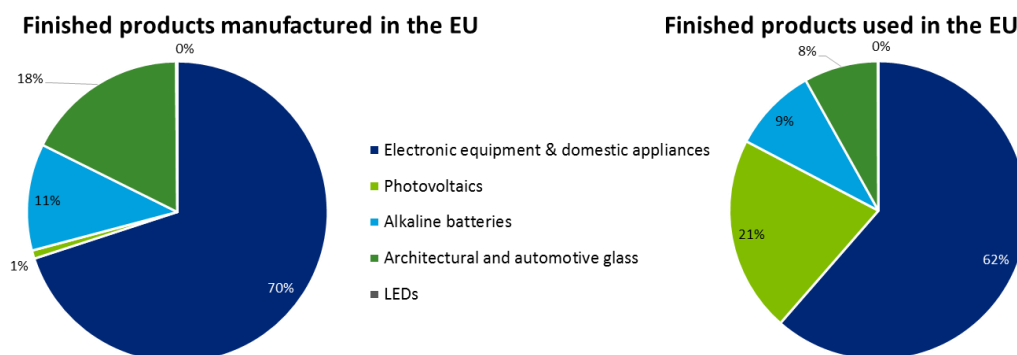


Figure 49: Shares of finished products containing indium manufactured in the EU and shares of finished products containing indium used in the EU (taking into account exports and imports of products)

The indium contained in waste is mostly non-functionally recycled. There is very little post-consumer functional recycling of indium globally and so most is lost. The annual addition to stock in landfill is estimated at around 56 t (calculation based on waste generated from processing to recycling step, extraction tailings excluded).

Value chain distinguishing steps occurring or not within the EU

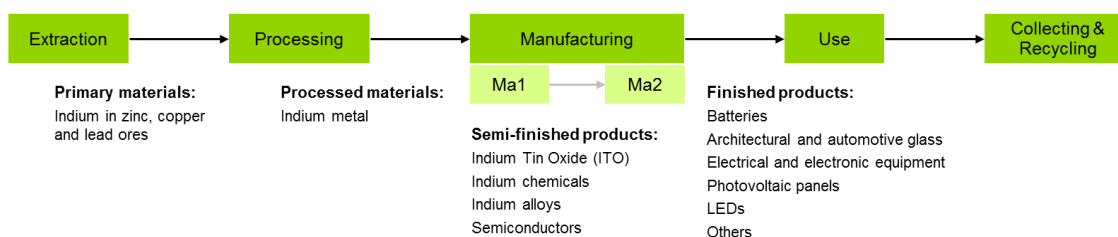


Figure 50: Value chain of indium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

Many published data sources are used for this MSA as most manufacturers and trade associations were unable to provide data.

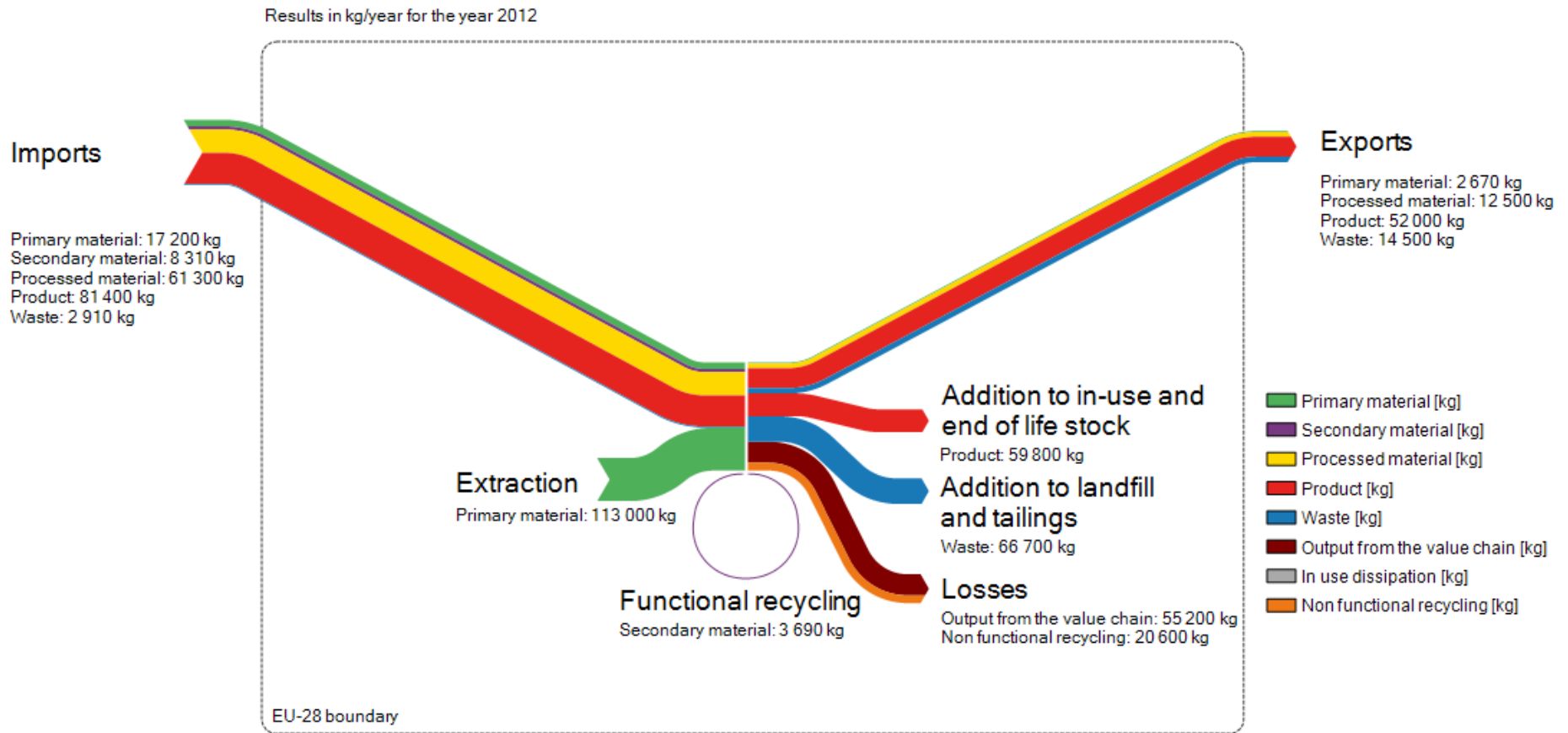
Most primary indium is produced as a by-product of zinc mining and refining. However, the indium content of zinc ores mined in the EU or the zinc ores imported into the EU are not published. Therefore, to determine the flows of indium in ores and from refineries, it has been necessary to calculate an average global indium content of zinc ores. Moreover, indium is also recovered from secondary sources, in particular from ITO coating production: no reliable data on secondary indium production in the EU could be found and so the MSA uses estimates from using relatively old data from the USGS.

The Eurostat database provides the quantities of indium metal imported and exported and Nyrstar publish the amount of metal they produce in their French refinery. This gives an indication of indium metal consumption in the EU, but there is very little data available on how it is used. It is therefore assumed that indium metal consumed in the EU is used to make a variety of alloys and chemicals. However the Eurostat database does not include data for these materials.

Reliable data for the global uses of indium are available, but not specifically for the EU. Globally, most indium is used in components and materials used to manufacture electrical equipment and most of these components, such as displays are produced outside the EU. Eurostat data on electrical products and for waste has been used to determine the flow of indium in these materials and products. However it has been necessary to estimate an average indium concentration based on the amount of indium used annually in electrical equipment globally and the total quantity of equipment produced.

Sankey diagram for Indium

Figure 51: Simplified Sankey diagram for indium



3.3.12 Lithium

Value chain

Lithium is obtained from mineral ores and brines and is concentrated after extraction. Lithium concentrate can be directly used in manufacture industries without further processing or can be processed to produce lithium carbonates, oxides, hydroxides, bromides, chlorides, butyllithium and lithium metal.

These materials are used to manufacture various finished products such as batteries (and products including batteries), glass, ceramics, products made of aluminium alloys, lubricating greases, electronic components and pharmaceutical products. Lithium is also used in the manufacturing industry for the production of metals (aluminium smelting, steel casting), polymers (synthetic rubbers, plastics) and cements without being incorporated into the finished products.

The figure below presents the value chain of lithium and its main uses.

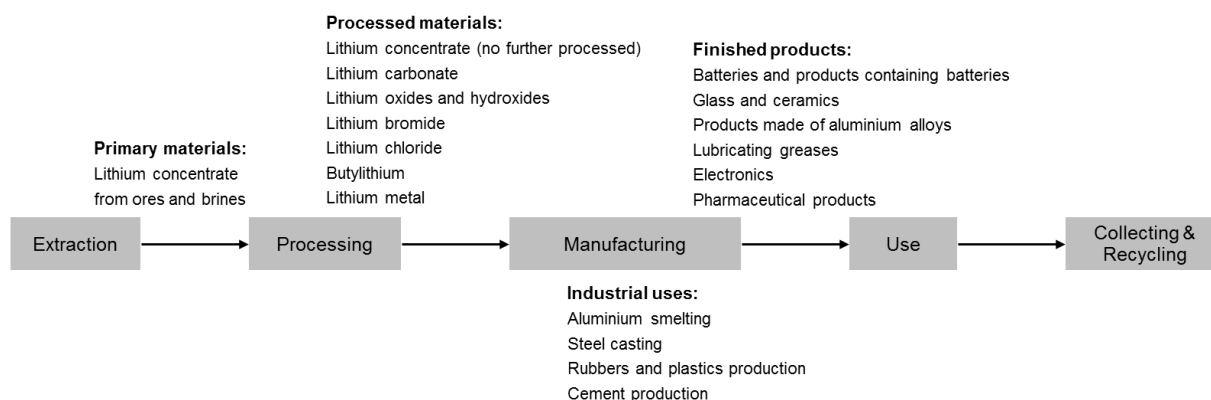


Figure 52: Value chain of lithium

Description of the main flows and stocks

Flows and stocks are accounted in mass of Lithium Carbonate Equivalents (LCE, unit used in the lithium industry) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

World reserves of lithium are estimated around 69 Mt of LCE, with around 10,000 t in the EU. The world annual production of lithium concentrate is around 197,000 t of LCE and the main producers are Chile, China, Australia and Argentina.

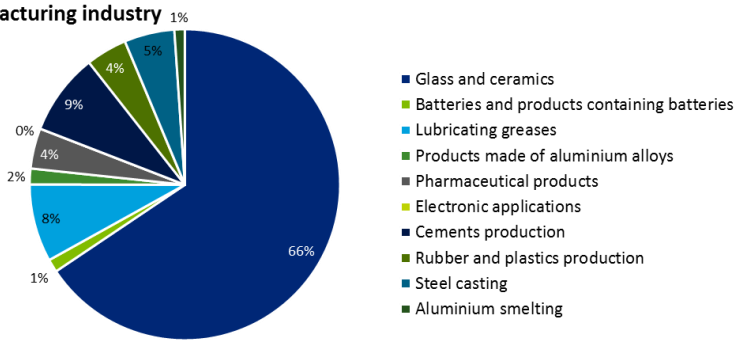
In the EU, 1,900 t of LCE are produced from ore (lepidolite), mainly in Portugal. This domestic production of primary material is directly used in glass and ceramics industries in the EU. Imports of primary materials and processed materials amount around 21,000 t of LCE. These imports are mainly in the form of lithium concentrate, lithium carbonate and lithium oxides and hydroxides.

With these materials either produced or imported in the EU (total consumption around 23,000 t of LCE), the European industry manufactures various finished products containing around 18,000 t of LCE and consisting mainly of glass and ceramics. These products are mostly sold in the European market (around 15,000 t of LCE sold in the EU compared to 4,600 t of LCE exported).

The important amount of waste generated at the manufacture step is due to the use of processed materials containing lithium for several industrial uses (production of aluminium and steel, rubbers and plastics and cements) (see Figure 28 – left).

Imports of finished products amount around 8,400 t of LCE, which is more than half the LCE content in the domestic production of finished products sold in the EU. Batteries and products containing batteries represent almost 70% of these imports (in mass of LCE). The European final consumption of products containing lithium is around 23,800 t of LCE per year (see Figure 28-right).

Finished products manufactured in the EU and other uses of Li in the EU manufacturing industry



Finished products used in the EU

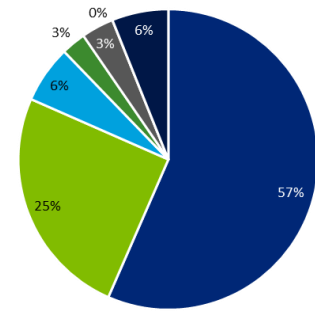


Figure 53: Shares of finished products containing lithium manufactured in the EU and other uses of lithium in the EU manufacturing industry (left) and shares of finished products containing lithium used in the EU (right)

Considering the estimated lifespan and the annual growth of consumption of the finished products containing lithium, the quantity annually added to stock is around 7,500 t of LCE. Around 500 t of LCE are exported in products for reuse and around 2,300 t of LCE per year are lost by dissipative use (lubricating greases and pharmaceutical products). About 12,800 t of LCE are collected for waste management.

Batteries, glass, products made of aluminium alloys and electronic appliances are recycled in significant proportion. However, there is no functional recycling of lithium, as the separation of lithium from these products is not possible or very costly. Therefore, lithium is either sent to disposal with other materials or recycled in a large magnitude material stream, which does not allow the recovery of lithium.

Value chain distinguishing steps occurring or not within the EU

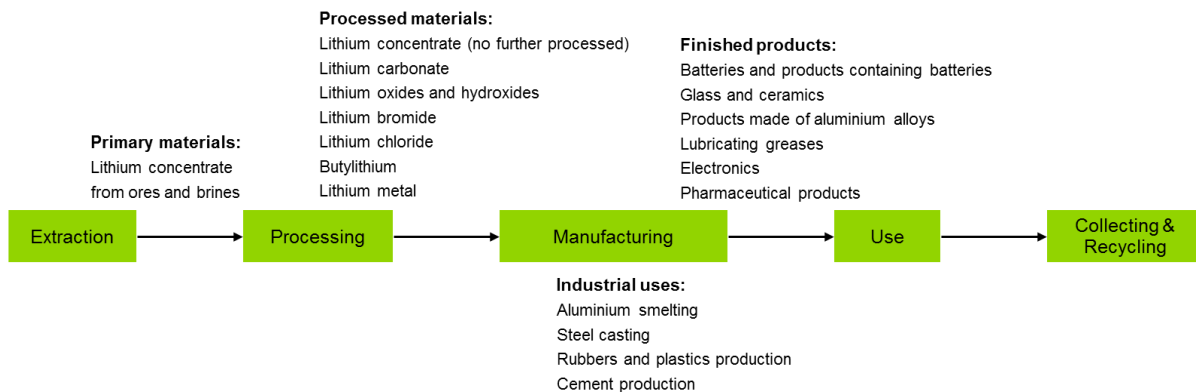


Figure 54: Value chain of lithium, steps in green occur in the EU, steps in orange occur only outside of the EU

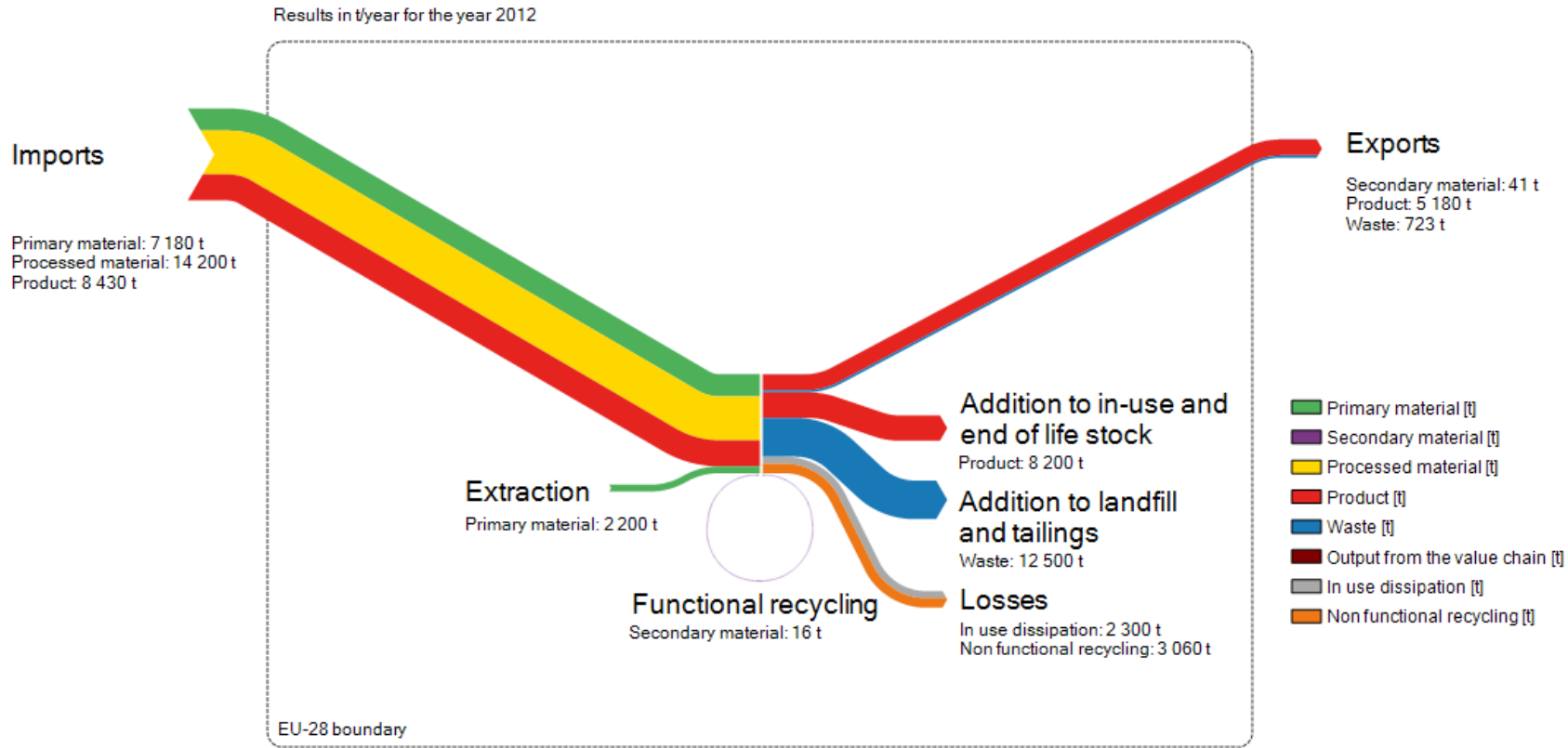
Data sources, assumptions and reliability of results

The main data sources for the development of the MSA of lithium are the BGS, the USGS, the BRGM and the Eurostat PRODCOM database. Some data on the consumption and imports of lithium in the European industry are provided by the companies Rockwood Lithium, SQM, and Umicore and by the association RECHARGE.

From the use step to the recycling step, the flows and stocks of lithium are highly estimative and calculated based on trade statistics of lithium-bearing products, average lifespan and average content of lithium in them. A number of hypothesis are taken regarding the fate of the products and their end of life. This approach and the lack of data lead to a low robustness of the results for the steps of use, collecting and recycling.

Sankey diagram for lithium

Figure 55: Simplified Sankey diagram for lithium



3.3.13 Magnesite

Value Chain

The MSA on magnesite focuses on natural magnesite only, therefore synthetic magnesia is not included in this study. Around 5% of the worldwide magnesia is produced from synthetic process from natural brines or seawater (mainly in Mexico, USA and Japan; EU countries are Ireland, Netherlands and France). The potential of synthetic magnesia is limited compared to natural magnesia due to high production costs.

After extraction of magnesite ($MgCO_3$), the naturally occurring carbonate of magnesium, the raw material is processed into various forms of magnesia – caustic calcined magnesia, dead-burned magnesia and fused magnesia.

Caustic calcined magnesia is used in agricultural and industrial (construction, steel, pharmaceutical, chemical) applications. These uses include feed supplement to cattle, fertilisers; electrical insulations, industrial fillers, in flue gas desulphurization, wastewater treatment and soil remediation agents; or as sorrel cement, in construction materials, etc. Dear-burned magnesia is used in various refractory applications, such as basic magnesia bricks, ladles, or in cement and glass making kilns. The main applications of fused magnesia are in refractory and electrical insulating markets.

Moreover, part of the magnesite in the value chain is associated to biological flows: magnesia is an essential plant nutrient and it is an abundant element in the animal and human body. However due to the lack of data, only part of this cycle is accounted for in the MSA (MgO content in animal faeces, manure and vegetal waste, food waste and common sludge).

The figure below presents the value chain of magnesite with the main uses.

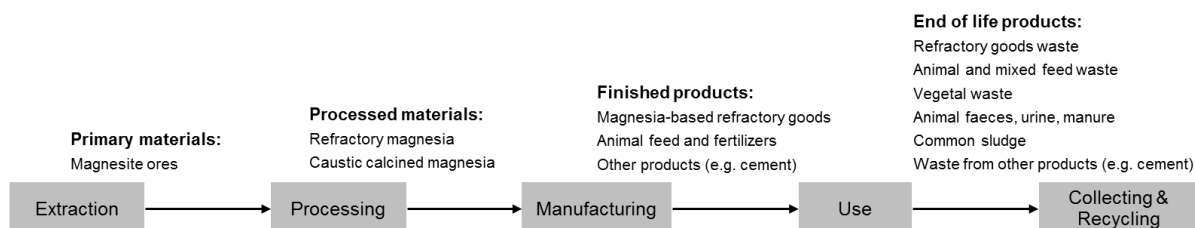


Figure 56: Value chain for magnesite

Description of the main flows and stocks

Flows and stocks are accounted in mass of magnesia (MgO) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

The natural resources of magnesia are virtually unlimited as several natural minerals can be used for its production. Reserves of magnesite in the EU amount to 662 Mt of MgO content (mainly in Slovakia, Austria, Greece, Spain, Poland), compared to 3,707 Mt worldwide (mostly China, Turkey and Russia).

More than 1,000 kt of MgO content are extracted in the EU as magnesite, accounting for 10% of the world extraction. Primary material is sold in the EU rather than exported (less than 7 kt exported from the EU). Besides its own extraction, the EU imports 12 kt of magnesia in magnesite each year. Stock of primary material in tailings accounts for almost 8,000 kt of MgO content and could be a remarkable source for future use.

The EU countries process more than 1,100 kt of MgO content as refractory (dead-burned and fused) and caustic calcined magnesia, among which 28% is exported from the EU. Imports of processed materials amount to 671 kt of MgO content.

The European industry uses these materials to manufacture several categories of finished products (see Figure 57 – left), which are sold in the European market (880 kt of MgO content) or exported for use outside of the EU (620 kt of MgO content). The largest portion (63%) in total production accounts for refractory goods. The total EU production of refractories is around 979 kt of MgO content, which highly exceeds the EU consumption of 619 kt: 620 kt are exported from the EU. In comparison,

imports of refractory goods account for 261 kt. Regarding animal feed and fertilisers, the total EU production (362 kt of MgO content) approximately covers consumption, with less than 2 kt imported.

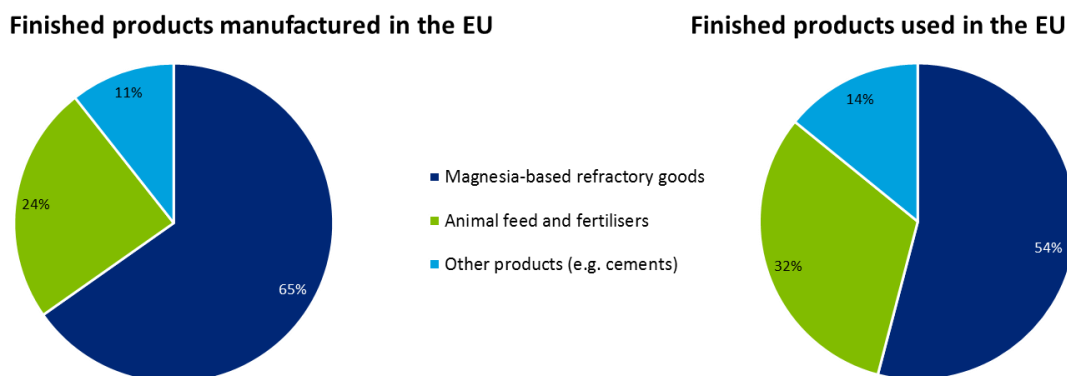


Figure 57: Shares of finished products containing magnesia manufactured in the EU and shares of finished products containing magnesia used in the EU (taking into account exports and imports of products)

Stock of the magnesite-containing products in the EU is mostly created by refractories (over 85% of the stock) and the category of other products. Considering the lifetime and the annual growth of consumption of finished products, the quantity annually added to stock is around two third of the quantity of MgO content placed on the European market (addition to in-use and end-of-life stocks around 573 kt a year, stock evaluated at around 15,000 kt). Around 253 kt is collected for waste management each year, and around 315 kt of MgO content is lost by dissipative use (mostly animal feed and fertilisers).

Magnesia contained in waste flows ends up in landfill or is recycled. Post-consumer functional recycling rate is around 14% (recycling of waste from animal feed and fertilisers), while non-functional recycling rate is around 37%, i.e. respectively 34 kt and 94 kt of MgO content. The stock accumulated in landfill over the last 20 years is estimated at around 1,800 kt of MgO content.

Value chain distinguishing steps occurring or not within the EU

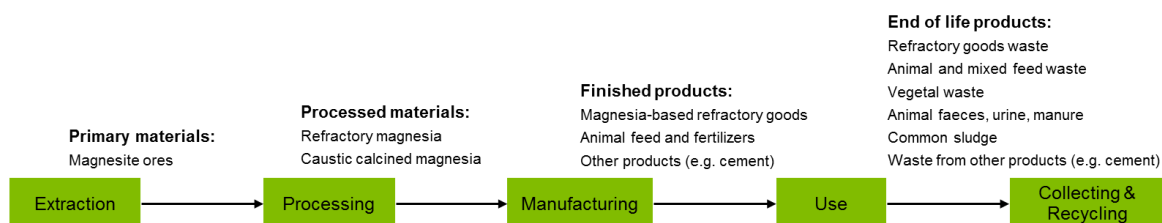


Figure 58: Value chain for magnesite, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The main source in the MSA of magnesite consists of the expertise gathered from Euromines experts, based on Roskill publication and their own data. Other sources include the Eurostat ComExt, Prodcom and waste databases, as well as the Ecoinvent database (for processing and manufacturing wastes). However please note that the Roskill report does not distinguish between the intra-EU and extra-EU trade flows for manufactured products, which explain the lower reliability of these flows when based on that source.

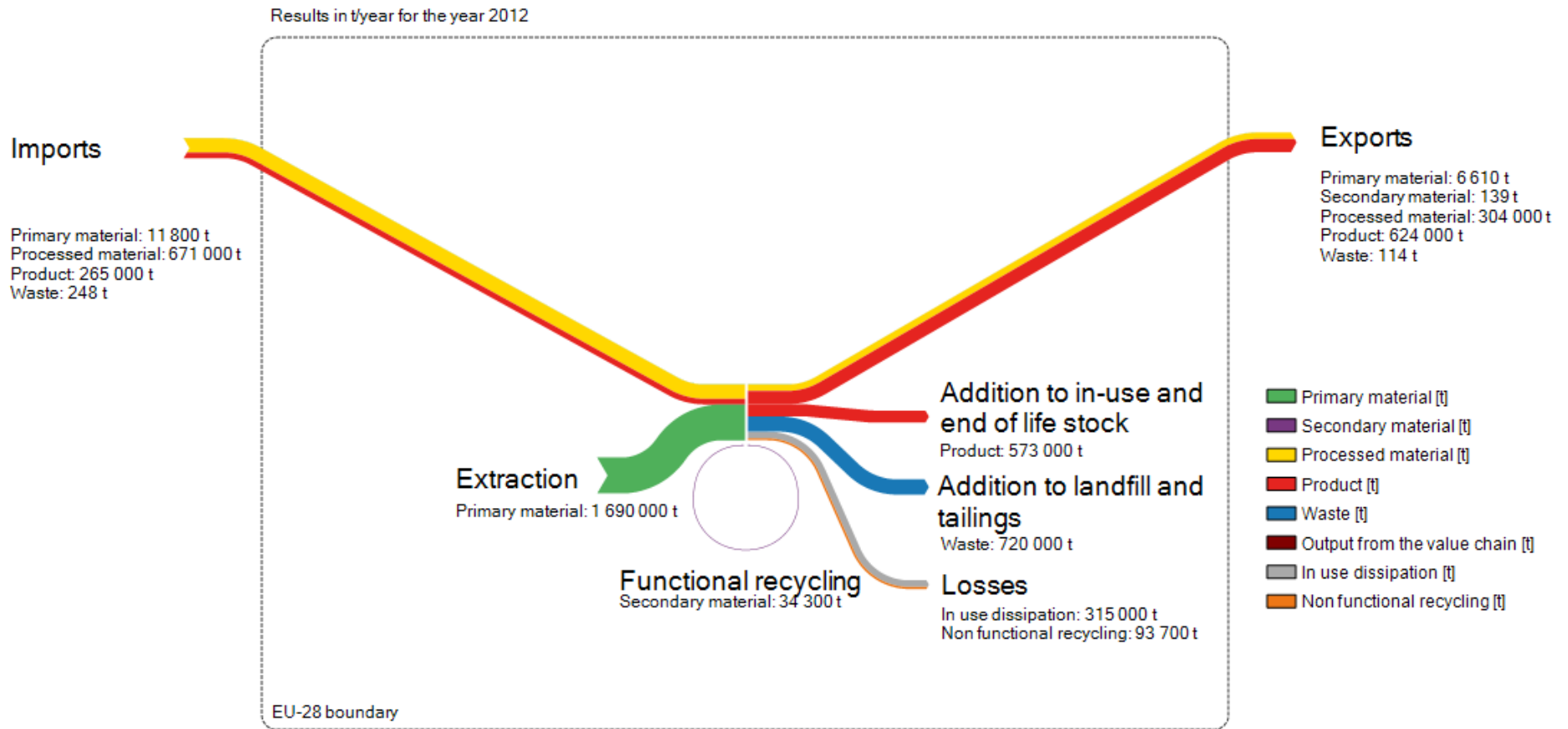
Overall data for exploration to processing phases can be considered reliable. In the manufacturing step, assumptions are made on the share of use of particular processed products for manufacturing of finished-products. Moreover, the category "other products" is used as a balancing product group in order to arrive at material balance in manufacturing step. The results are therefore subject to high uncertainties. In the use step, most of the indicators are calculated based on assumptions on lifespan, dissipation rate or the rate of particular products kept by users after end of life. The uncertainties are therefore increased in that step.

Regarding waste flows in the MSA, shares of recycled vs. disposed flows are provided by Euromines expertise or from the Eurostat waste database; a few hypothesis were made on magnesia-based refractory goods. Moreover, data is available in gross weight for the four categories of waste from animal feed and fertilisers (i.e. animal faeces, manure and vegetal waste, food waste and common sludge), thus estimations are made on the MgO content originating from anthropogenic sources. On the overall, uncertainties on parameters in the collecting step are similar to those in the use step.

Very little information was found on efficiency of recycling and share of functional/non-functional recycling. These factors are therefore estimated, leading to higher uncertainties in the recycling step.

Sankey diagram for Magnesite

Figure 59: Simplified Sankey diagram for magnesite



3.3.14 Magnesium

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.

The primary materials are processed into magnesium and then further processed into aluminium alloys and magnesium alloy for die-casting, the latter being finally processed into magnesium die-casting parts.

Aluminium alloys containing magnesium are used in a wide range of applications such as packaging, transport and construction. 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 is also an efficient desulphurizing agent used in the production of crude steel (but not incorporated in steel).

In addition, magnesium has a range of other metallurgical, chemical and electrochemical uses, although these all remain relatively minor sources of consumption.

The figure below presents the value chain of magnesium with the main uses.

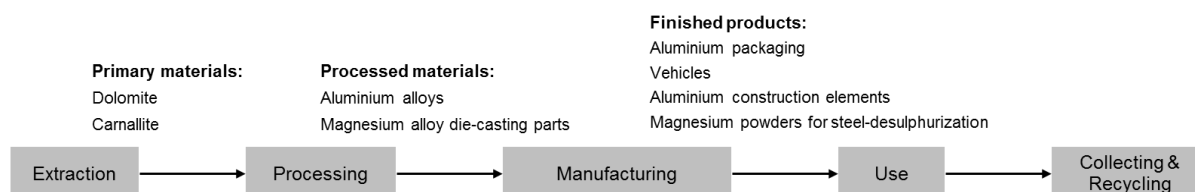


Figure 60: Value chain of magnesium

Description of the main flows and stocks

Flows and stocks are accounted in mass of magnesium (Mg) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

The reserves of primary material used for production of magnesium are sufficient to supply current and future requirements. Worldwide extraction of primary material is around 830 kt of Mg. The major producer of magnesium is China, which is responsible for about 85 % of worldwide magnesium production.

There is no primary production of magnesium in the EU, which is totally dependent on imports of semi-processed materials: imports of magnesium and magnesium alloys for die-casting represent respectively 63 kt and 48 kt in Mg content. This input is used to process aluminium alloys and magnesium alloy die-casting parts, which are sold on the EU market (124 kt of Mg content); exports from the EU are negligible.

The consumption of processed materials by the EU manufacturing industry is about 150 kt in magnesium content, among which 19 kt are imports (mostly aluminium alloys) and 7 kt of Mg are secondary material from post-consumer recycling. The main use of processed materials is in the automotive industry for the manufacture of cars and other vehicles (42 kt of Mg in production sold in the EU, 17 kt of Mg in exports and 3 kt of Mg in manufacturing waste). The second most common use of magnesium is the production of aluminium construction elements (42 kt of Mg sent to use in the EU, 9 kt of Mg exported and 6 kt of Mg converted to waste) followed by aluminium packaging (30 kt of Mg sent to use in the EU and 1 kt of Mg exported) (see Figure 61 – left).

In order to cover its requirements, the EU further imports around 38 kt of Mg in finished products at the use step: including mainly 21 kt of Mg in magnesium powders for steel-desulphurization, 9 kt of Mg in aluminium construction elements and 7 kt of magnesium in vehicles (see Figure 61 – right).



Figure 61: Shares of finished-products containing magnesium (Mg) manufactured in the EU and shares of finished-products containing magnesium (Mg) used in the EU (taking into account exports and imports of products)

The total in-use stock of magnesium yields 2,300 kt. The largest stock of magnesium is related to aluminium construction elements (1,400 kt) followed by vehicles (902 kt). Relatively small amount of magnesium is incorporated in packaging stock – about 31 kt.

The amount of magnesium in end of life products collected for treatment is about 128 kt, mostly in vehicles. Only a minor part of this amount is sent to recycling* (24 kt of Mg), about 6 kt of Mg for vehicles, 4 kt of Mg for aluminium packaging and 14 kt of Mg for aluminium construction elements.

Production of secondary material from functional recycling is around 19 kt of Mg. This material is sent partly to processing (12 kt) and partly to manufacture (7 kt). Around 2 kt of Mg are recycled with a large magnitude material stream (non-functional recycling). A negligible part of magnesium in secondary materials is exported.

The stock accumulated in landfill in the EU over the last 20 years is estimated around 2.8 million t of Mg, with an annual addition of 114 kt of Mg (calculation based on waste generated in steps processing to recycling).

Value chain distinguishing steps occurring or not within the EU

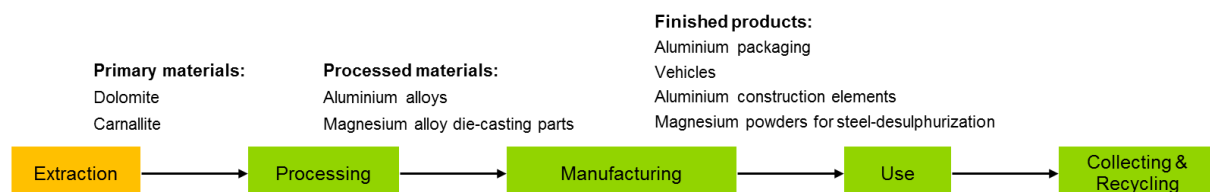


Figure 62: Value chain of magnesium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The main data sources used for magnesium include USGS, British Geological Survey, Eurostat Comext, Prodcum and waste databases, International Organization of Motor Vehicle Manufacturers and Ecoinvent database for calculation of processing and manufacturing waste flows. The suitability of Ecoinvent database for calculation of this figure should be further re-assessed. Further input presents the information from the International Magnesium Association who pointed out at public available market and process data.

Overall data for exploration to processing steps can be considered quite reliable. For the manufacture step, it was necessary to estimate some coefficients such as the average content of magnesium in cars. Such coefficients have been partly calculated in order to reach mass balance and the results are thus subjects to high uncertainties. For the use step, most of the parameters are calculated with the use of equations developed within the project. This requires a lot of assumptions to be made on

lifespan, dissipation rate or rate of particular products kept by users after end of life. Due to this fact, the parameters relating to the use step are subjects to even higher uncertainties.

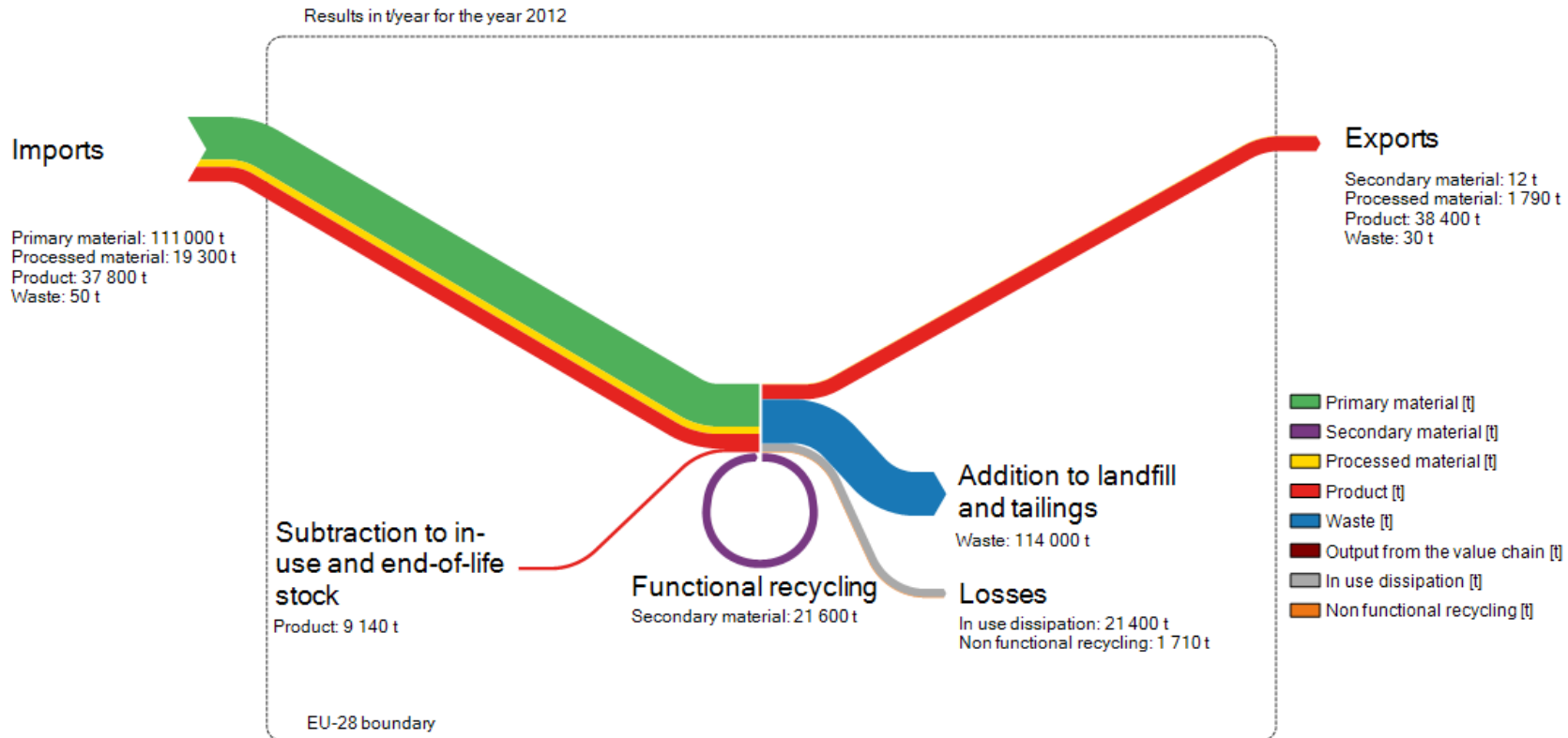
Eurostat waste statistics contains various data usable for collecting. Unfortunately, there are some discrepancies between amounts of end-of-life products collected for treatment calculated within the project and the Eurostat waste treatment data. It was assumed that Eurostat data on recycling are more precise than data on disposal which were amended in order to keep the material balance. It, however, results in some quite high figures for disposal of materials – e.g. for magnesium in aluminium packaging only about 12 % of magnesium goes to recycling while the rest goes to disposal. These figures have to be considered very uncertain and might indicate that not all packaging at end-of-life is a subject to official collecting systems, but significant part also goes to unofficial black dumping.

Very little information was found on efficiency of recycling and share of functional/non-functional recycling. Therefore, it results in very high uncertainties at the recycling step.

* The International Magnesium Association (IMA) published a 2-page Status report “Magnesium Metal in a Circular Economy” on 18 August 2015. It emphasizes that recycling in all phases of the life cycle is the dominant element of a Circular Economy. According to this report, magnesium enjoys very high recycling rates as part of aluminium alloys (> 90% end-of-life recycling rate for the automotive and construction sectors, and > 60% recycling rate for aluminium packaging); recycling is also significant for magnesium alloy die-casting products. The only Mg application without a recycling loop is iron desulphurization. These new data could not be used for the MSA on magnesium presented above as this was already finalised at the time of publication of the IMA report. It can be assumed that the parameters in the recycling step would be significantly impacted by these changes, with higher values on production of secondary material. These new data should therefore be checked and employed in the future upgrades of the study.

Sankey diagram for magnesium

Figure 63: Simplified Sankey diagram for magnesium



Nota bene: Due to negative annual rate of consumption of some products containing magnesium, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow "Subtraction to in-use and end-of-life stock" in the Sankey diagram, which is an input from the EU market to the EU waste management.

3.3.15 Natural graphite

Value Chain

Three different types of natural graphite ores are mined which require different processing: crystalline (or flake) graphite, microcrystalline (or amorphous) graphite and vein (or lump) graphite. First processing generally involves mechanical separation and flotation which is done in close vicinity of the mine. Further processing required for higher quality products includes milling, spheroidisation and purification (while the last two steps are only required for anode materials, for expanded graphite and nuclear applications).

The main uses of natural graphite as finished products comprise refractory materials, anode materials for Li-ion cells and primary batteries, friction materials and lubricants. Other uses include products based on expanded graphite (gasket / sealing applications, thermal management), as well as applications in nuclear sectors (pebble bed reactors). The figure below presents the value chain of natural graphite with the main uses.

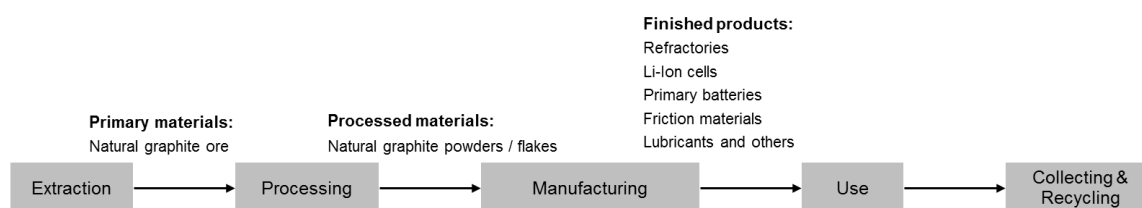


Figure 64: Value chain of natural graphite

Description of the main flows and stocks

Flows and stocks of natural graphite are accounted in mass of carbon (C) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Worldwide reserves of natural graphite are estimated as 110,000 kt of C content, whereas the EU reserves are assumed to be around 30 kt. World annual production is around 1,200 kt, mainly from China, India, and Brazil. There are no imports of natural graphite ores into the EU since the first processing steps of mechanical separation and flotation only take place near by the mines. Three active mines exist in the EU, namely in Kaisersberg (Austria), Kropfmühl (Germany) and in Woxna (Sweden), for a European total production of about 0.3 kt in 2012 (there are no exports of natural graphite ores).

The EU industry is highly dependent on imports of pre-processed and processed natural graphite (powders or flakes) which amount to 80 kt per year. The European industry uses processed natural graphite to manufacture various finished products (see Figure 19: – left). Most of the finished products are sold on the EU market (about 52 kt of C content) rather than exported (about 16 kt of C content). The share of exports among total EU production is higher for refractories (30% exported, 70% sold in the EU) than for other finished products.

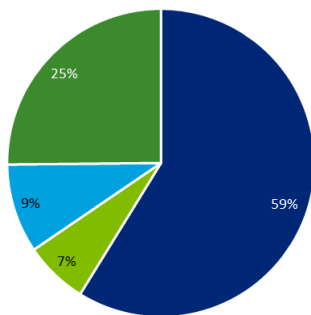
Up to 12% of the input material can be lost during the entire processing and manufacturing route (depending on the product). Part of the waste generated is directly reprocessed on site, however most of the natural graphite contained in waste is sent for disposal. Please note that some countries have bans on landfilling wastes with well-defined calorific values, e.g. in Germany.

Imports of finished products in the EU amount 21 kt per year of graphite content, highly dominated (65 %) by Li-ion accumulators imported both as single cells and as parts of electric vehicles and portable electronic devices. These imports represent 75% of the total consumption of Li-ion cells in the EU (see Figure 19: – right). The total EU consumption of finished products containing natural graphite is about 73 kt of C content.

Considering the lifetime of the finished products containing natural graphite and the annual growth of consumption of these products, about 10 % of the quantity of natural graphite put on the European market is annually added to the in-use stock of natural graphite (addition to stock around 7.7 kt per year, stock of around 120 kt). Half of the natural graphite put on the EU market is sent to waste

management after its use in end-of-life products, the rest is dissipated in use (lubricants, friction materials, and to some extent refractories).

Finished products manufactured in the EU



Finished products used in the EU

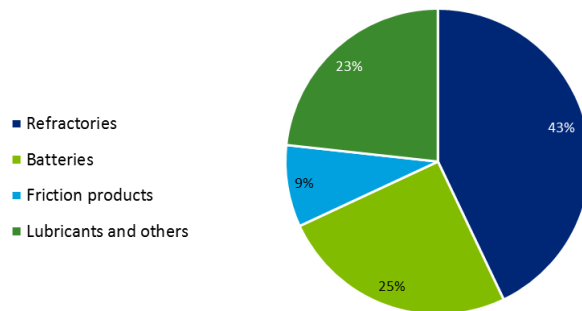


Figure 65: Shares of finished products containing natural graphite manufactured in the EU and shares of finished products containing natural graphite used in the EU (taking into account exports and imports of products)

Most of the natural graphite contained in the end-of-life products ends up in landfill, either as hazardous waste (due to contamination during use) or in standard landfill. The stock accumulated in landfill over the last 20 years is estimated around 620 kt (calculation based on waste generated from processing to recycling step, extraction tailings excluded), with annual addition about 42 kt of C content.

Due to technical and economic reasons, only a small proportion (10% in average) of these fractions is currently recycled. Functional recycling only exist for refractory material, which is applied on small scale only. Moreover natural graphite is oxidized to CO₂ during the recycling of batteries and accumulators. As there is no appropriate parameter in the MSA to describe such process (i.e. output from the value chain from recycling as CO₂ emissions), the project team chose to consider this flow as non-functional recycling.

Value chain distinguishing steps occurring or not within the EU

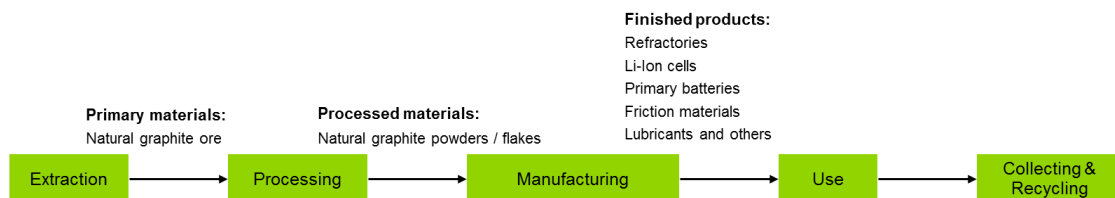


Figure 66: Value chain of natural graphite, steps in green occur in the EU, steps in orange only outside of the EU

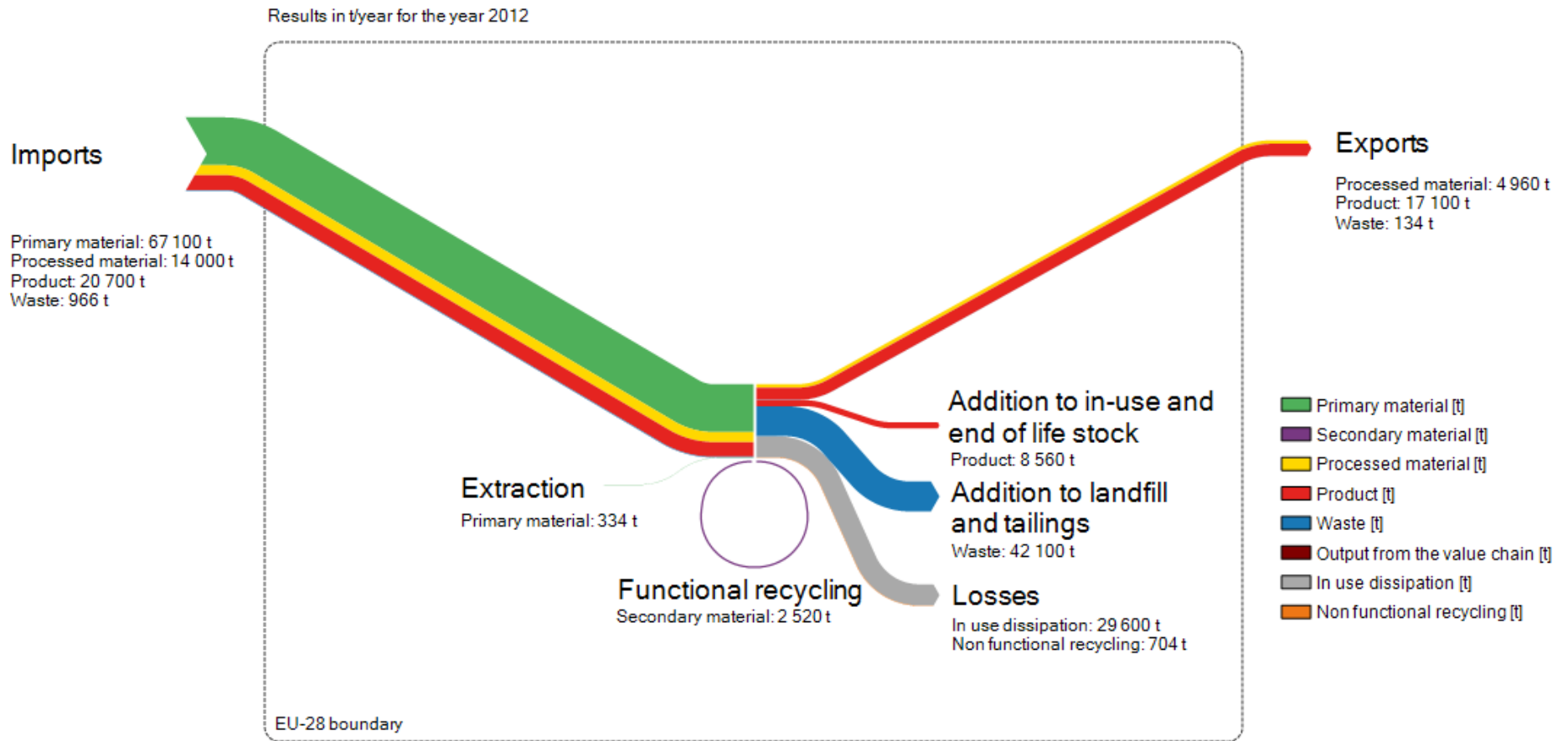
Data sources, assumptions and reliability of results

For the steps of exploration and extraction literature data from USGS, BRGM, and the Austrian Ministry of Science, Technology and Commerce is used. Concerning the steps of processing and manufacturing, the main data sources are the Eurostat databases (Prodcom and Comext, which provide information on the production and traded flows of raw materials and manufactured products); as well as experts and publications from industry and industry associations (e.g. ECGA, EUROMINES, RECHARGE, IMERYYS), who provided information on the details of processing and manufacturing steps, on the content of natural graphite in consumer products and on waste flows. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing and manufacturing.

For the steps use, collection and recycling, data is partially available on Eurostat database. However a number of other data sources is used to characterize each of the final applications and their representative products (e.g. data on lifespan, annual growth of use in each sector, collection rate of end-of-life products, recycling efficiency). Furthermore, several hypotheses are made on the dissipation in use and the shares of different waste treatments. For these reasons, the level of reliability of results for the steps use, collecting, and recycling is lower than for the previous steps.

Sankey diagram for natural graphite

Figure 67: Simplified Sankey diagram for natural graphite



3.3.16 Niobium

Value Chain

After extraction, niobium ore is processed into ferroniobium and niobium metal and some chemical compounds. Ferroniobium is used to make high strength low alloy steels and stainless steels and niobium metal & chemicals are used to make superalloys, superconductors and lithium niobate.

These semi-finished products are used in various applications such as vehicles, pipelines & construction (from HSLA and stainless steel), aircraft engines (from superalloys), MRI, electronic equipment, etc. The figure below presents the value chain of niobium with the main uses.

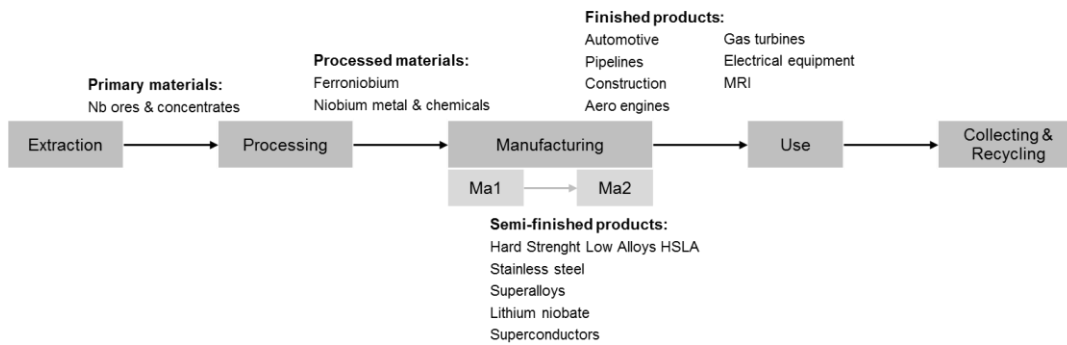


Figure 68: Value chain of niobium

Description of the main flows and stocks

Flows and stocks are accounted in mass of niobium (Nb) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of niobium take place outside of the EU. There are no reserves of niobium in the EU and consequently there is no extraction of niobium ore. World reserves are estimated as 1,413 kt of niobium content and the world annual production was around 59 kt, with more than 99% from Brazil and Canada.

All niobium ores & concentrates are processed by mining companies into ferroniobium, niobium metal or chemicals. Imports in the EU of such processed materials represent around 14 kt in niobium content. The European industry uses these materials to manufacture various finished products (see Figure 19: – left) which are either sold in the European market (about 8 kt in niobium content) or exported (about 4.4 kt). During the manufacturing step, some steel scrap containing niobium is produced which is non-functionally recycled with other types of steel in the EU (reprocessed) or exported. Superalloy scrap is also recycled but some of this is functionally recycled.

Imports of finished products in the EU amount to 1.4 kt of niobium content, which is much less than the niobium content in the domestic production sold in the EU. The proportions of niobium in finished products used in the EU are shown in Figure 19: – right.

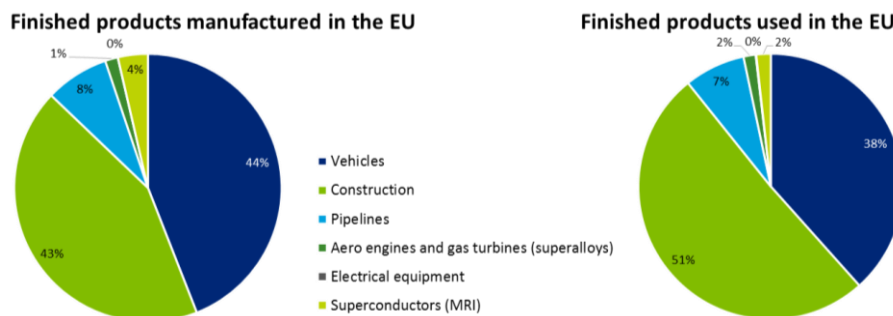


Figure 69: Shares of finished products containing niobium manufactured in the EU and shares of finished products containing niobium used in the EU (taking into account exports and imports of products)

The use of niobium in steels in particular has grown considerably in recent years, the amount going into stock (9.9 kt) is much more than reaching end of life (less than 1 kt). Those stock values have not been assessed by calculation based on growth rates but using expert data. Niobium steels used in construction are too new to yet have reached end of life and so the main niobium-containing products reaching end of life are vehicles and replaced turbine blades.

The niobium contained in the waste is mostly non-functionally recycled. There is very little post-consumer functional recycling of niobium globally and most is diluted into recycled steels. The annual addition to stock in landfill is estimated at around 0.2 kt.

Value chain distinguishing steps occurring or not within the EU

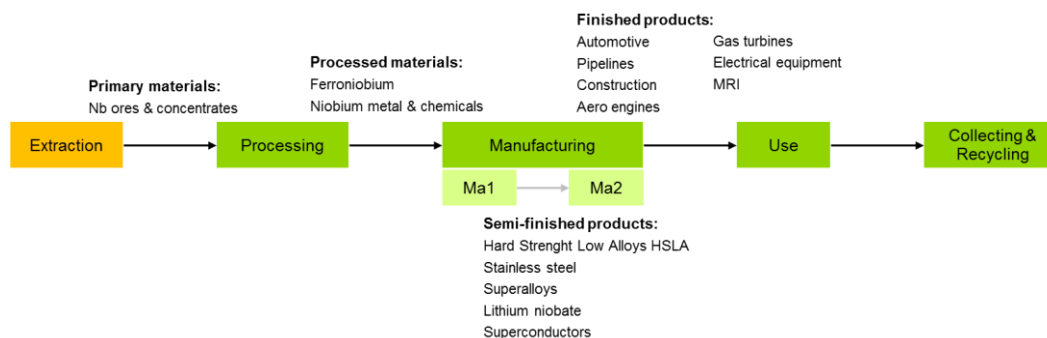


Figure 70: Value chain of niobium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

Many data sources were used for this MSA as most manufacturers and trade associations were unable to provide data. An industry expert reviewed the MSA data and provided useful comments and suggestions but also were not able to provide much data.

Most niobium is from three mines, two in Brazil and one in Canada. These companies publish production figures and data is also available from USGS. The companies that operate these mines process ores and produce refined materials, mainly ferroniobium, but also niobium metal and alloys and some compounds. Niobium is imported into the EU only as refined products. Eurostat includes data for imports and exports of ferroniobium but no other products.

The main uses of niobium in the EU are as steel alloys which are used for construction, vehicles, pipelines and a few other uses. Data on some of these is available from Eurostat, trade associations and the CRM report, but this data is incomplete and so many parameters had to be estimated using data from several sources. Due to the complexity of these calculations and the need to make assumptions, the accuracy of these values may not be very high.

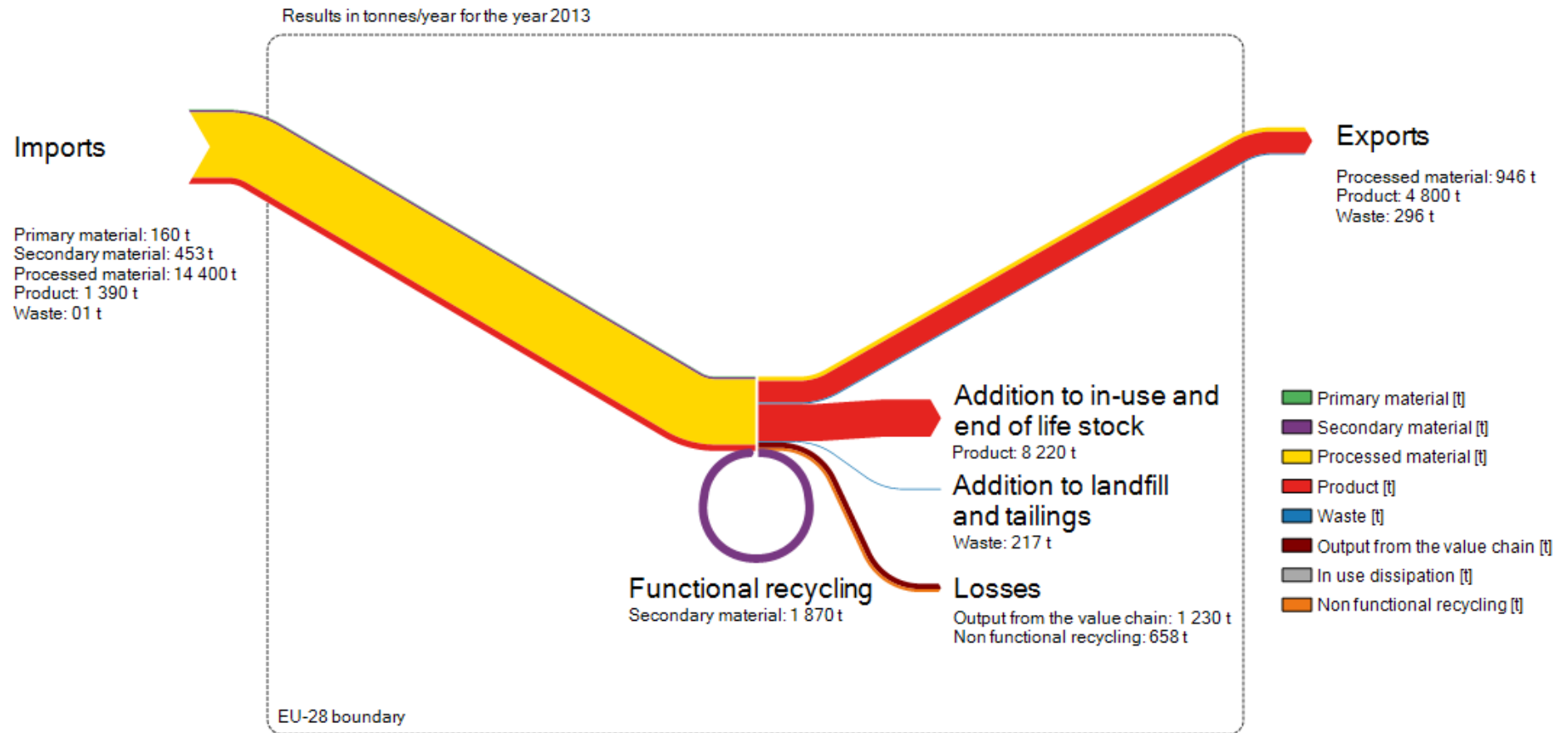
Flows of niobium in steel have been estimated using data on the quantity of ferroniobium used in the EU (90% of ferroniobium is used to make special steels) with Comext import and export data. Reliable and detailed data on the manufacture, import and export of vehicles is published so that accurate flow data can be determined. However, there is only limited and somewhat old data for pipelines. There was no data for the main use in construction and so this had to be assumed to be the difference between all special steels used in the EU less the material used for vehicles and pipelines.

Niobium alloys are also used to make superalloys which are used in aircraft engines and in gas turbines and industry experts were consulted to estimate values of these parameters. However, the total quantity of niobium used for these two applications is significantly smaller than estimates made in previous studies.

End of life is straightforward for vehicles as Eurostat data is available and appears to be reliable. The very long lifetimes of pipelines and buildings, bridges, etc. mean that niobium steels will not reach end of life for many years into the future and so there is no end of life to consider for these applications. Niobium steel scrap (from fabrication, vehicles, etc.) is always non-functionally recycled. The only functional recycling that occurs is of superalloy scrap which is remelted for re-use.

Sankey diagram for Niobium

Figure 71: Simplified Sankey diagram for niobium



3.3.17 Platinum Group Metals – Palladium

Value Chain

After extraction, palladium ores are concentrated, usually at the extraction site or nearby. The palladium ore concentrates are refined through various processes into highly purified powders of palladium metal. Unwrought palladium is then manufactured into a large variety of applications, such as automotive catalysts (to convert noxious car emissions into non-toxic products), chemical catalysts, electronic applications, as well as dental uses. Moreover, some uses of palladium are similar to those of gold, particularly in jewellery applications and investment (with an increasing worldwide demand for palladium ingots in the past decades).

The figure below presents the value chain of palladium and its main uses.

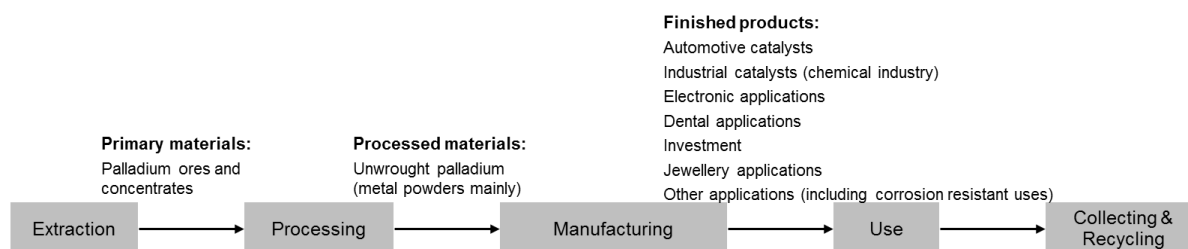


Figure 72: Value chain of palladium

Description of the main flows and stocks

Flows and stocks are accounted in mass of palladium (Pd) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Reserves and resources of palladium in the EU are unknown; although local data is available for some mining sites. Worldwide reserves are estimated at around 6,100 t of palladium, whereas worldwide resources reach 38,200 t of palladium.

Palladium extraction occurs in two countries in the EU: Finland and Poland, accounting for 0.4 t of palladium per year, i.e. less than 1% of worldwide extraction, which is over 200 t of palladium per year. Less than 0.1 t of palladium ores is not recovered in the concentration processes in the EU annually and therefore disposed in mine tailings. There are no exports of palladium ores and concentrates from the EU, and the EU refining industry is a large importer of palladium ores, with 62 t of palladium content imported in 2012. Trade of palladium between the EU and the rest of the world occurs in semi-finished forms as well: around 9 t of palladium were exported in 2012 and around 16 t of palladium were imported.

The use of palladium in the European industry to manufacture finished products is estimated at 64 t of palladium content. Automotive catalysts in diesel-powered vehicles represent 71% of the total palladium used in the EU. In comparison, palladium in jewellery and investment uses represent respectively 9% and 3% of the palladium consumed each year in the EU (see Figure 40 – left); however, stocks in use for these applications are very important since these products are accumulated for a long time.

Most of the finished products are sold in the EU market rather than exported, with production sold accounting for 40 t of palladium content. Palladium exported in finished products from the EU amounts for 24 t of palladium content, 77% of which in exports of automotive catalysts. In comparison, imports of finished products in the EU represent 15 t of palladium. The distribution of palladium consumption between finished applications in the EU are presented below in Figure 40 – right.

Considering the lifespan and annual growth of consumption of each final application, the quantity annually added to stocks is equivalent to 25 t of palladium content, with in-use stock and end-of-life stocks of 560 t of palladium content. In-use dissipation of palladium in finished-products is not negligible (over 4 t of palladium content), particularly for industrial catalysts as well as dental applications.

Recycling of palladium varies significantly among applications: automotive catalysts represent the main source of secondary material in the EU. Production of secondary material from post-consumer functional recycling in the EU is around 10 t of palladium, i.e. about 14% of the input palladium (as primary and secondary material) in processing. In comparison, around 9.8 t of palladium are estimated to be annually sent to landfill (calculated sum of total waste flows generated from processing until recycling, extraction tailings excluded).

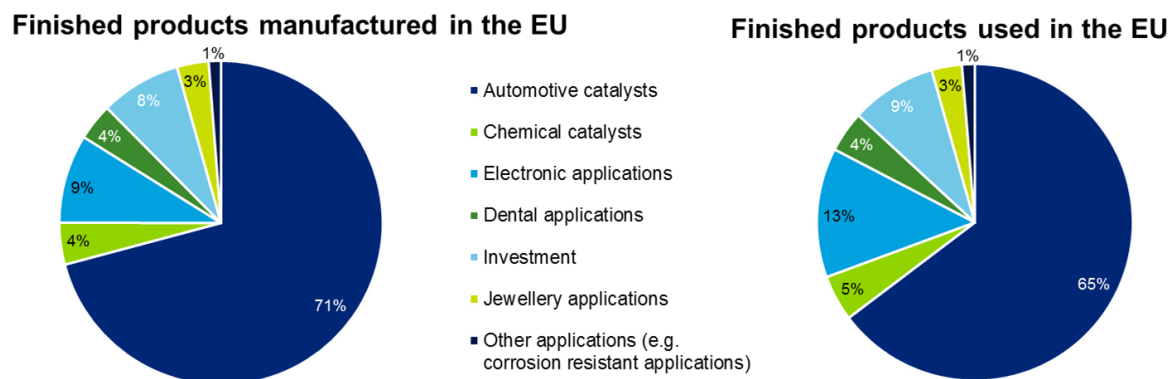


Figure 73: Shares of finished products containing palladium manufactured in the EU (left) and shares of finished products containing palladium used in the EU (right)

Value chain distinguishing steps occurring or not within the EU

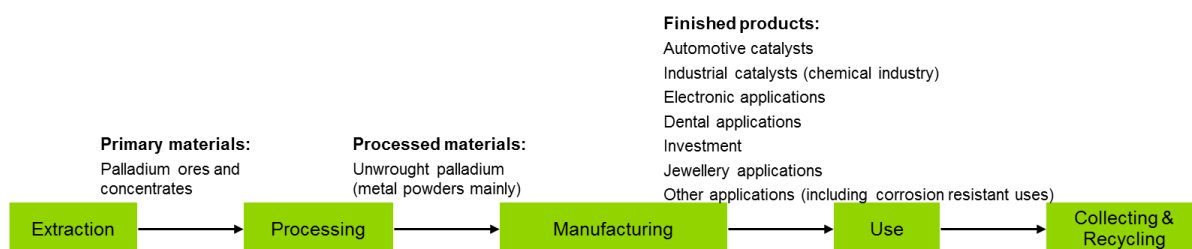


Figure 74: Value chain of palladium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The annual market reports on Platinum Group Metals issued by Johnson Matthey and the expertise of the International Platinum Group Metals Association (IPA) are the main source of data for the MSA of palladium. Johnson Matthey reports are in particular used for the analysis of the manufacturing step: total EU demand of palladium to manufacture finished products; distribution between these applications in EU; as well as recycling step: recycled volumes sent to processing and manufacturing. This reference was preferred over other sources of data such as the USGS, as it is considered as the most complete and reliable according to the experts consulted.

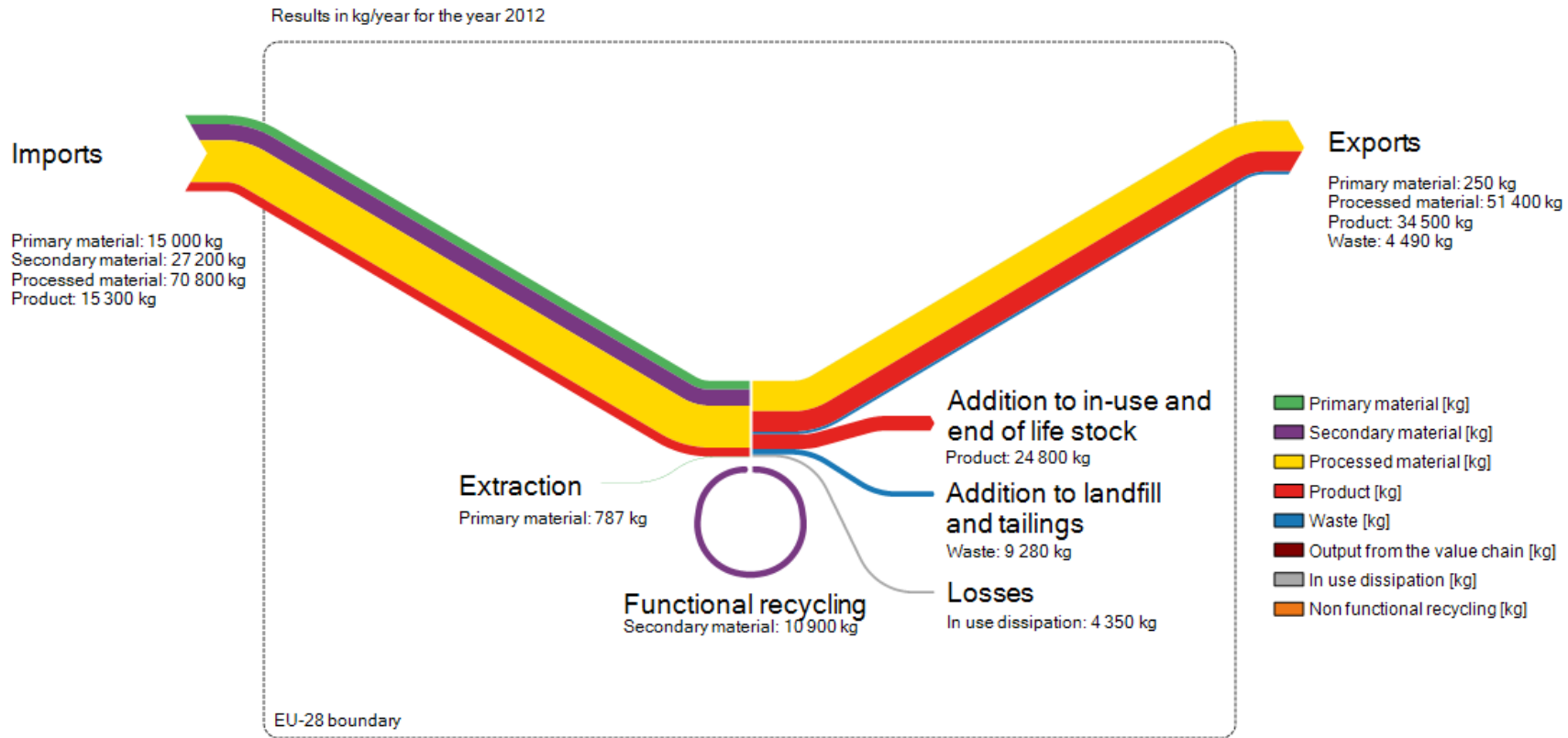
Among other data sources, the study BRGM (2014) is used for reserves and resources worldwide; the BGS World mineral production books provide country information on mining of palladium ores, for the EU as well as worldwide. The data quality score of the associated data is high.

The Eurostat Comext database is used to calculate the trade between the EU and the rest of the world of processed material and semi-finished products. The Eurostat Prodcom database is used to calculate the shares of exports among total EU production and the shares of imports among EU consumption, for representative products in various applications.

However, there is no data available on the production sold of processed materials, as well as the exports of finished products from the EU. These parameters are calculated using a number of assumptions, and therefore the associated quality score is lower. These uncertainties impact also on the reliability of the results in the collecting and recycling steps.

Sankey diagram for palladium

Figure 75: Simplified Sankey diagram for palladium



3.3.18 Platinum Group Metals – Platinum

Value Chain

After extraction, platinum ores are concentrated, usually at the extraction site or nearby. The platinum ore concentrates are refined through various processes into highly purified powders of platinum metal. Unwrought platinum is then manufactured into a large variety of applications, such as automotive catalysts (to convert noxious car emissions into non-toxic products), industrial catalysts (in chemical and petroleum industries), electronic applications, as well as medical uses. Moreover, some uses of platinum are similar to those of gold, particularly in jewellery applications (such as rings of platinum) and investment (with an increasing worldwide demand for platinum ingots in the past decades).

The figure below presents the value chain of platinum and its main uses.

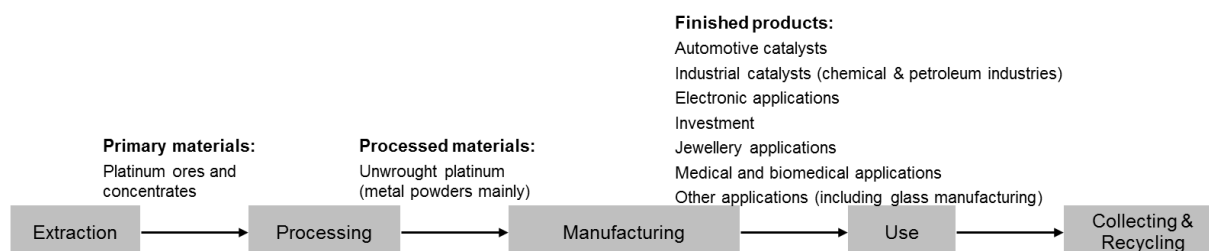


Figure 76: Value chain of platinum

Description of the main flows and stocks

Flows and stocks are accounted in mass of platinum (Pt) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Reserves and resources of platinum in the EU are unknown; although local data is available for some mining sites. Worldwide reserves are estimated at around 7,900 t of platinum, whereas worldwide resources reach 43,600 t of platinum.

Platinum extraction occurs in two countries in the EU: Finland and Poland, accounting for 0.46 t of platinum per year, i.e. less than 1% of worldwide extraction, which is about 180 t of platinum per year. About 0.1 t of platinum ores are not recovered in the concentration processes in the EU annually and therefore are disposed in mine tailings. There are no exports of platinum ores and concentrates from the EU, and the EU refining industry is a large importer of platinum ores, with 52 t of platinum content imported in 2012. Trade of platinum between the EU and the rest of the world occurs in semi-finished forms as well: around 10 t of platinum were exported in 2012 and around 18 t of platinum were imported.

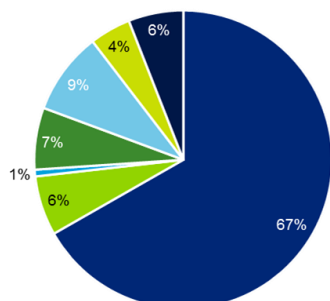
The use of platinum in the European industry to manufacture finished products is estimated at 63 t of platinum content. Automotive catalysts in diesel-powered vehicles represent 67% of the total platinum used in the EU. In comparison, platinum in glass manufacturing, jewellery and investment uses represent lower shares of the platinum consumed each year in the EU (see Figure 40 – left); however, stocks in use for these applications are important since these products are accumulated for a long time.

Most of the finished products are sold in the EU market rather than exported, with production sold accounting for 43 t of platinum content. Platinum exported in finished products from the EU amounts for 20 t of platinum content, 85% of which in exports of automotive catalysts. In comparison, imports of finished products in the EU represent 10 t of platinum. The distribution of platinum consumption between finished applications in the EU are presented below in Figure 40 – right.

Considering the lifespan and annual growth of consumption of each final application, the quantity annually added to stocks is equivalent to 12 t of platinum content, with in-use stock and end-of-life stocks of 710 t of platinum content. In-use dissipation of platinum in finished-products is not negligible (10 t of platinum content), particularly for industrial catalysts and medical applications.

Recycling of platinum varies significantly among applications: automotive catalysts represent the main source of secondary material in the EU. Production of secondary material from post-consumer functional recycling in the EU is around 14 t of platinum, i.e. about 20% of the input platinum (as primary and secondary material) in processing. In comparison, around 4.7 t of platinum are estimated to be annually sent to landfill (calculated sum of total waste flows generated from processing until recycling, extraction tailings excluded).

Finished products manufactured in the EU



Finished products used in the EU

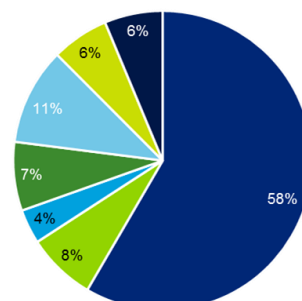


Figure 77: Shares of finished products containing platinum manufactured in the EU (left) and shares of finished products containing platinum used in the EU (right)

Value chain distinguishing steps occurring or not within the EU

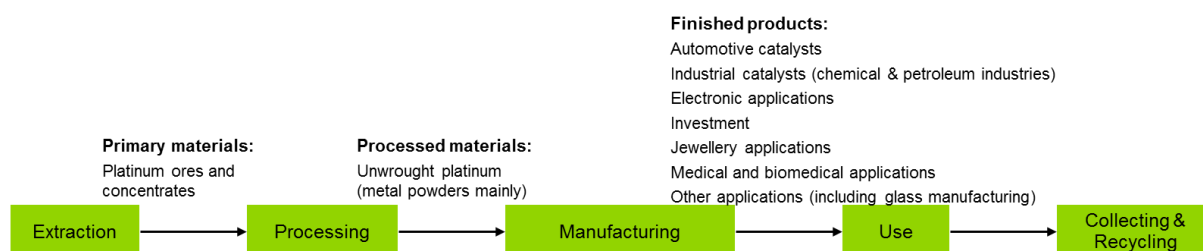


Figure 78: Value chain of platinum, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The annual market reports on Platinum Group Metals issued by Johnson Matthey and the expertise of the International Platinum Group Metals Association (IPA) are the main source of data for the MSA of platinum. Johnson Matthey reports are in particular used for the analysis of the manufacturing step: total EU demand of platinum to manufacture finished products; distribution between these applications in EU; as well as recycling step: recycled volumes sent to processing and manufacturing. This reference was preferred over other sources of data such as the USGS, as it is considered as the most complete and reliable according to the experts consulted.

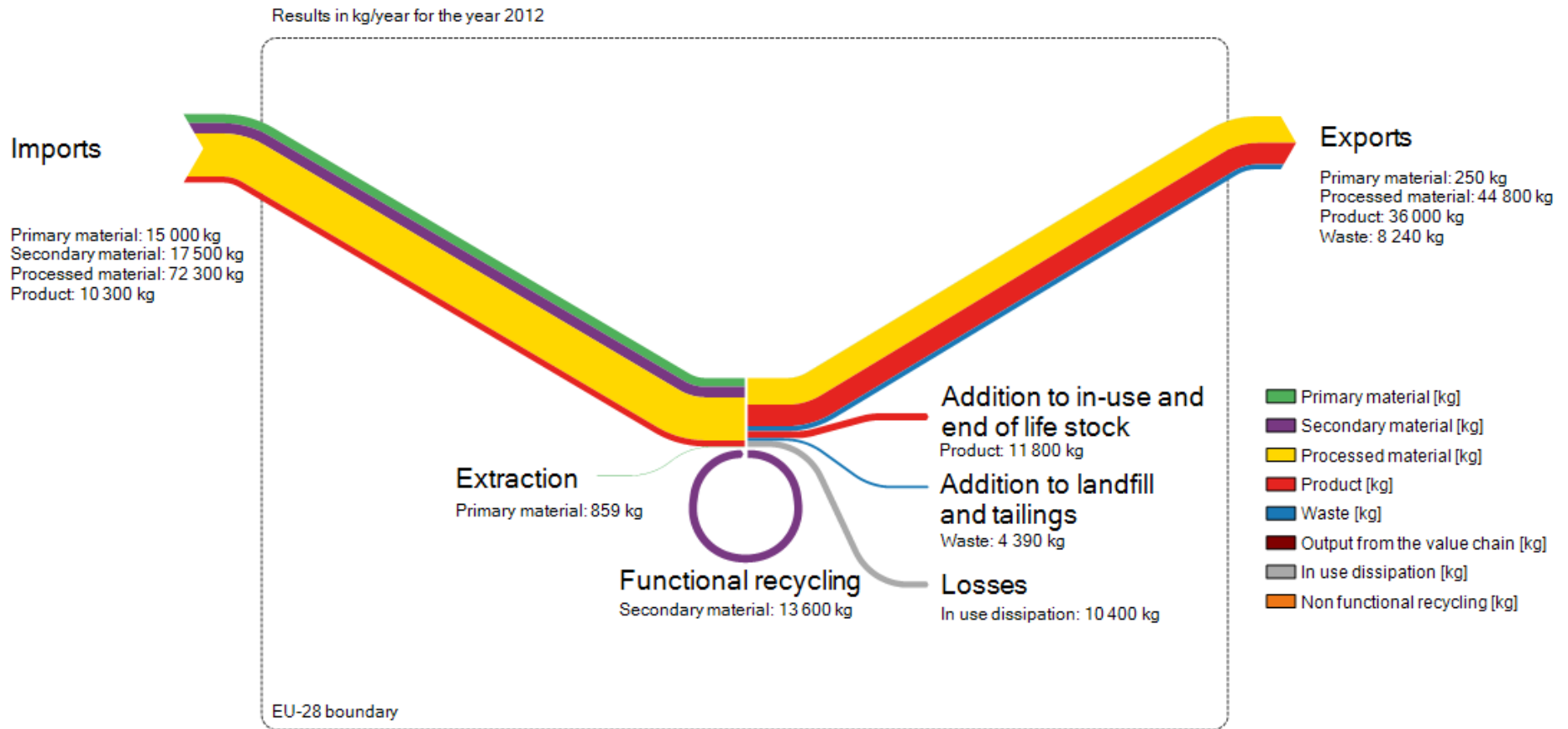
Among other data sources, the study BRGM (2014) is used for reserves and resources worldwide; the BGS World mineral production books provide country information on mining of platinum ores, for the EU as well as worldwide. The data quality score of the associated data is high.

The Eurostat Comext database is used to calculate the trade between the EU and the rest of the world of processed material and semi-finished products. The Eurostat Prodcom database is used to calculate the shares of exports among total EU production and the shares of imports among EU consumption, for representative products in various applications.

However, there is no data available on the production sold of processed materials, as well as the exports of finished products from the EU. These parameters are calculated using a number of assumptions, and therefore the associated quality score is lower. These uncertainties impact also on the reliability of the results in the collecting and recycling steps.

Sankey diagram for platinum

Figure 79: Simplified Sankey diagram for platinum



3.3.19 Platinum Group Metals – Rhodium

Value Chain

After extraction, rhodium ores are concentrated, usually at the extraction site or nearby. The rhodium ore concentrates are refined through various processes into highly purified powders of rhodium metal. Unwrought rhodium is then manufactured into a large variety of applications, such as automotive catalysts (to convert noxious car emissions into non-toxic products), chemical catalysts, and mechanical equipment in glass manufacturing, as well as electronic uses.

The figure below presents the value chain of rhodium and its main uses.

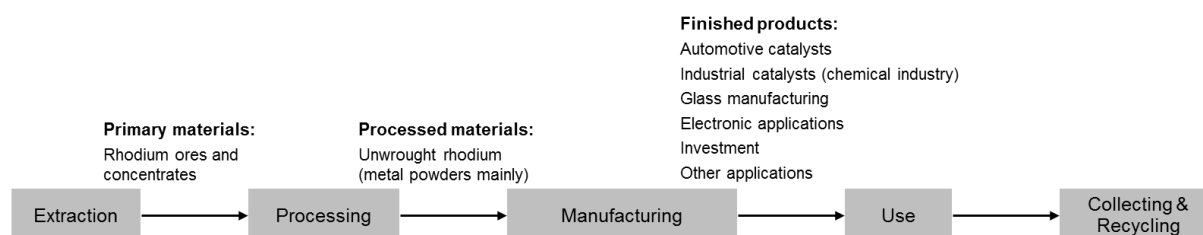


Figure 80: Value chain of rhodium

Description of the main flows and stocks

Flows and stocks are accounted in mass of rhodium (Rh) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Reserves and resources of rhodium in the EU are unknown; although local data is available for some mining sites. Worldwide reserves are estimated at around 580,000 kg of rhodium, whereas worldwide resources reach 4,500,000 kg of rhodium.

There is no extraction of rhodium in the EU; worldwide extraction is over 22,000 kg of rhodium per year. The EU refining industry is a large importer of rhodium ores, with almost 14,000 kg of rhodium content imported in 2012. Trade of rhodium between the EU and the rest of the world occurs in semi-finished forms as well: around 800 kg of rhodium were exported in 2012 and 1,000 kg of rhodium were imported.

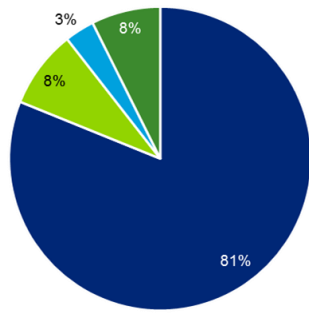
The use of rhodium in the European industry to manufacture finished products is estimated at 6,500 kg of rhodium content. Automotive catalysts in diesel-powered vehicles (along with palladium) represent 81% of the total rhodium used in the EU. In comparison, rhodium in glass manufacturing represents 3% of the rhodium consumed each year in the EU (see Figure 40 – left); however, stock in use in that application is very important since the products are accumulated for a long time.

Most of the finished products are sold in the EU market rather than exported, with production sold accounting for 4,300 kg of rhodium content. Rhodium exported in finished products from the EU amounts for 2,200 kg of rhodium content, almost entirely through exports of automotive catalysts. In comparison, imports of finished products in the EU represent 700 kg of rhodium. The distribution of rhodium consumption between finished applications in the EU are presented below in Figure 40 – right.

Considering the lifespan and annual growth of consumption of each final application, the quantity annually added to stocks is equivalent to 1,200 kg of rhodium content, with stocks of 63,000 kg of rhodium content. In-use dissipation of rhodium in finished-products is much lower, with only 400 kg of rhodium content, from industrial catalysts.

Recycling of rhodium in the EU is accounted for automotive catalysts only; production of secondary material from post-consumer functional recycling in the EU is around 1,600 kg of rhodium, i.e. more than 10% of the input rhodium (as primary and secondary material) in processing. In comparison, around 900 kg of rhodium are estimated to be annually sent to landfill (calculated sum of total waste flows generated from processing until recycling, extraction tailings excluded).

Finished products manufactured in the EU



Finished products used in the EU

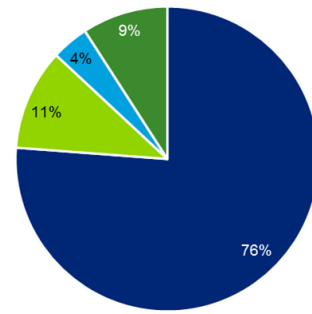


Figure 81: Shares of finished products containing rhodium manufactured in the EU (left) and shares of finished products containing rhodium used in the EU (right)

Value chain distinguishing steps occurring or not within the EU

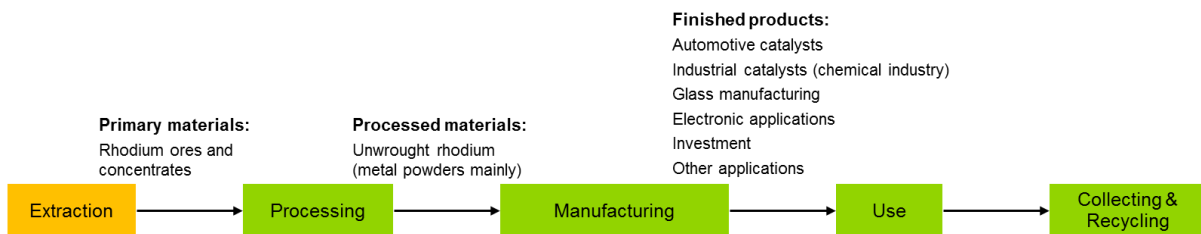


Figure 82: Value chain of rhodium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The annual market reports on Platinum Group Metals issued by Johnson Matthey and the expertise of the International Platinum Group Metals Association (IPA) are the main source of data for the MSA of rhodium. However only worldwide information is provided (regarding total demand for rhodium to manufacture finished products; distribution between these applications; and recycling volumes sent to processing and manufacturing), therefore the data specific to the EU is calculated using a number of assumptions.

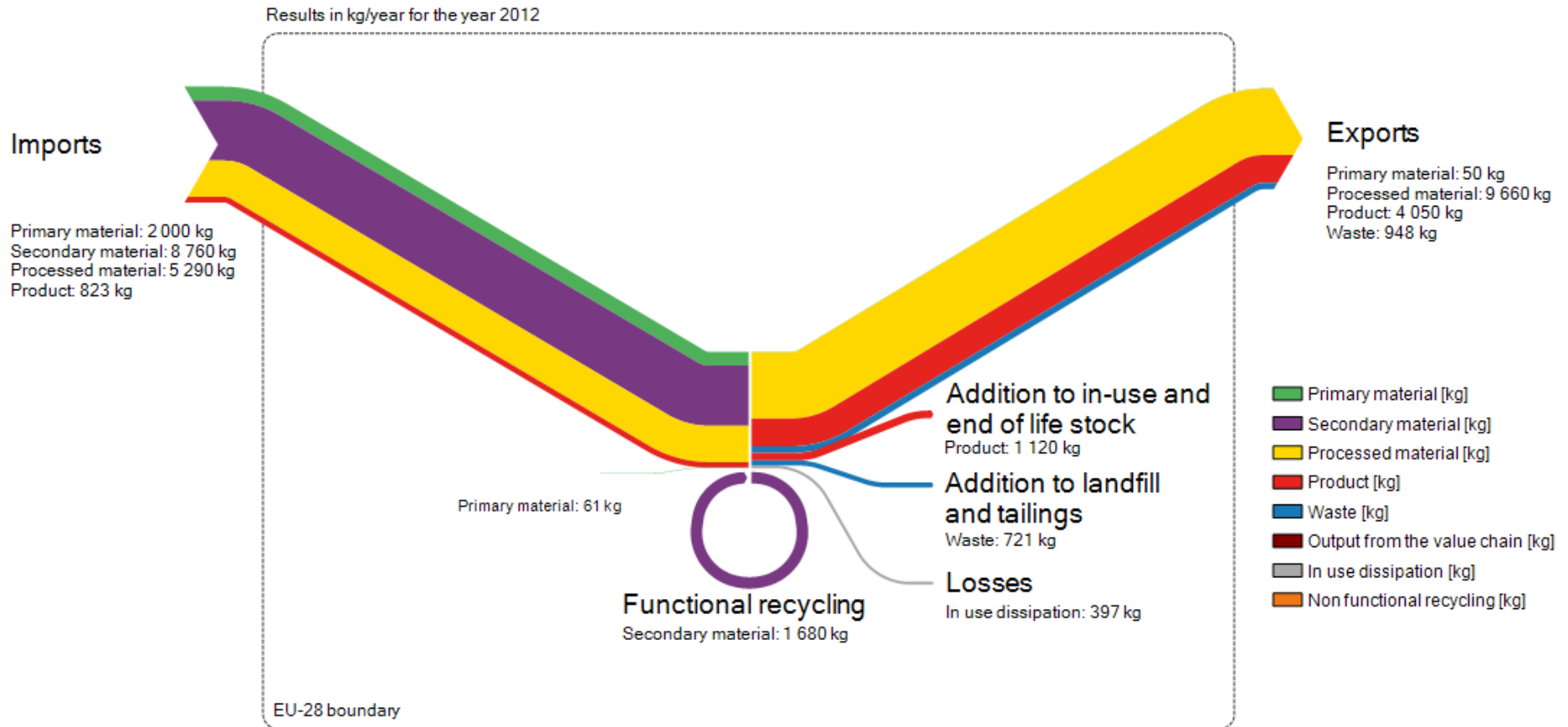
Among other data sources, the study BRGM (2014) is used for reserves and resources worldwide; the BGS World mineral production books provide country information on mining of rhodium ores. The data quality score of the associated data is high.

The Eurostat Comext database is used to calculate the trade between the EU and the rest of the world of processed material and semi-finished products. The Eurostat Prodcom database is used to calculate the shares of exports among total EU production and the shares of imports among EU consumption, for representative products in various applications.

Moreover, the production sold of processed materials, as well as the exports of finished products from the EU are calculated using additional assumptions; the associated quality score is lower. These uncertainties impact also on the reliability of the results in the collecting and recycling steps.

Sankey diagram for rhodium

Figure 83: Simplified Sankey diagram for rhodium



3.3.20 Phosphate rock

Value Chain

Phosphate rock refers to rocks containing about 300 phosphate minerals, usually apatite, which can be commercially exploited, either directly or after processing. It thus also denotes the product obtained from the mining and subsequent metallurgical processing of phosphorus-bearing ores. Phosphate rock – besides organic sources as bone meal and guano – is the only source of phosphorus that is inevitable for modern agriculture. The resources are relatively abundant globally and reserves are significant and sedimentary phosphate deposits occur on every continent; however, current production of phosphate rock is concentrated in a limited number of countries.

Approximately 91% of the phosphate rock mined is used to produce mineral fertilisers and animal feed and food additives; the remainder is used to produce elemental phosphorus and other industrial phosphates. The figure below presents the value chain of phosphate rock with its main uses.

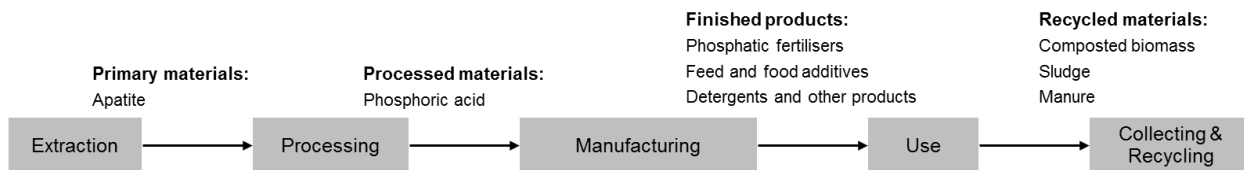


Figure 84: Value chain of phosphate rock

Description of the main flows and stocks

Flows and stocks are accounted in mass of phosphorus (P) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

Within the EU, there are only small reserves of phosphate-bearing rock – less than 4 Mt of P content (in Finland). In comparison, worldwide reserves of phosphate rock are estimated at about 11,500 Mt of P content. Extracted volumes are low in the EU (70 kt of phosphorus content), compared to a worldwide extraction of 37,000 kt of P in phosphate rock. The largest producers of phosphate rock are China, the USA, Morocco, Peru and Russia. The European industry is thus highly dependent on imports, which amount 500 kt of P content in primary phosphates and 300 kt of P content in processed material (as phosphoric acid).

Processed materials are consumed, along with secondary material from recycling (up to 180 kt of P content in the EU), to manufacture final products (see Figure 85 – left). The total production amounts 1,000 kt in phosphorus content, among which 800 kt is sold on the EU market. Most of these materials are used to manufacture mineral fertilisers; the main part is sent for use in the EU (668 kt of phosphorus content), the rest is exported (209 kt of P content). The other uses of phosphate are detergents and other chemicals, followed by animal feed and food additives (about 10% of the total production is exported for both applications).

Imports of finished products in the EU represent a total of 1,000 kt of phosphorus content, for an EU consumption of phosphate of 1,800 kt of P content (see Figure 85 – right). The total stock of phosphates in use in the EU amounts 264 kt of P content, mainly as fertilisers (224 kt of P content). These figures may be affected by the general assumption on lifespan (one year, as the yearly production of all applications is used up in the same year).

The amount of phosphorus in end-of-life products (i.e. animal and mixed food waste, vegetal waste, animal faeces, urine and manure and common sludge) collected for treatment is about 271 kt. About 2/3 of the collected end-of-life products is sent for recycling. The yearly amount of products heading for disposal is about 91 kt of P content therefore there is a significant stock of phosphorus in landfills (about 2,500 kt).

Secondary materials flow result mostly from post-consumer recycling (around 180 kt/year of P content). The recycled phosphorus is a result of recycling of biogenic waste flows such as food and vegetal waste, manure and common sludge. It is considered as functional recycling because using such secondary material as fertiliser prevents from using mineral fertilisers (i.e. primary material).

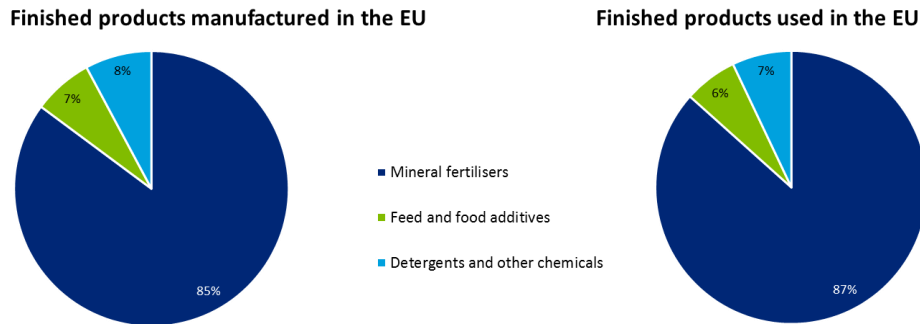


Figure 85: Shares of finished products containing phosphorus manufactured in the EU and shares of finished products containing phosphorus used in the EU (taking into account exports and imports of products)

Value chain distinguishing steps occurring or not within the EU



Figure 86: Value chain of phosphate rock, steps in green occur in the EU, steps in orange occur only outside the EU

Data sources, assumptions and reliability of results

The main data sources for phosphate rock case study included International Fertiliser Industry Association, USGS, British Geological Survey, Eurostat Comext, Prodcorn and waste databases, and Ecoinvent database for calculation of processing and manufacturing waste flows. The suitability of Ecoinvent database for this purpose should be further re-assessed. An important input presents the information from the International Fertiliser Industry Association experts who provided data on imports and manufacturing phosphate rock, phosphoric acid and phosphatic fertilisers in the EU.

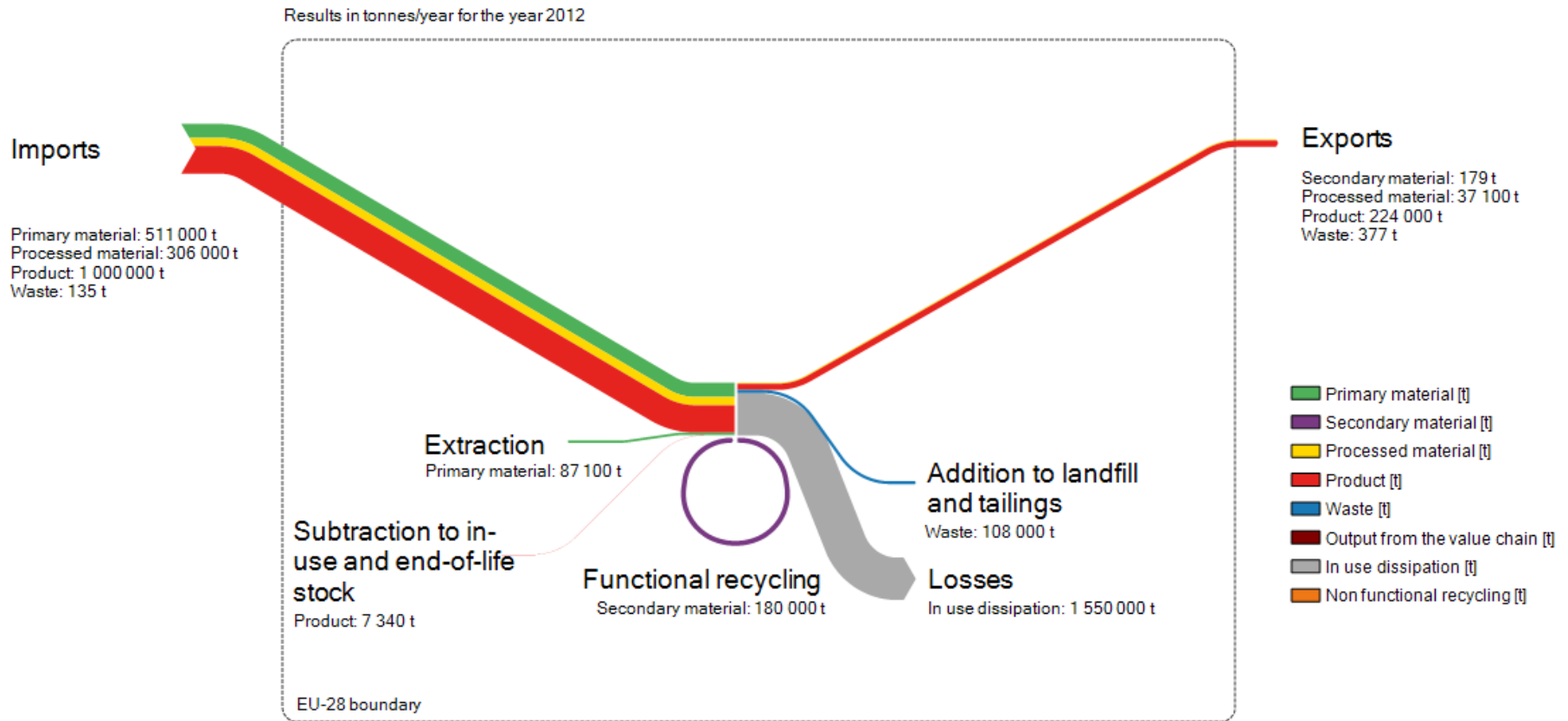
Overall data for steps exploration to processing can be considered quite reliable. Data on step manufacturing are reliable for phosphatic fertilisers but the reliability is lower for feed and food additives and detergents and other products where some coefficients found in literature must have been used for their quantification as well as some assumptions on exports. For the step use, most of the indicators were calculated with the use of equations developed within the project. This required a lot of assumptions to be made on lifespan, dissipation rate and the rate of particular products kept by users after end of life. Due to this fact the parameters in step use are subjects to quite high uncertainties and have not been validated by experts.

Eurostat waste database contains data useful for the collecting step of the MSA on biogenic flows including food and vegetal waste, manure and common sludge. The biogenic flows represent the recycling of phosphorus from phosphatic fertilisers, feed and food additives and detergents and their inclusion required estimation of their P content originating from anthropogenic sources. Some relevant waste flows were not included due to lack of data (e.g. bone meal and animal bodies). In general it can be concluded that uncertainties related to parameters in step collecting are similar as those related to the step use.

Little information usable within this project was found on efficiency of recycling and share of functional/non-functional recycling. These factors therefore have been estimated which results in high uncertainties related to indicators of the recycling step. It must be noted that the global results of this material have not been validated by experts.

Sankey diagram for phosphate rock

Figure 87: Simplified Sankey diagram for phosphate rock



Nota bene: Due to negative annual rate of consumption of some products containing phosphate, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow “Subtraction to in-use and end-of-life stock” in the Sankey diagram, which is an input from the EU market to the EU waste management.

3.3.21 Rare Earth Elements – Dysprosium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including Dy oxides and compounds (such as NdFeB alloys).

These processed materials are converted into semi-finished products consisting in permanent magnets.

Then, these semi-finished products are used in finished products using permanent magnets, such as electric and non-electric vehicles, electronic equipment (HDDs, PCs, phones, printers, small domestic devices, etc.), wind turbines...

The figure below presents the value chain of dysprosium with the main uses.

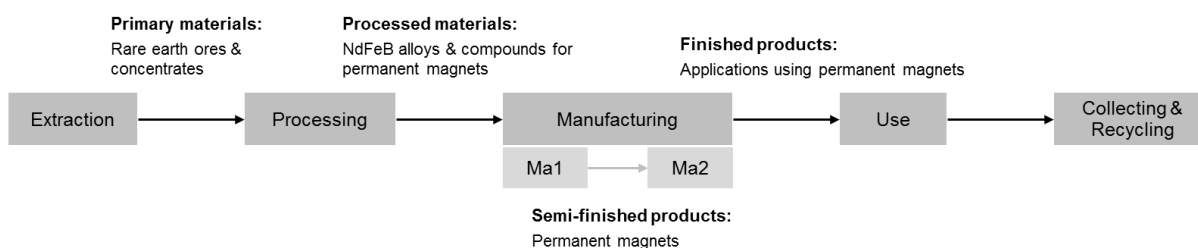


Figure 88: Value chain of dysprosium

Description of the main flows and stocks

Flows and stocks are accounted in mass of dysprosium (Dy) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of neodymium take place outside of the EU.

There are no reserves of rare earths (and thus of dysprosium) in the EU (whereas continental Europe - including Sweden and Greenland - possesses resources and reserves of rare earths) and consequently there is no production of rare earth ores in the EU. World reserves are estimated as 1.1 million of t of dysprosium content and the world annual production is around 1,000 t of dysprosium content, mainly in China.

Imports of dysprosium in concentrates and semi-processed materials in the EU amount about 40 t, used to make NdFeB alloys (40% of which are exported). About 31 t of Dy are also imported in processed materials. The NdFeB alloys are then converted into permanent magnets (about 50 t), quite all sold in the EU. Permanent magnets are also largely imported in the EU (140 t of dysprosium).

The European industry uses these materials to manufacture 185 t of Dy contained in various finished products using permanent magnets which are mainly sold in the European market (75%). During this manufacture step, the EU industry generates few scrap (5 t of dysprosium content) due to efficient internal recycling.

Dysprosium contained in imports of finished products amounts for 57 t per year, for an EU final consumption around 200 t of dysprosium per year.

Considering the lifespan of the finished products containing dysprosium and the annual growth of consumption of these products, two third of the quantity of dysprosium put on the EU market is annually added to stock (annual addition to stock around 133 t of dysprosium content, stock estimated at about 1,460 t of Dy). Only 45 t of dysprosium contained in end-of-life products are sent to waste management.

The dysprosium contained in the waste ends up in landfill (30%) or is recycled (70%). However, there is no post-consumer functional recycling of neodymium in the EU, and the dysprosium contained in the waste is non-functionally recycled in the steel or cement industry (32 t). Based on the growth rate

of consumption of finished products containing Dy, the stock accumulated in landfill in the EU over the last 20 years is estimated around 124 t of dysprosium.

Value chain distinguishing steps occurring or not within the EU

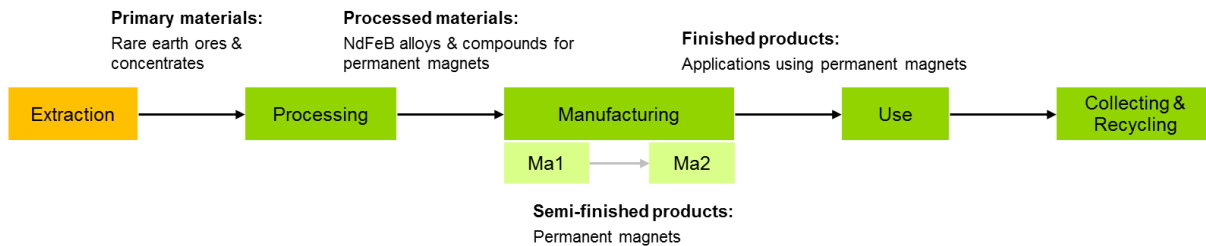


Figure 89: Value chain of dysprosium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

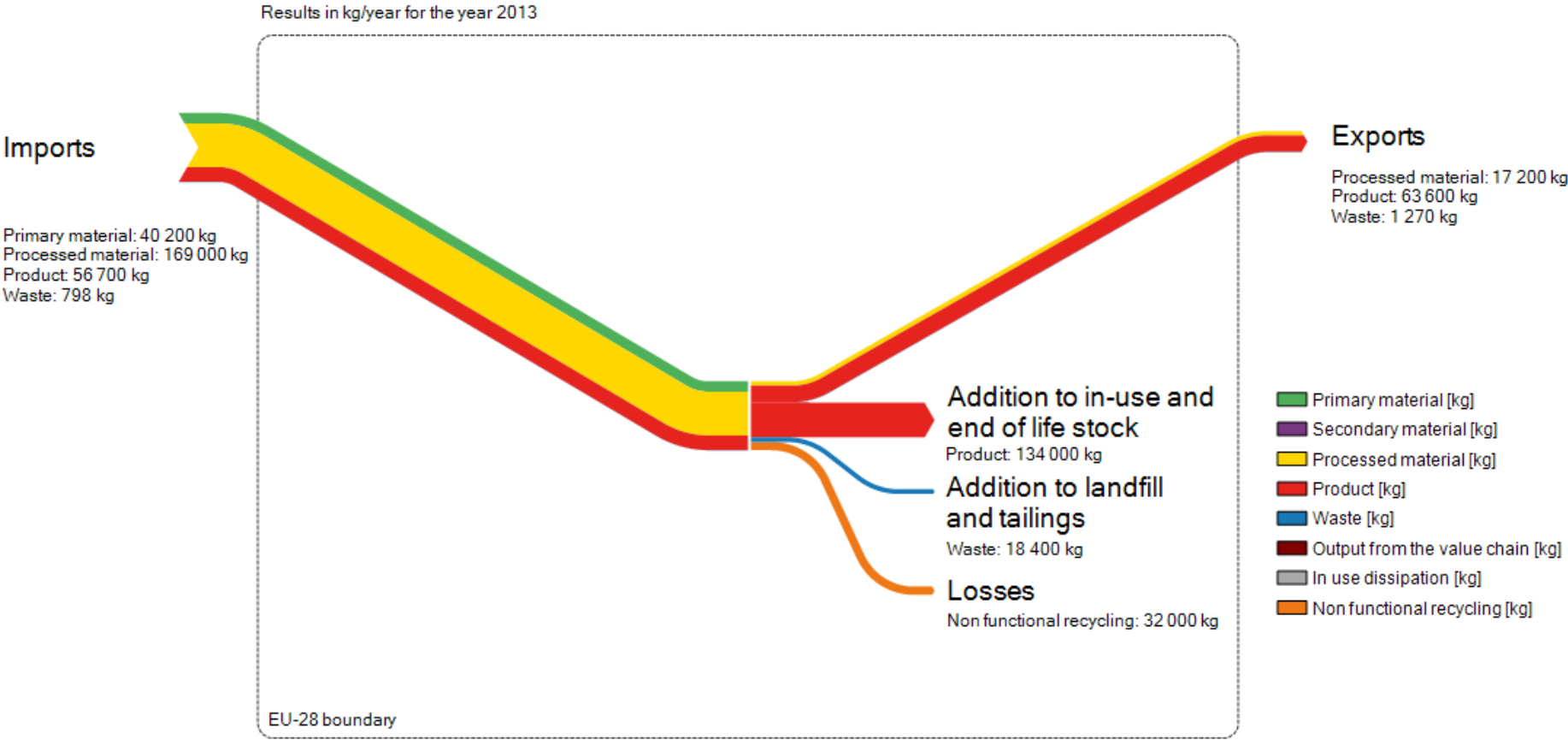
The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index

The main source of data for the elaboration of this MSA is the results of the ASTER study, a paper published in 2015 in the Journal of Cleaner Production, along with the team who worked on this project (BIO, BRGM and Solvay), which provided all data from extraction to first steps of manufacture, as well as data on uses and recycling. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing, manufacturing and use.

From the Use step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in the EU of various finished products. For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for dysprosium

Figure 90: Simplified Sankey diagram for dysprosium



3.3.22 Rare Earth Elements – Erbium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including Er oxides and compounds (such as glass additives for example).

These processed materials are used to make coloured glass and optical fibres amplifiers, the last finished product being not included in our study due to non-significant tonnages.

The figure below presents the value chain of erbium with the main uses.



Figure 91: Value chain of erbium

Description of the main flows and stocks

Flows and stocks are accounted in mass of erbium (Er) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of neodymium take place outside of the EU.

There are no reserves of rare earths (and thus of erbium) in the EU (whereas continental Europe - including Sweden and Greenland - possesses resources and reserves of rare earths) and consequently there is no production of rare earth ores in the EU. World reserves are estimated as 612,000 of t in erbium content and the world annual production is around 650 t in erbium content, exclusively extracted in China.

The EU does not import any erbium concentrates and does not produce any processed materials containing erbium (glass additives). They are all imported (about 36 t).

The glass additives are used by the European industry to manufacture coloured glass, which is mainly sold in the European market (90%). During this manufacture step, no scrap is generated due to efficient internal recycling.

Imports of coloured glass are very small (less than 4 t), for an EU final consumption around 35 t of erbium per year.

Considering the lifespan of the glass containing erbium and the annual growth of consumption of this product, less than 10% of the erbium put on the EU market is annually added to stock (annual addition to stock less than 3 t of Er, stock estimated at about 200 t of Er). About 32 t of erbium contained in end-of-life products are sent to waste management.

The erbium contained in the glass waste is mainly recycled (90%). However, there is no post-consumer functional recycling of erbium in the EU, but a non-functional recycling, as erbium is diluted in the mix of recycled glass, new erbium has to be added to decolorize and re-colorize the recycled glass. The stock accumulated in landfill in the EU over the last 20 years is estimated around 30 t in erbium content.

Value chain distinguishing steps occurring or not within the EU



Figure 92: Value chain of erbium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

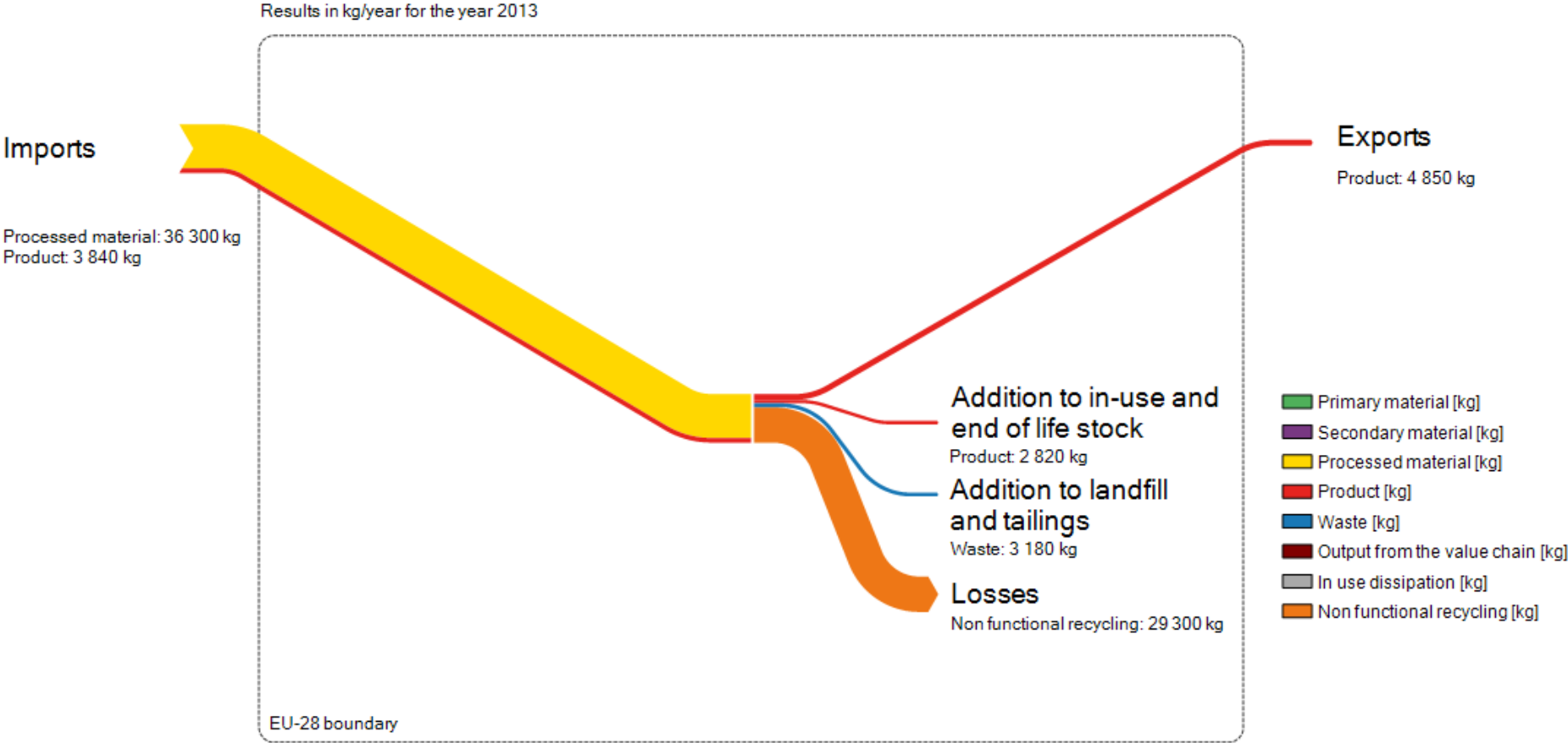
The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index.

No dedicated source was identified for the use of erbium in the EU. Eurostat data was used for the imports of processed materials. The reliability of data for those upstream steps is quite good.

From the manufacturing step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency). General data about glass was used (from La Société Chimique de France), but several hypotheses were also made due to lack of data (in particular for lifespan of glass, share and time kept by users at end of life and trade of waste). For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for erbium

Figure 93: Simplified Sankey diagram for erbium



3.3.23 Rare Earth Elements – Europium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including europium oxides and compounds (such as phosphor powders).

These processed materials are converted into fluorescent lamps.

The figure below presents the value chain of terbium with the main uses.

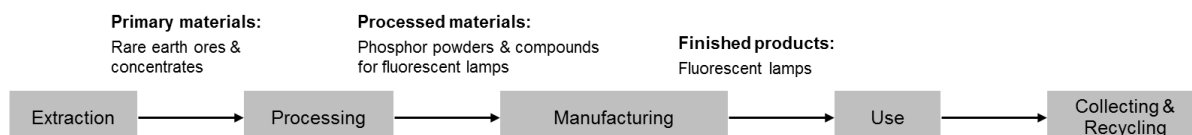


Figure 94: Value chain of europium

Description of the main flows and stocks

Flows and stocks are accounted in mass of europium (Eu) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of terbium take place outside of the EU.

There are no reserves of rare earths (and thus of europium) in the EU (whereas continental Europe - including Sweden and Greenland - possesses resources and reserves of rare earths) and consequently there is no production of europium ores in the EU. World reserves are estimated as 360,000 t of europium content and the world annual production is around 270 t of europium content, mainly in China (90%), but also in India, US, Russia and Australia.

Imports of europium in concentrates in the EU amount about 9 t, used to make - in addition to the input of 34 t of Eu from secondary materials- 43 t of europium in phosphor powders. Those processed materials are also imported in large amounts (up to 46 t of europium content).

Phosphor powders are then converted into fluorescent lamps (60 t, of which 40% are exported). Due to efficient internal recycling, there is no processing or manufacturing waste disposed in the EU at these steps.

The europium contained in imports of fluorescent lamps amounts for 32 t per year, the same quantity of the europium content as in the domestic production sold in the EU. The European final consumption is around 70 t of europium content per year in fluorescent lamps.

Considering the lifespan of the fluorescent lamps and the negative annual growth of consumption of these products, about 26 t of europium are destocked annually from the in-use and end-of-life stocks of products (which amount around 525 t of Eu). About 96 t of europium contained in end-of-life products are sent to waste management.

The europium contained in the waste ends up in landfill (65%) or is recycled (35%). Since 2012, the post-consumer functional recycling of europium from used fluorescent lamps is efficient in the EU (about 33 t). The stock accumulated in landfill in the EU over the last 20 years is estimated around 810 t of europium content.

Value chain distinguishing steps occurring or not within the EU

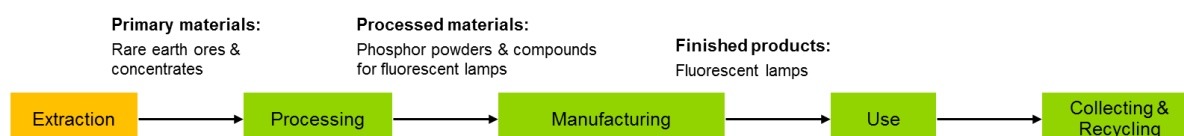


Figure 95: Value chain of europium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

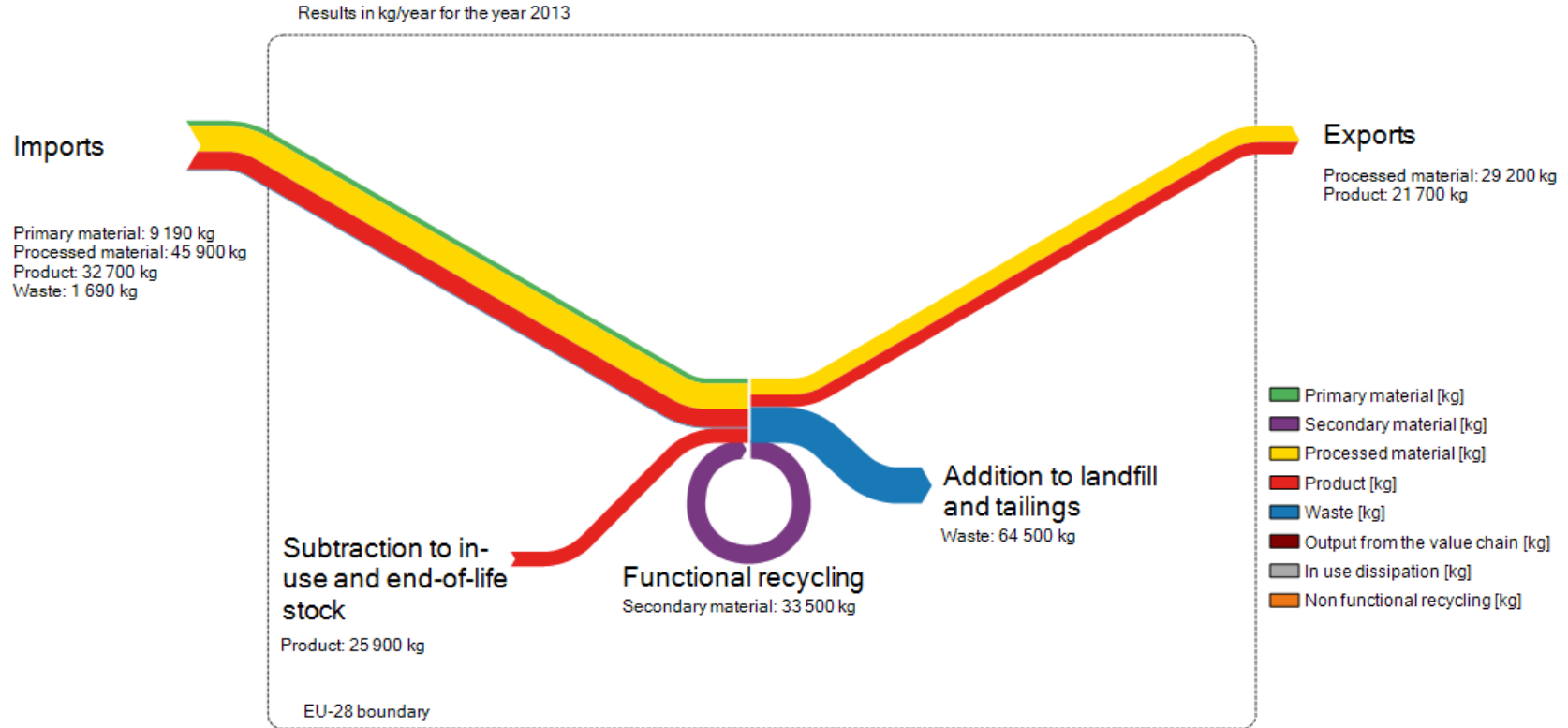
The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index

The main source of data for the elaboration of this MSA is the results of the ASTER study, a paper published in 2015 in the Journal of Cleaner Production, along with the team who worked on this project (BIO, BRGM and Solvay), which provided all data from extraction to first steps of manufacture, as well as data on uses and recycling. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing, manufacturing and use.

From the Use step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in the EU of various finished products. For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for europium

Figure 96: Simplified Sankey diagram for europium



Nota bene: Due to negative annual rate of consumption of some products containing europium, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow “Subtraction to in-use and end-of-life stock” in the Sankey diagram, which is an input from the EU market to the EU waste management

3.3.24 Rare Earth Elements – Neodymium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including neodymium oxides and compounds (such as alloys and mischmetal).

These processed materials are converted into semi-finished products consisting mainly of permanent magnets (from NdFeB alloy), batteries (from mischmetal), alloys and auto catalyst mix.

Then, these semi-finished products are used in finished products in various applications using permanent magnets or batteries or alloys or auto catalyst, such as electric and non-electric vehicles, electronic equipment (HDDs, PCs, phones, toys, printers, small domestic devices, etc.), wind turbines...

The figure below presents the value chain of neodymium with the main uses.

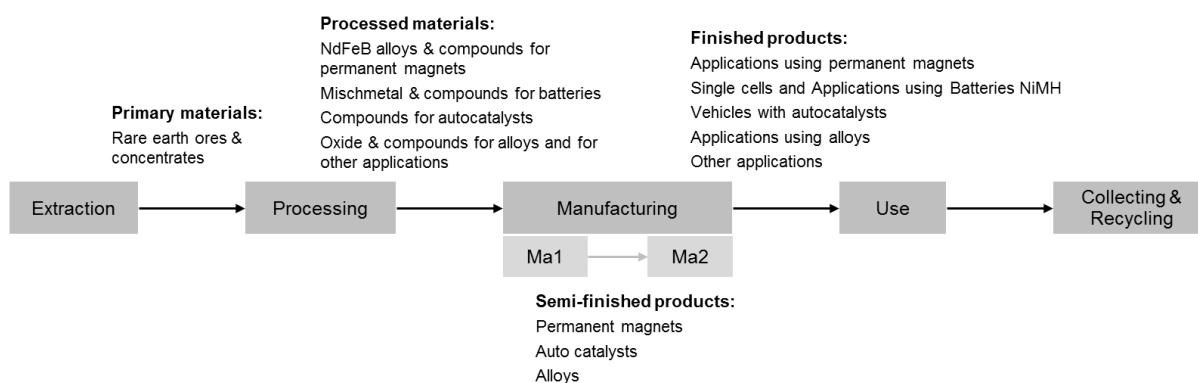


Figure 97: Value chain of neodymium

Description of the main flows and stocks

Flows and stocks are accounted in mass of neodymium (Nd) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of neodymium take place outside of the EU.

There are no reserves of rare earths (and thus of neodymium) in the EU (whereas continental Europe - including Sweden and Greenland - possesses resources and reserves of rare earths) and consequently there is no production of rare earth ores in the EU. World reserves are estimated as 19.4 million t of neodymium content and the world annual production is around 15,800 t of neodymium content, mainly in China (90%), but also in India, US, Russia and Australia.

Imports of neodymium in concentrates and semi-processed materials in the EU amount to about 180 t, used to make about 200 t of processed materials such as NdFeB alloys, mischmetal and neodymium oxides (40% of which are exported). Processed materials are also imported in large amounts (up to 275 t of neodymium content).

Those processed materials are then converted into semi-finished materials, among them about 200 t of permanent magnets (only 4% exported), batteries, alloys and auto catalysts. Such semi-finished products are also largely imported (570 t of Nd content, of which 96% are in magnets).

The EU industry uses these materials to manufacture 935 t of neodymium contained in various finished products (see Figure 15 – left) which are mainly sold in the European market (75%). During this manufacture step, the EU industry generates few scrap (21 t of Nd, originating from the manufacture of magnets) due to efficient internal recycling.

Neodymium contained in the imports of finished products amount 385 t per year (60% of which are applications using permanent magnets), which is half the neodymium content in the domestic

production sold in the EU. The European final consumption is around 1,060 t of neodymium content per year (see Figure 15 – right).

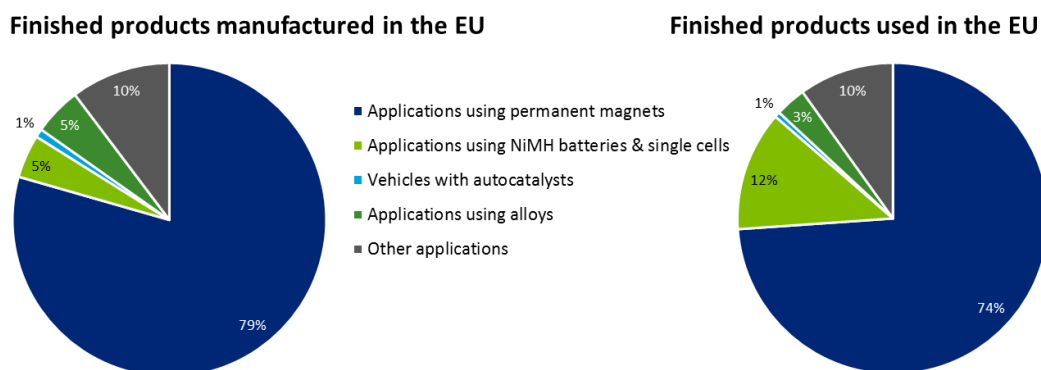


Figure 98: Shares of finished products containing neodymium manufactured in the EU (left) and shares of finished products containing neodymium used in the EU (right)

Considering the lifespan of the finished products containing neodymium and the annual growth of consumption of these products, more than half the quantity of neodymium put on the EU market is annually added to stock (annual addition to stock around 563 t of Nd, stock estimated at about 8,000 t of Nd). About 420 t of neodymium contained in end-of-life products are sent to waste management.

The neodymium contained in the waste ends up in landfill (40%) or is recycled (60%) with a large magnitude material stream. However, there is very few post-consumer functional recycling of neodymium in Europe (about 14 t from spent batteries), and the big majority of neodymium contained in the waste is non-functionally recycled in the steel or cement industry. The stock accumulated in landfill in the EU over the last 20 years is estimated around 1,475 t of neodymium.

Value chain distinguishing steps occurring or not within the EU

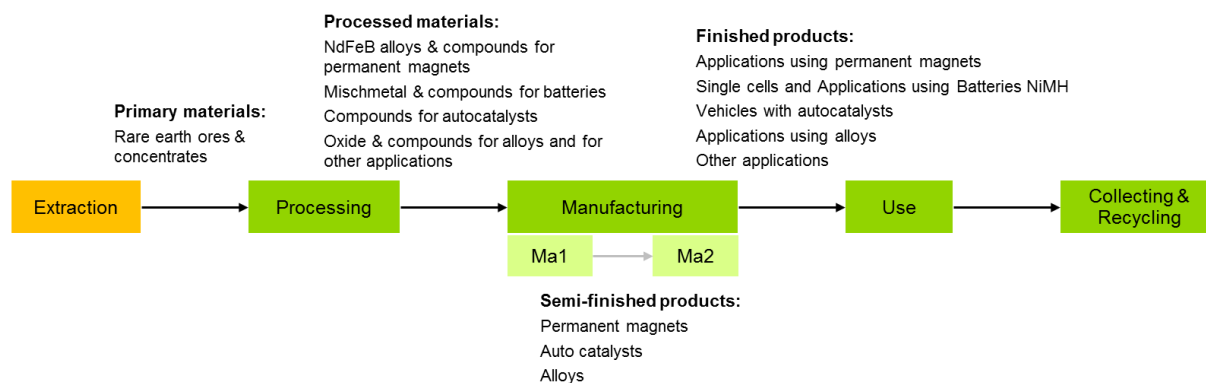


Figure 99: Value chain of neodymium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index.

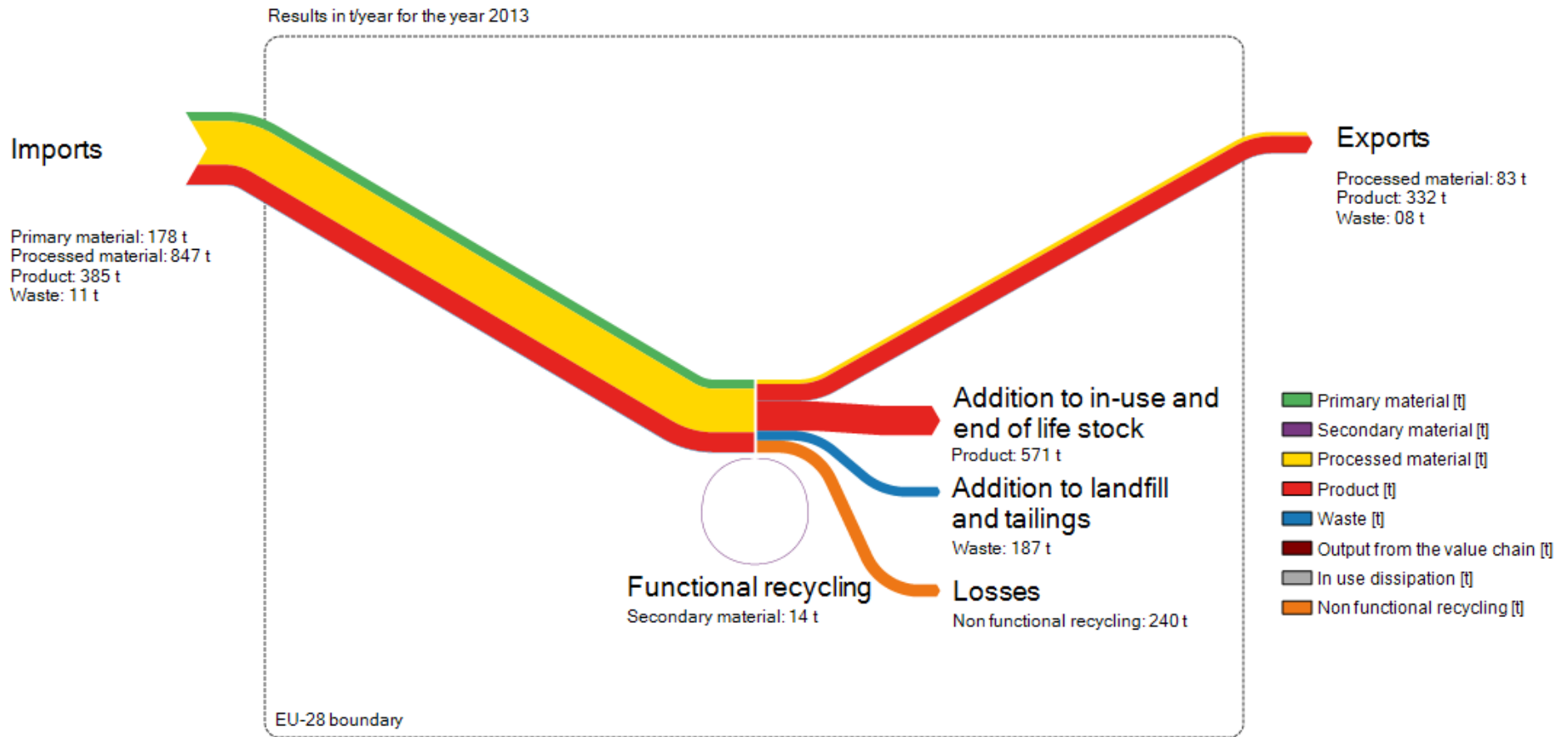
The main source of data for the elaboration of this MSA is the results of the ASTER study, a paper published in 2015 in the Journal of Cleaner Production, along with the team who worked on this project (BIO, BRGM and Solvay), which provided all data from extraction to first steps of manufacture, as well as data on uses and recycling for the applications “permanent magnets” and “batteries”. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing and recycling for these applications. Data is much less reliable for other applications (alloys, auto catalyst) due to lack of data.

Due to inconsistent results from Eurostat data for the processing step, the values for this step have been conservatively based on the input of Nd from the extraction step and the need of Nd for the manufacture step, for which data was available and much more reliable.

From the Use step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in the EU of various finished products. For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for neodymium

Figure 100: Simplified Sankey diagram for neodymium



3.3.25 Rare Earth Elements – Terbium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including Tb oxides and compounds (such as alloys and phosphor powders).

These processed materials are converted into semi-finished products such as permanent magnets (from NdFeB alloy), or directly into fluorescent lamps (from phosphor powders).

In addition to fluorescent lamps, various applications using permanent magnets are manufactured, such as electric and non-electric vehicles, electronic equipment (HDDs, PCs, phones, printers, small domestic devices, etc.), wind turbines...

The figure below presents the value chain of terbium with the main uses.

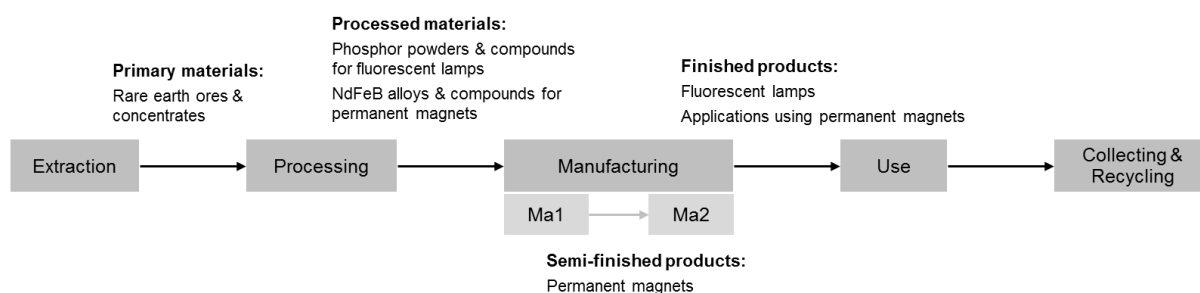


Figure 101: Value chain of terbium

Description of the main flows and stocks

Flows and stocks are accounted in mass of terbium (Tb) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of terbium take place outside of the EU.

There are no reserves of rare earths (and thus of terbium) in the EU and consequently there is no production of rare earth ores. World reserves are estimated as 240,000 t of terbium and the world annual production is around 250 t of terbium content, mainly in China (90%), but also in India, US, Russia and Australia.

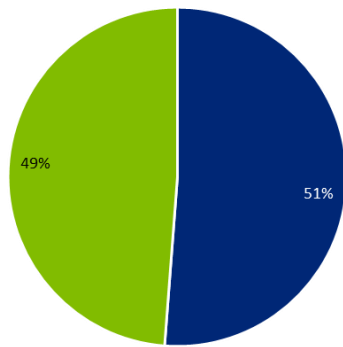
Imports of terbium in concentrates and semi-processed materials in the EU amount about 14 t, used to make 35 t of terbium in processed materials such as NdFeB alloys and phosphor powders. Processed materials are also imported in large amounts (up to 36 t of terbium content).

Those processed materials are then converted into permanent magnets (9.6 t, exports are negligible thus imports are equal to the EU production sold in the EU), or directly into fluorescent lamps (39 t, of which 40% are exported).

The European industry uses these materials to manufacture 76 t of terbium contained in various finished products (see Figure 15 – left) which are mainly sold in the European market (70%). Due to efficient internal recycling, there are no processing or manufacturing waste disposed in the EU at these steps.

The terbium contained in imports of finished products amount 32 t per year, which is two third the terbium content in the domestic production sold in the EU. The European final consumption is around 85 t of terbium per year (see Figure 15 – right).

Finished products manufactured in the EU



Finished products used in the EU

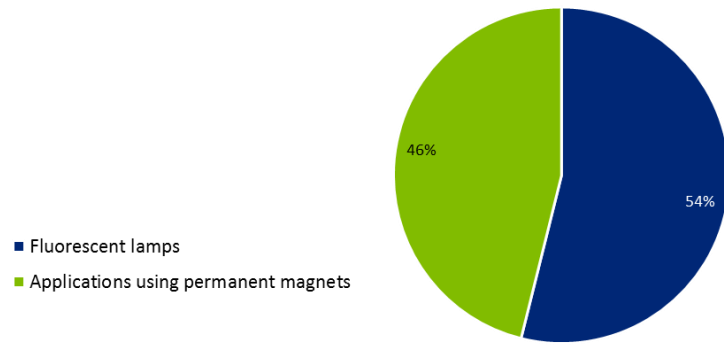


Figure 102: Shares of finished products containing terbium manufactured in the EU (left) and shares of finished products containing terbium used in the EU (right)

Considering the lifespan of the finished products containing terbium and the annual growth of consumption of these products, only 10% of the terbium put on the European market is annually added to stock (annual addition to stock around 10 t of Tb, stock estimated at about 635 t of Tb). About 72 t of terbium contained in end-of-life products are sent to waste management.

The terbium contained in the waste ends up in landfill (60%) or is recycled (40%). Since 2012, the post-consumer functional recycling of terbium from used fluorescent lamps is efficient in the EU (about 22 t), with also few terbium contained in the waste non-functionally recycled in the steel or cement industry (6 t). The stock accumulated in landfill in the EU over the last 20 years is estimated around 550 t of Tb.

Value chain distinguishing steps occurring or not within the EU

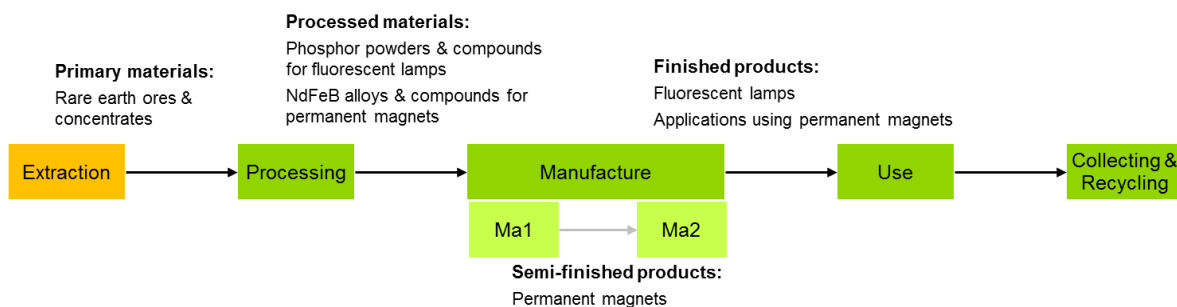


Figure 103: Value chain of terbium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

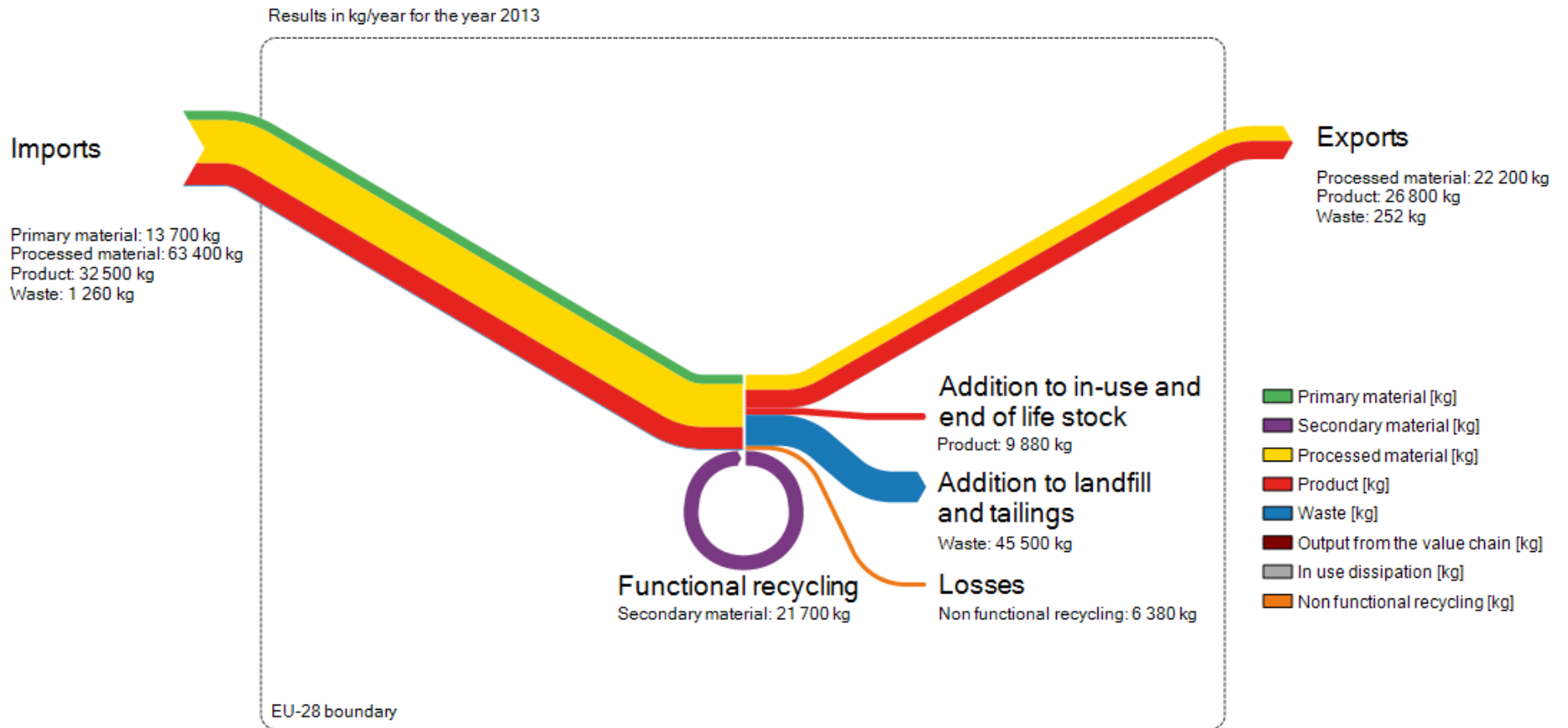
The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index

The main source of data for the elaboration of this MSA is the results of the ASTER study, a paper published in 2015 in the Journal of Cleaner Production, along with the team who worked on this project (BIO, BRGM and Solvay), which provided all data from extraction to first steps of manufacture, as well as data on uses and recycling. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing, manufacturing and use.

From the Use step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in Europe of various finished products. For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for terbium

Figure 104: Simplified Sankey diagram for terbium



3.3.26 Rare Earth Elements – Yttrium

Value Chain

After extraction, rare earths ores and concentrates are separated and processed into single rare earth oxides and compounds, including Y oxides and compounds (such as Y-stabilized zirconia and phosphor powders).

These processed materials are converted into semi-finished products such as ceramics for oxygen sensors (from YSZ), or directly into fluorescent lamps (from phosphor powders).

In addition to fluorescent lamps, vehicles equipped with oxygen sensors and other applications are manufactured.

The figure below presents the value chain of yttrium with the main uses.

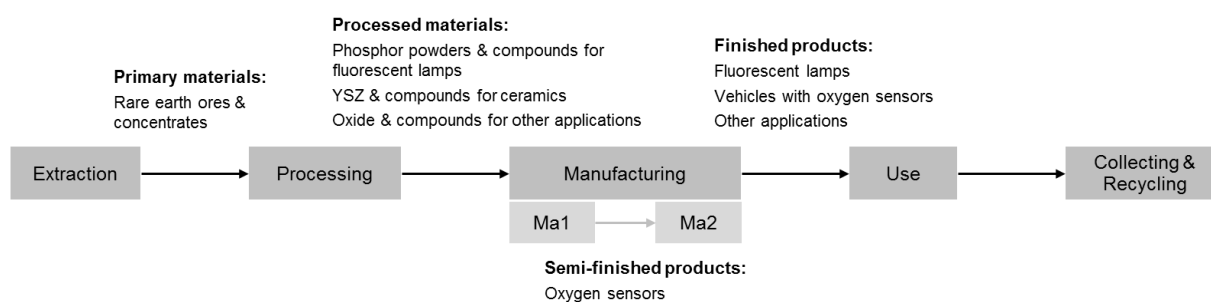


Figure 105: Value chain of yttrium

Description of the main flows and stocks

Flows and stocks are accounted in mass of yttrium (Y) and are representative of the year 2013. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

The first stages of the value chain of yttrium take place outside of the EU.

There are no reserves of rare earths (and thus of yttrium) in the EU (whereas continental Europe - including Sweden and Greenland - possesses resources and reserves of rare earths) and consequently there is no production of rare earth ores in the EU. World reserves are estimated as 5.4 million of t of yttrium content and the world annual production is around 6,700 t of yttrium content, quite exclusively in China.

Imports of yttrium in concentrates in the EU amount about 100 t, used to make 150 t of yttrium in processed materials such as phosphor powders, YSZ and other compounds. Processed materials are also imported in large amounts (more than 680 t of yttrium content).

Those processed materials are then converted into oxygen sensor ceramics (10 t, mainly sold in the EU, 4.5 t imported), or directly into fluorescent lamps (more than 640 t, of which 40% are exported) or other applications.

The European industry manufacture 835 t of yttrium contained in various finished products (see Figure 15 – left) which are mainly sold in the EU market (60%). Due to efficient internal recycling, there are no processing or manufacturing waste disposed in the EU at these steps.

The yttrium contained in the imports of finished products amounts for 450 t per year. The EU final consumption is around 970 t of yttrium per year (see Figure 15 – right).

Considering the lifespan of the finished products containing yttrium and the negative annual growth of consumption of these products, about 270 t of yttrium are destocked annually from the in-use and end-of-life stocks of products (which amount around 7,000 t of Y). About 1,230 t of yttrium contained in end-of-life products are sent to waste management.

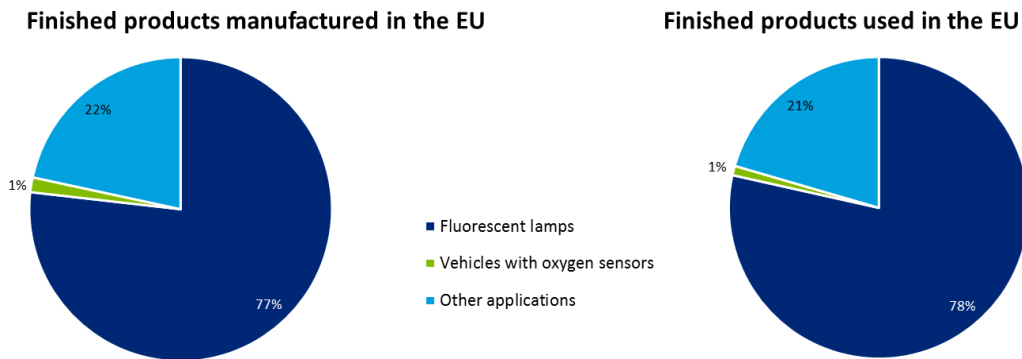


Figure 106: Shares of finished products containing yttrium manufactured in the EU (left) and shares of finished products containing yttrium used in the EU (right)

The yttrium contained in the waste ends up in landfill (60%) or is recycled (40%). Since 2012, the post-consumer functional recycling of yttrium from used fluorescent lamps is efficient in the EU (more than 360 t), with also some yttrium contained in the waste non-functionally recycled (110 t). The stock accumulated in landfill in the EU over the last 20 years is estimated around 9,550 t of yttrium.

Value chain distinguishing steps occurring or not within the EU

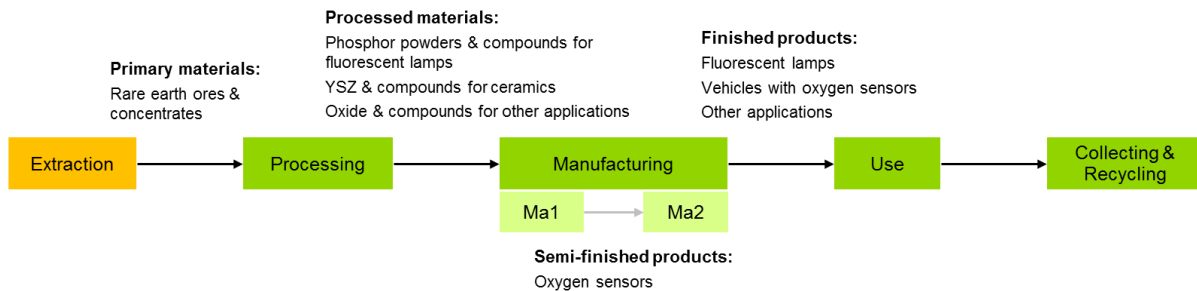


Figure 107: Value chain of yttrium, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

The data for resources and reserves comes from USGS, the ERECON report, as well as the TMR Advanced Rare-Earth Projects Index

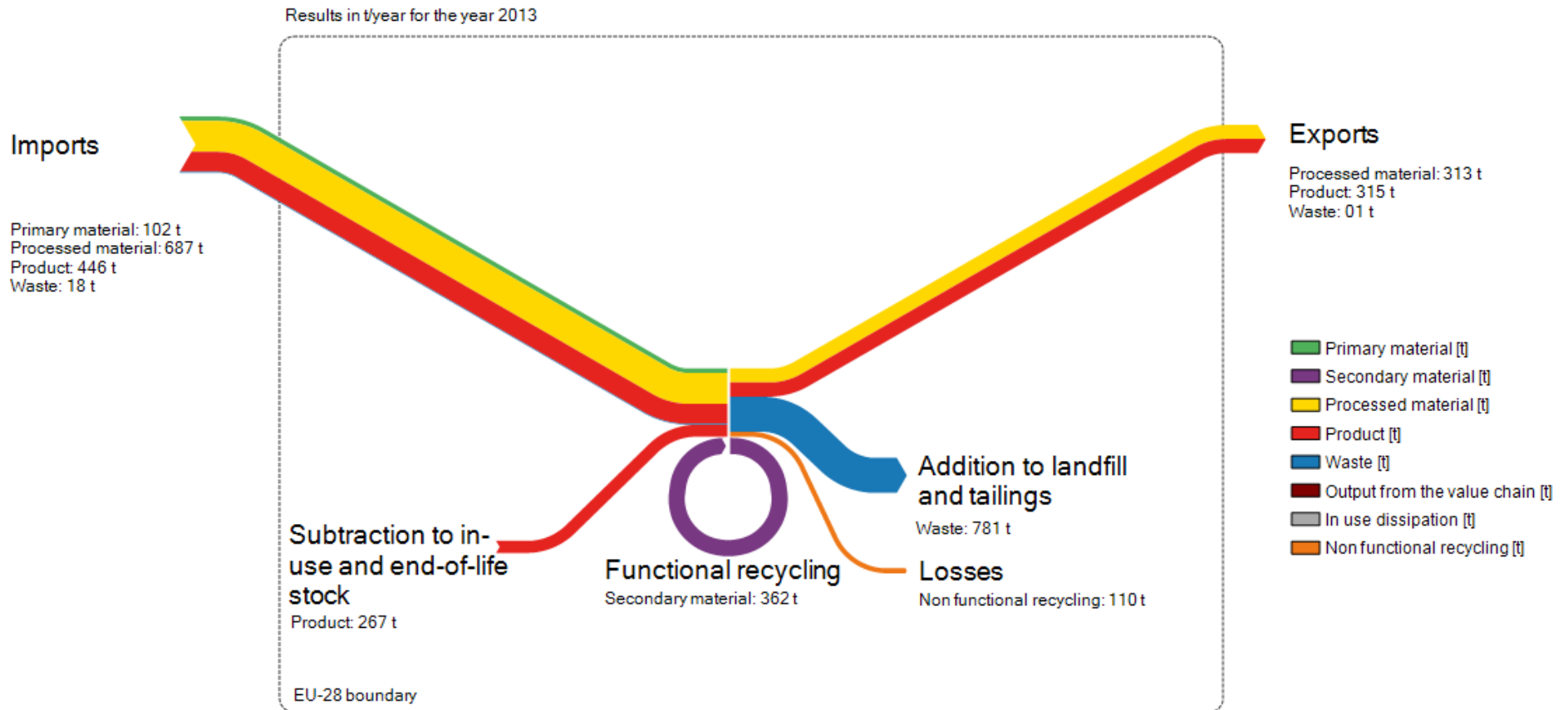
The main source of data for the elaboration of this MSA is the results of the ASTER study, a paper published in 2015 in the Journal of Cleaner Production, along with the team who worked on this project (BIO, BRGM and Solvay), which provided all data from extraction to first steps of manufacture, as well as data on uses and recycling for the application “fluorescent lamps”. Hence, the results can be considered as a quite robust for the steps exploration, extraction, processing, manufacturing, and recycling for this application. Data is much less reliable for other applications and oxygen sensors due to lack of data.

Due to inconsistent results from Eurostat data for the processing step, the values for this step have been conservatively based on the input of Y from the extraction step and the need of Y for the manufacture step, for which data was available and much more reliable.

From the Use step to the recycling step, a top-down approach (global input flows are split into exports and production sold of various outputs in order to ensure mass balance all along the value chain) is used to model the rest of the flows. This exercise requires a number of other data sources to characterise each of the different uses and their representative products (e.g., data on lifespan, annual growth of use in each sector, quantity of end-of-life products kept by users, collection rate of end-of-life products, recycling efficiency), as well as hypothesis on the ratio between exports and production sold in the EU of various finished products. For these reasons, the level of reliability of results for the steps use, collecting and recycling are low.

Sankey diagram for yttrium

Figure 108: Simplified Sankey diagram for yttrium



Nota bene: Due to negative annual rate of consumption of some products containing yttrium, the annual variation of the in-use stock and the end-of-life stock is negative (each year more products are destocked (to go to the waste management) than new products that are consumed). This is represented by the flow “Subtraction to in-use and end-of-life stock” in the Sankey diagram, which is an input from the EU market to the EU waste management.

3.3.27 Silicon

Value Chain

This MSA aims to focus on silicon only, i.e. excluding silica or ferrosilicon and their applications. Silicon is a very high purity material and can only be processed from vein quartz and quartz pebbles, due to their high silica content.

Two grades of processed materials exist: the metallurgical grade silicon (MG, < 99.99%) is used to produce silicones and aluminium alloys and the electrical grade silicon (EG, > 99.99%) is used to produce wafers. Those semi-finished products are then used to manufacture various finished products such as chemical products (e.g. shampoos, fixing materials, insulating materials used in cables etc.), products made of aluminium alloys for the automotive and construction industry, as well as electronic and photovoltaic applications.

One can notice that the processing of silicon also generates silica fumes as by-product. Although the element Si is valued in that by-product, it was not embedded in this value chain because of its lower purity. The figure below presents the value chain of silicon and its main uses.

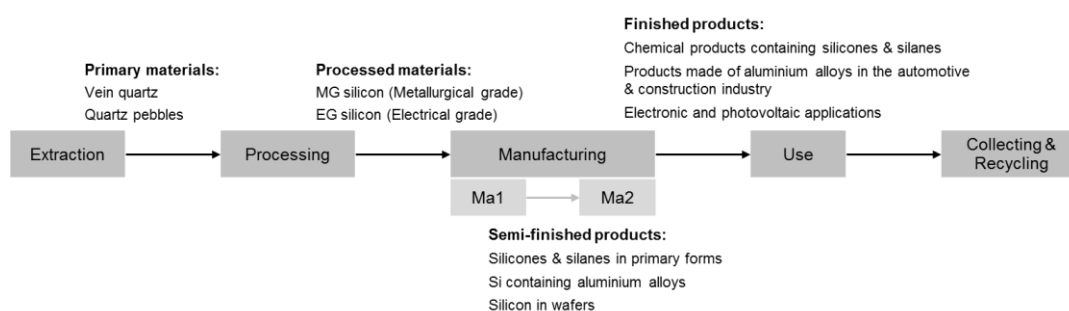


Figure 109: Value chain of silicon

Description of the main flows and stocks

Flows and stocks are accounted in mass of silicon (Si) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of sources in Annex 2). The values presented here are not raw data but aggregated results.

There is no data available on reserves and resources of silicon in vein quartz and quartz pebbles at the EU level or worldwide. However, it is acknowledged that reserves are large enough to meet the worldwide consumption needs for the next decades.

Quartz for the silicon industry (vein quartz and quartz pebbles) is extracted as main product. Most of the quartz processed in the EU into silicon originates from European countries, namely Spain and France. Around 180 kt of silicon contained in primary material is extracted and sold in the EU, whereas around 115 kt are exported. Besides, around 65 kt of silicon in primary material are imported. The EU production of MG and EG silicon is around 190 kt of silicon: 140 kt are sold in the EU, 50 kt are exported. In addition, around 50 kt of silicon are generated as silica fumes during the processing step.

Imports of processed materials and semi-finished products represent the majority of the silicon supply for European manufacturers. These imports are around 445 kt of silicon. Most of the silicon imported is under metallurgical grade (375 kt of silicon). It can be used at this grade or can be further refined in the EU as electrical grade before being used to produce semi-finished products and finished products.

The European industry manufactures various finished products (see Figure 40 – left) which are mostly sold in the European market (around 420 kt of silicon among the EU production). During the manufacturing step, most of the waste generated as spills from the production of electronic appliances and photovoltaic panels is directly reused in other applications, which only require the purity of MG silicon (these flows do not appear in the MSA because they stay within the manufacturing step). The waste not recycled ends up in landfill (among which, ashes from energy recovery).

The domestic production of finished-products represents the largest part of the EU final consumption of silicon. Indeed, the EU imports of finished products only amount for 85 kt of silicon content.

However, in the case of electronic and photovoltaic applications, imports of finished products represent up to 80% of the EU consumption (see Figure 40– right).

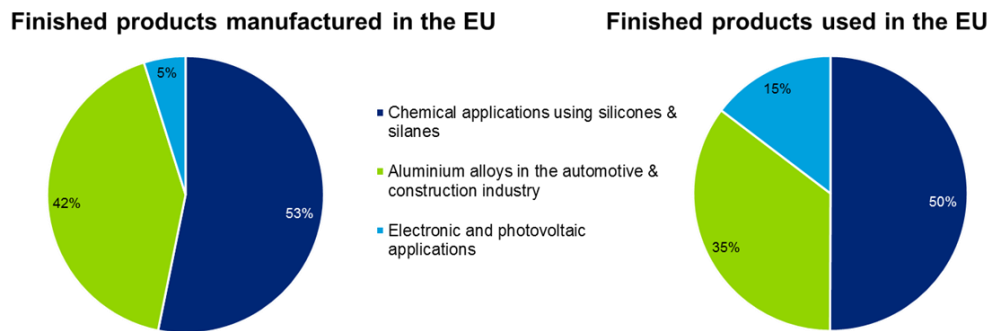


Figure 110: Shares of finished products containing silicon manufactured in the EU (left) and shares of finished products containing silicon used in the EU (right)

Considering the lifespan and the annual growth of consumption of the finished products containing silicon, the quantity annually added to stock is equivalent to 45% of the quantity of silicon put on the EU market (addition to in-use and end-of-life stock around 220 kt of silicon per year, stock evaluated at 5,300 kt of silicon). Around 200 kt of silicon are collected for waste management and around 60 kt of silicon are lost by dissipative use (chemical applications).

Most of the silicon contained in products at end of life ends up in landfill (after an energy recovery process). A small part goes to the aluminium recycled stream. However, there is no functional recycling of silicon from products at end of life. Although the technology for recycling silicon exists, there is currently no recycling of silicon as old scrap due to economic reasons and because of low volumes (mainly for photovoltaic panels) at end of life in recent years. Around 230 kt of silicon is estimated to be annually sent to landfill (calculated sum of total waste flows generated from processing until recycling, extraction tailings excluded).

Value chain distinguishing steps occurring or not within the EU

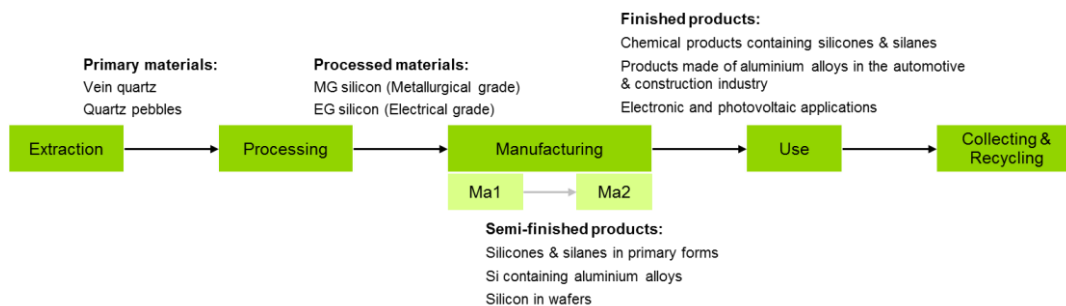


Figure 111: Value chain of silicon, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

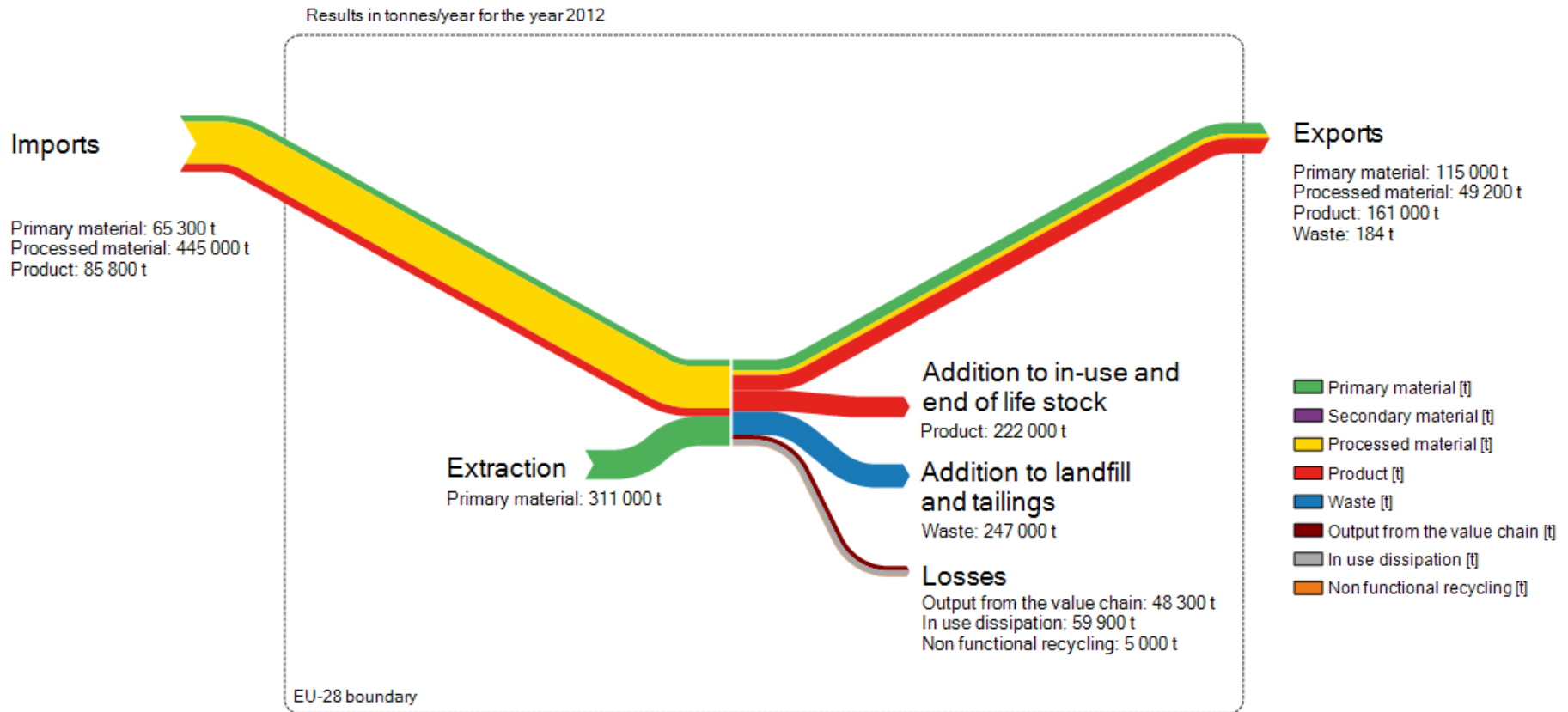
As mentioned above, there is no data available on reserves and resources of silicon contained in vein quartz and quartz pebbles; please note that some sources may aggregate this information with data on reserves and resources of silica.

Data on the total European production of processed silicon is provided by BGS, and by Eurostat for the imports and exports of processed silicon; as well as those of quartz used for the silicon industry. The total European extraction of quartz for the silicon industry is calculated using this information, which limits the reliability of the results for the extraction step. The silicon input at the manufacture step in the EU and the EU distribution between each of the manufactured applications, is provided by the European study on the list of Critical Raw Materials. Data is available on Eurostat to calculate shares of trade flows (compared to production sold) for each intermediate product from silicon to finished-product.

Based on this information, a top-down approach is used to calculate the distinct flows for the manufacture, use, collecting and recycling step. Other data was gathered to characterize each of the finished products (lifespan, in-use dissipation, growth rate, etc.). Various hypotheses are made when data is not available, particularly regarding trade flows of waste from finished products between the EU and the rest of the world. Thus the reliability of the results for the use and collecting step is quite low.

Sankey diagram for Silicon

Figure 112: Simplified Sankey diagram for silicon



3.3.28 Tungsten

Value Chain

After extraction, tungsten ore is processed in two main intermediate products: ammonium paratungstate (APT thereafter) / tungsten oxides (further processed form of APT), and ferrotungsten. Although APT and tungsten oxides are similar, the MSA aims to focus on APT as the main tungsten intermediate; thus the two materials are not aggregated in one step but separated between processing and manufacturing.

While ferrotungsten is used in tungsten containing steel; APT and tungsten oxides are manufactured into various tungsten semi-finished products: tungsten metal (highly conductive when pure), tungsten carbides (wear resistance), tungsten alloy (highly dense, for heavy parts) or chemical compounds.

Finished applications are then manufactured from those tungsten components. For instance, lighting products are made from 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. The figure below presents the value chain of tungsten and its main uses.

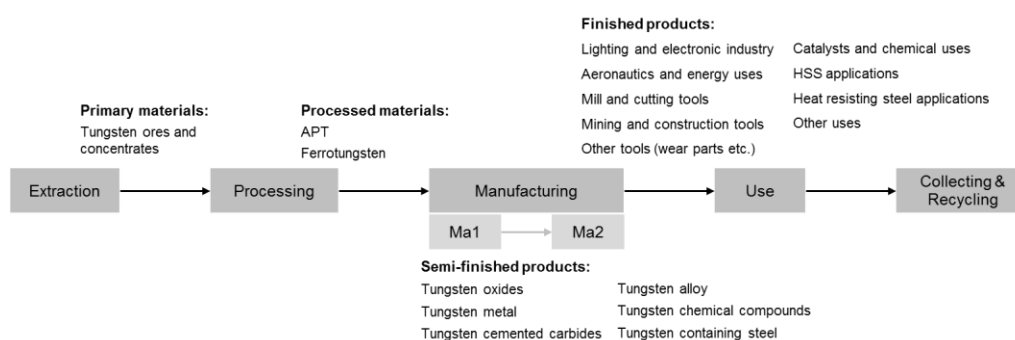


Figure 113: Value chain of tungsten

Description of the main flows and stocks

Flows and stocks are accounted in mass of tungsten (W) and are representative of the year 2012. All the quantitative results originate from calculations made by the project team and are based on several data sources (list of the sources in the Annex 2). The values presented here are not raw data but aggregated results.

Reserves of tungsten in the EU are of 79 kt of tungsten content, located in Portugal, Spain, Austria and the UK (with a project starting at Hemerdon), whereas worldwide reserves are about 3,077 kt of tungsten. Resources of tungsten are estimated at 500 kt in the EU, compared to 7,000 kt of tungsten worldwide.

Tungsten extraction represents around 2,000 t of tungsten content in the EU, i.e. less than 3% of the global extraction (China accounting for more than 80% of it). Around 45% of the EU extracted tungsten is sold on the EU market. About 700 t is annually disposed in mine tailings as extraction waste. Most of the tungsten ores to be processed in the EU (into APT and ferrotungsten) is imported (2,600 t of tungsten, higher than the EU production sold of tungsten ores of 900 t). The processed materials (APT and ferrotungsten) are mostly sold on the EU market rather than exported outside of the EU.

The European industry manufactures various semi-finished products (such as oxides, metal, etc.), from the processed materials until the finished products (lamps, mining tools etc.). The EU consumption of semi-finished products is of 19,500 t of tungsten content; tungsten carbides represent the main part of it, with a total consumption of 13,000 t of tungsten. Tungsten carbides are mainly used to manufacture wear resistant tools, for mining or metal cutting (see Figure 40 – left).

Exports and imports of processed and semi-finished products vary among sectors, however the overall balance for the manufacturing step seems stable, with 10,900 t of tungsten in imports of processed and semi-finished products, compared to 9,800 t in exports of semi-finished and finished products.

Most of the finished products are sold on the EU market rather than exported (13,800 t of tungsten in products manufactured and sold in the EU, compared to 5,400 t exported). In comparison, 8,100 t of tungsten are imported as finished products in the EU. The trade flows are similar (compared to production sold) among all final applications, therefore the distribution in the EU of those applications does not vary significantly between total production and consumption of finished products (see Figure 40 – right).

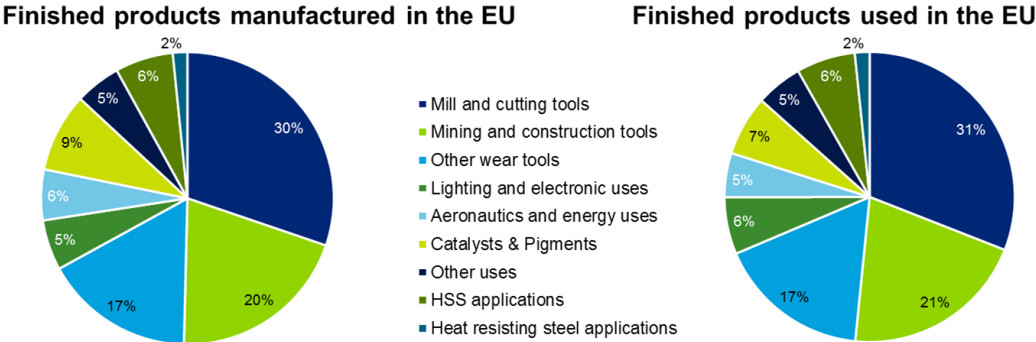


Figure 114: Shares of finished products containing tungsten manufactured in the EU (left) and shares of finished products containing tungsten used in the EU (right)

Considering the lifespan and annual growth of consumption of each final application, the quantity annually added to stocks is equivalent to 2,700 t of tungsten, with in-use stock and end-of-life stock up to 41,900 t of tungsten. In-use dissipation of tungsten finished-products is not negligible, particularly for wear resisting applications such as metal milling and construction tools. Catalysts remain the main contributor to this flow (1,400 among 3,000 t of tungsten for all applications using tungsten).

Recycling of tungsten is significant, representing half of the tungsten contained in the total EU production of semi-finished products. Various recycling processes exist, depending on the purity of the waste and on the output material. Functional recycling (going to either processing or manufacture) represents 10,200 t of tungsten. By comparison, annual addition to stock in landfill (waste generated from processing to recycling step, extraction tailings excluded) is calculated as 6,200 t of tungsten.

Value chain distinguishing steps occurring or not within the EU

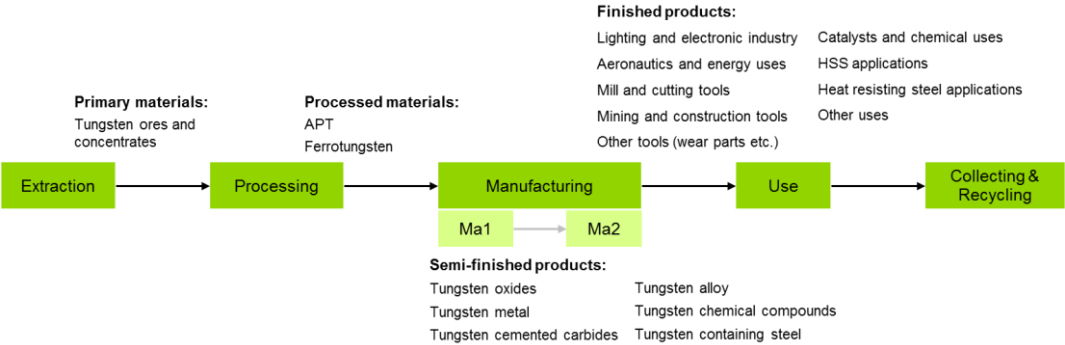


Figure 115: Value chain of tungsten, steps in green occur in the EU, steps in orange occur only outside of the EU

Data sources, assumptions and reliability of results

Eurostat database is used for various products, when the corresponding code is available (mostly for steps extraction and processing and some products in manufacture). The tungsten content is available from various expertise (BGS, Roskill) and references. Eurostat database is preferred over Roskill as it reports extra-EU trade whereas Roskill reports intra- and extra-EU trades aggregated.

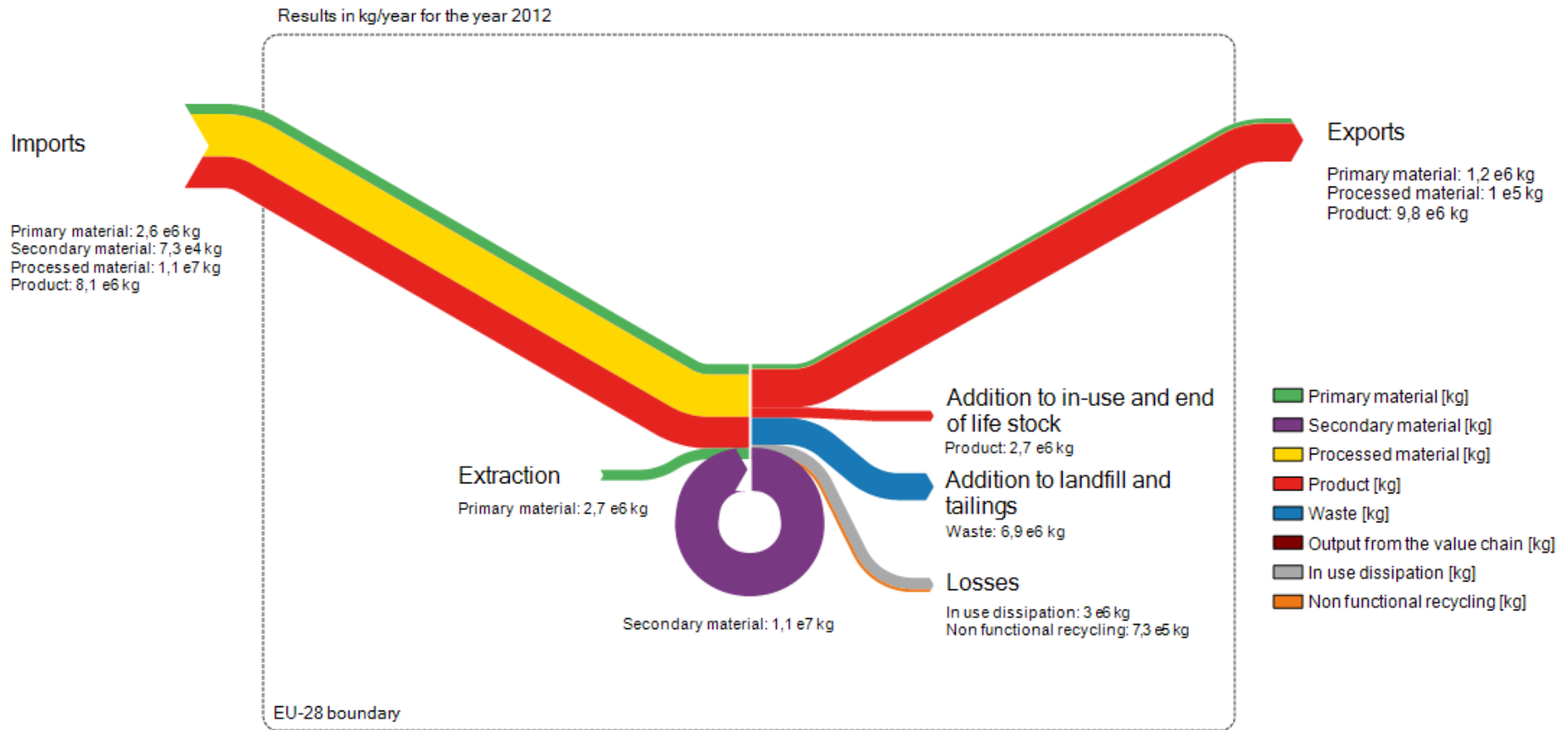
Data on the EU consumption of semi-finished products is provided from various expertise (among which ITIA). No data is available on final applications. Therefore a top down approach is used to calculate, from data on semi-finished products, the distinct flows for the steps manufacturing to

recycling. Information was gathered to characterize each of the finished products (lifespan, in-use dissipation, growth rate). Several hypothesis are made when data was not available, particularly regarding trade flows for a specific application. Therefore the reliability of the results for these steps is quite low. In a similar way, data on semi-finished products is used to calculate missing flows in the first sub-steps within manufacturing. Hypothesis are used for these sub-steps and thus impacted the overall reliability of the results in the manufacturing step.

Data provided in the MSA on tungsten recycling mainly originates from expertise gathered during personal communications with stakeholders. The results calculated in the MSA consider data on both quantities and quality (e.g. tungsten content, recycling process) of the recycled volumes, in order to best reflect reality. However the calculated recycling rate differs from data in literature because distinct definitions are used (focusing respectively on collected volumes and in use consumption).

Sankey diagram for tungsten

Figure 116: Simplified Sankey diagram for tungsten



4. Recommendations for updating and improving the Material System Analysis

The following sections present a number of recommendations for the European Commission to continue working on the update and improvement of the data inventory created during this project.

The project team has drawn these recommendations based on the experience gained working on this project. The following sections contain the view of the authors of this project and is not to be perceived as the opinion of the European Commission.

Sections 4.1 and 4.2 presents recommendations for the European Commission on actions related to the Material System Analysis.

Sections 4.1.1 and 4.1.2 propose some short-term actions to continue with the work presented in this document. Sections 4.2.1 and 4.2.2 suggest some initiatives at medium and long term that could improve the approach to develop MSA and the integration of the different sources of data and statistics in the EU.

Section 4.3 presents specific recommendations at short term for the team in charge of the revision and update of the data inventory for a Material System Analysis.

4.1 Short-term recommendations for the European Commission

4.1.1 Disclosure of information

The comprehensive MSA of the material flows in the EU industry is essential to get a sound background necessary for policy making and industry decisions on raw materials. This MSA builds knowledge and understanding of the flows of a number of critical and some non-critical raw materials in the EU.

The data generated in this project could be useful for the development of the Circular Economy Package of the European Commission, in a sense that it would allow decisions that provide balanced, secure and sustainable supply of raw materials throughout their entire life cycle.

However, according to several representatives of trade associations consulted during the project, a public MSA database would reveal broad information which could result in a disadvantage for the European industry. The argument was that the trade flows of critical materials and other key raw materials would be easily available for other market participants around the world which could better adjust their trade strategies by having a better access to the information about the European situation. This argument is in conflict with the original idea to better inform the EU industry as well as relevant governmental and non-governmental institutions to base their decisions on a sound knowledge base.

Therefore, it should be further discussed whether this new knowledge base about key raw materials results in more advantages than disadvantages to involved actors in the EU. The level of disaggregation of the data disclosed is a key aspect in this discussion. Highly aggregated data on material flows in the EU may help preserve sensitive information, but this will not provide much useful information. On the other hand, data on material flows disaggregated per industry sector or per traded goods would definitely be more informative for all users, at the cost of disclosing some delicate information.

It is therefore recommended to better analyse the situation by looking at “sensitive parameters” of the MSA for one example of critical raw material. Those sensitive parameters could be identified with

representatives of the relevant trade associations and analysed in order to figure out if they really result in information which could harm EU material policies.

Alternatively, the publication of each MSA and the degree of aggregation could be consulted and validated by the affected stakeholders in a case-by-case basis. In this way, the European Commission would ensure that the publication of the MSA would not interfere with the interests of EU stakeholders.

4.1.2 Update of the Material System Analysis

The present Material System Analysis is built on the basis of the situation of the EU economy in 2012, although a limited number of parameters may refer to other years due to lack of specific data. The information regarding supply and demand trends of materials in the EU are very scarce. Therefore, the present MSA may become obsolete in a short period of time. For this reason, it is recommended to update the MSA data periodically every 3 to 5 years. The quality of the data in a MSA depends highly on the availability of external data sources, either as a result of scientific research or provided by the industry. A time period lower than 3 years is not likely to be enough to allow a significant amount of new scientific production on this topic to be published. On the other hand, industrial and mining data are usually collected in a yearly basis, which would allow a thorough periodic review of part of the MSA.

These subsequent updates of the MSA would need to review the external data sources used in the present MSA with the objective of updating the specific data to the most recent year available at the time of research. Some approaches or calculation methods may also be object of revision, in case it is found that new external data is made available, or that the economic situation has evolved and the assumptions made became obsolete.

A possible strategic objective of MSA may be to optimise the recovery of certain materials at the different steps of their life cycle. Such optimization could be measured by comparing the amount of material wasted to the primary material input to each process. New “group 2” parameters could be added to each life cycle step to measure the “material waste rate”. For example:

$$C.2.4. \text{ Material waste rate in processing} = (C.1.5 + C.1.6) / (B.1.1 + B.1.2 + C.1.3 + C.1.4 + D.1.5 + G.1.1)$$

4.2 Medium- and long-term recommendations for the European Commission

4.2.1 Complementary work for a full Material System Analysis in the EU

One of the suggestions received from the stakeholders consulted on the methodology for developing the MSA referred to the approach proposed for the present project, which has been developed following a material-centric approach. The method used in the present project allows us to have a global view of the life cycle of the material from exploration and extraction to use, collecting and recycling, although the details and accuracy of some parameters and life cycle stages are sometimes low. An alternative method proposed by one stakeholder is to follow a product-centric approach in which the amounts of critical materials contained in products are quantified in a bottom-up calculation by using statistical data. This method could be applied in a reduced scope in a number of independent studies, namely on one material or group of materials. Otherwise, this method could be applied to study a number of materials together in a single model rather than in independent databases, and to explore in detail a huge number of products, technologies and industrial sectors that could potentially use the materials studied. The advantage of this latter option would be to reflect the interlinkages that different materials may have within the EU economy, the sectors that concentrate the highest quantities of critical materials, and to prioritise strategies to secure the supply and sustainable use.

Alternatively, it would also be interesting to develop prospective MSAs for short and long periods of time, based on production and demand models, technological trends, development of substitute materials, and other parameters. This would allow the user of the database to have a broader view of the expected evolution of production and uses of materials in the future, foresee potential shortages, and prepare possible alternative models of supply.

The full Material System Analysis in the EU is supposed to feed into the analysis of criticality of materials for the EU, as one of the main sources of data. However, both studies could benefit and complement each other. The study on criticality of raw materials will be reviewed in 2016, and could benefit from the data gathered and the knowledge created by the present project. In a similar way, the

revision of the study on criticality will include a number of materials that are not studied in the present project. That work will definitely be useful for any future extension of the MSA to other materials in the EU economy.

4.2.2 Recommendations for the improvement of EU databases with regards to the Material System Analysis needs

This section aims to provide the European Commission with recommendations on how to best improve the current EU databases with regard to the MSA needs.

Indeed Eurostat databases such as ComExt, PRODCOM and the waste database are a valuable source of information for the MSA of materials, but their use suffers from several limitations in this regard. These limitations are described below with recommendations of how changes could be made to benefit future MSAs.

4.2.2.1 Accuracy of the data

There might be some inaccuracy in the data provided, for instance from a Member State reporting incorrect information. An example can be provided with COMEXT code 38249075 for lithium niobate wafer imports and exports: the total EU exports are far too large, and examination of Member State data indicates that this is due to incorrect data from Spain.

It could be valuable to improve the frequency of **internal controls** on the values provided by each Member State, particularly when the information differs of more than 20% from one year to the other.

4.2.2.2 Units

Depending on the database, the units can be different for a same product (for example “pieces”, “kg”, “square meters”...). These units are often not interchangeable without additional information.

Conversion charts based on available and published information would be very useful. However some research may be needed for some codes.

4.2.2.3 Clarity of the name of codes

The understanding of some categories may be unclear due to the lack of precision in the name or the absence of related metadata. Code 81109000 is an example: the name is “Antimony articles n.e.s” but it is unclear what types of articles this code refers to. As a result, manufacturers, importers and exporters may not use the correct codes resulting in inaccurate data.

A **detailed guidance** could be published on the Eurostat website (in addition to the existing list of codes), explaining how each of the displayed codes should be interpreted. This may help avoiding some of the inaccuracies that are encountered.

4.2.2.4 Update of the codes

Some new products may not be accurately represented in the databases whereas some quite old products which are not produced any more are still taken into account in the codes. These situations are mainly encountered for high tech products, where critical raw materials are often used and it is therefore an obstacle for the development of MSA on such materials. For example, the code 26201100 represents “laptop PCs and palm-top organisers”. However, palm-top organisers are no longer produced in large volumes and their functions are now included in the functions provided by smart phones.

Thus, more frequent updates could be done regarding the codes relating to high tech products, which are likely to change quite often.

4.2.2.5 Combinations of materials gathered in a same code

Data on many rare or uncommon materials (including critical raw materials) are often aggregated with other materials. For example, ComExt code 81129150 is for waste and scrap containing gallium, indium and thallium. However, no data can be found specifically on gallium or indium in waste and scrap. Unless the average distribution between each material is known, this ComExt code cannot be valued in the context of MSA (i.e. it is not possible to use this trade data in MSA for specific materials).

A solution would be to **subdivide the existing codes** in order to have material-specific data or to **provide an average distribution** between the distinct materials for these types of code. This would

be of particular interest for the extraction and processing steps and for the materials considered as critical.

4.2.2.6 Material content in ores, concentrates, processed materials, scrap, wastes, ashes...

The material content in scrap, waste or ashes is generally unknown. Moreover, there can be some variation in the available information regarding the material content in ores, concentrates or processed materials (as alloys for example). The British Geological Survey provided in the past valuable data for many materials. However, this data might not match the current composition of products and this data is not always consistent with the codes displayed in the Eurostat database.

MSA would benefit from the determination and publication of **average material contents** for codes providing information specific to ores and concentrates, wastes, scrap, etc that are traded between the EU and the rest of the world. A regular review and update would be most welcome, for instance every 5 years.

4.2.2.7 Differences regarding the availability of data in PRODCOM and ComExt databases

When looking at specific products containing the studied materials, data on imports and exports is often available in the ComExt database but there may be no corresponding data on EU production in the PRODCOM database. For instance, ComExt code 38249075 provides data on import and export for lithium niobate wafers but there is no PRODCOM code providing the EU production, although several Member States manufacture this type of product.

On the contrary, the PRODCOM code 26201100 provides the EU production for laptop PCs but there is no information on imports and exports in the ComExt database, even if most laptop computers sold in Europe are made outside of the EU.

It is recommended to harmonise the availability of data on specific products in the PRODCOM and ComExt databases, with specific information when there no production in EU or no imports or exports.

4.2.2.8 Specific focus on Eurostat waste database

Eurostat waste database provides information on waste electrical and electronic equipment (WEEE), end of life vehicles (ELV), batteries and non-specific wastes such as municipal waste, hazardous waste, etc.

However, the database presents different limitations described below:

- The available information on batteries at end of life is quite limited, which is an obstacle for the development of the MSA of several critical raw materials used in different types of batteries (lithium and cobalt in lithium batteries, indium in alkali batteries, and antimony in lead-acid batteries).
- Although the quantities of electrical and electronic equipment placed on the EU market are provided by the WEEE database for all Member States with a reasonable accuracy, data from many Member States is still missing on quantities collected, treated, recovered and reused in the EU or treated outside the EU. In addition, calculation of the amount disposed to landfill is difficult due to the fact that WEEE treated outside of approved schemes is not known.
- Eurostat ELV database displays more detailed information than the WEEE Eurostat database, particularly regarding waste such as ferrous scrap, non-ferrous scrap, shredder light fractions, batteries, tyres, etc. However, examination of data for Member States indicates some inconsistencies as data appears to be missing for some countries. Thus, it is difficult to calculate totals regarding waste treated in EU and waste treated outside EU.
- Eurostat waste database provides data regarding the quantities of hazardous and non-hazardous waste generated from a variety of sources (e.g. from households, from mining and quarrying and from construction) and provides data by type of waste (e.g. metallic waste, glass wastes, etc.). However, the material concentration in the waste is not known.

Providing data on waste flows is of great interest for the MSA. For example, the quantities of each fraction recycled and disposed for ELV are useful, but there is no equivalent for WEEE or batteries, even though the WEEE directive, which requires separate recycling of printed circuit boards, implies that these specific flows could be measured and published. Consequently, **more detailed data** would be particularly useful for WEEE and batteries (by battery type) for the development of MSA.

Moreover, it would be useful for MSA if data on waste treatment were systematically published at the EU level as well as the Member State level.

It is probably inevitable that data will be missing due to collection and treatment outside of approved schemes and also to some extent due to illegal exports. For the WEEE directive in the future, the amounts collected, treated and recycled will be estimated by Member States based on rigorous survey procedures and this will include WEEE recycled outside of approved schemes. This data will be very useful for MSA. A similar approach for ELVs and batteries would also be useful for MSA.

Finally, municipal, hazardous and non-hazardous waste data could be used for future MSAs if the average material contents were known. Also, it would be helpful to know the proportions treated, recycled, landfilled or exported, for all types of waste if the material contents were measured or determined by extrapolation from other data.

4.3 Technical recommendations for MSA practitioners

This section aims to provide the European Commission service or the project team who will be in charge of the update of the MSA with recommendations on how to face the main difficulties encountered and how to best improve the current results.

4.3.1 Technical recommendations on the overall MSA

4.3.1.1 Recommendations regarding data availability

General consistency of the data

Because the overall MSA for a material must be consistent, it is important to systematically review the quality of the sources used and to have a critical look on the data provided.

For instance, when using Eurostat databases, there might be inaccuracy in the data provided by a Member State which impacts the result at the European level. Then, it is important to keep a system-wide point of view of the European industry, check potential inconsistencies in the data provided and compare data sources. Regarding this particular example on Eurostat databases, checking all information that differs of more than 20% from one year to the other can enhance the quality of the results.

Data on material content of products

When using a bottom-up approach (i.e. product oriented approach), data on material content in products strongly affects the studied material flows calculated at the European level. However, data on material content is scarce, especially for finished products but also for some semi-finished products or processed materials. Moreover, material content may vary along the years and old data sources may not be relevant anymore.

Therefore, when no recent references are available, confirming the chosen material content by stakeholders appears crucial in order to limit the uncertainties of the results.

Data available at a European country level or at worldwide level

When data is not available at the European level but is available for one (or several) Member States, different extrapolations can be made in order to estimate the missing data, as for example:

- calculation of the European consumption of a product based on the consumption for one (or several) European countries, by using the population living within these perimeters (mostly for the use step),
- calculation of the European production of a product based on the production for one (or several) European countries, using the estimated production capacity of the industrial companies (mostly for the processing steps)...

In other situations, data may be available at the worldwide level only. In this case, an extrapolation based on the population does not make sense due to the large disparities between countries. Then, information on market shares or production capacity may be useful to estimate the result at the European level.

However in both cases, consultation of experts remains decisive to confirm such extrapolations.

Codes from Eurostat databases

The understanding of some codes in Eurostat databases may be difficult due to the lack of precision in the name of the code or because various products are aggregated under the same code. In such situation, industrial stakeholders might be able to provide further information, particularly if they use any of these codes themselves (e.g. distribution between two products).

Nevertheless, when the distinction between several products cannot be made for a specific code, it is recommended that the data is not used or is only used to calculate typical shares of imports and exports between Europe and the rest of the world.

Data on waste

Eurostat waste database provides with information on various types of waste and secondary material flows. However the data available is quite limited and not fully in line with the MSA needs. For example, it does not focus on specific materials or on specific life cycle steps (e.g. waste from processing, waste from manufacture...).

To overcome this lack of adapted data on waste, it is generally necessary to make some hypothesis. For instance, the share of waste exported during the manufacture step can be extrapolated from the share of waste exported at the collection step. Otherwise, the share of waste exported for a product at end of life (e.g. cars) can be used as a proxy of the share of waste exported for a component of such product (e.g. the motor of a car). Nevertheless, when the literature does not confirm such hypotheses, stakeholder consultation appears decisive in order to limit uncertainties.

4.3.1.2 Recommendation regarding potential future use of commercial reports

Data regarding the flows and the applications of the studied materials are available in commercial reports such as the reports published by Roskill or some reports published by trade associations or material federations. These reports are published by specialists on various commodities and gather information collected along the years, based on consultation of industrial stakeholders and experts. For example, Roskill reports provide information on the supply, demand, end-use applications, trade and prices of over 50 metals and minerals, as well as informed forecasts of future trends.

Some of these reports could potentially be of some support for the development of the MSA. However, the use of data contained in commercial reports could raise copyright issues (since some results of the MSA could be publicly available) or problems of dependence towards private companies or associations. In any case, the project team had access during the present project to a few commercial reports on the supply, demand, end-use applications, trade, prices and forecasts of materials. Based in the experience of the project team, the content of these commercial reports did not add valuable information to that already publicly available in other sources consulted.

However, the question of buying or not such commercial reports should be investigated in a case-by-case basis for the update of the MSA, for instance through a more detailed analysis of the advantages and drawbacks of such solutions. For example, the cost of purchasing a report might be offset by the time saved from tasks such as collection of data from other sources. It should be noted, nevertheless, that any data purchased may need to be analysed or treated somehow before being used for the purpose of a MSA. For example, it may not refer exactly to the geographical scope, time period, or specific compound needed.

Also, it would be necessary to take into account the position of the European Commission as such decision may have consequences on the global budget necessary for the update of the MSA and on other issues mentioned above, such as copy rights or dependence towards private companies.

4.3.1.3 Recommendation on mass balance through the Material System Analysis

When building a MSA, it is crucial to ensure the conservation of mass all along the value chain. All the mass entering the system must stay in this system as a stock or go out of this system. This mass balance principle has to be applied to each step of the life cycle.

If data used to calculate flows of related steps lead to an imbalance, then it is necessary to check the completeness of data (some products or spare parts could have been missed, leading to an incomplete coverage of the flow) as well as the robustness of data (quality and reliability of data). In

most cases, adjustments of data and changes in hypotheses have to be made in order to match the mass balance. Although these adjustments can be done on the flows based on the least reliable data, this leads unequivocally to limitations in the quality of data in benefit of a mass-balanced system. In any case, it is important to note down any adjustment and hypothesis made, together with the alternative value or method discarded, in order to be able to trace and replicate the process in further revisions.

Theoretically, the subsequent application of the mass balances for each life cycle step should give a balanced overall picture. This is possible if all the inputs and outputs of each step are known or can be calculated independently from the other life cycle steps. Nonetheless, some flows may need to be calculated based on the data for other phases. This requires the entire MSA to be completed before checking the mass balance of the MSA and of each step. This is for example the case of the processing step, which has input flows from the manufacture and the recycling steps. The manufacturing step itself has also inputs from the recycling step. Thus, in case of data gaps, a first overview of the MSA should be completed before verifying the conservation of mass at these steps.

The exception to this principle is the exploration step. This step is not connected to any other step of the life cycle of the materials and does not enter the mass balance of the MSA. Extraction data (production of primary material) cannot be used to estimate the resources and reserves, and vice-versa. As a consequence, if data of resources or reserves are not available, they cannot be deduced by any mean from the other MSA flows and the overall mass balance.

Therefore, when data on reserves and resources is unavailable or confidential, it may be more relevant not to provide the information rather than to make unrealistic hypothesis.

4.3.1.4 Recommendation regarding internal recycling within one life cycle step

Waste generated during a life cycle step can be internally recycled within this step. For instance, the manufacture of aluminium generates a large share of waste and most of it is directly recycled within the manufacture industry.

In some situations, data on waste internally recycled within one life cycle step is included in data on waste generated during this step. However, such internally recycled flow is not to be taken into account in the MSA, as such a flow makes a loop within one step and does not constitute a loss of material.

Therefore, internally recycled flows have to be distinguished from the other flows of waste sent to disposal or sent to other life cycle steps for recycling. It means that the calculation of the waste generated during a life cycle step should exclude internal recycling, by readjusting some data used. To this aim, one should pay attention to favour a modification of the calculated data rather than data provided by a source or an expert.

4.3.1.5 Recommendations on the approach used to fill the data gaps between distinct steps of the MSA

When data is missing for a specific step, it is generally possible to fill the data gap by using the available data on the previous or the next step of the life cycle.

The way to fill this data gap depends on the general approach used for the calculation of the parameters at the previous or at the next step: bottom-up approach or top-down approach.

For example, the parameters at the manufacture step can be calculated based on the available data but no information is available for the use step. It means that the production of finished products sold in Europe is known but the information on imports is missing.

Depending on the data available at the manufacture step, one of these two procedures can be followed:

- if data is available for each of the finished products (including data on material contents), the imports in Europe of finished products can be calculated using the bottom-up approach;
- if data is available for the overall sector, the imports in Europe can be calculated using the top-down approach.

Otherwise, it may be necessary to estimate the share of exports among production or the share of imports among consumption, either for a product (bottom-up approach) or at the European level (top-down approach). In such case, stakeholder consultation appears critical to confirm the chosen hypothesis. An example of hypothesis is the use of the value in euros of volumes imported, exported and sold from Eurostat database; assuming that the financial value of a product remains constant through the years and for all types of flows.

Finally, when data is available for a specific sector, such information should be prioritized compared to calculation using the top-down or bottom-up approaches explained above. This may lead to a combination of data calculated by using different methods. This would also be the opportunity to compare the results of the top-down and bottom-up approaches with the existing data.

4.3.1.6 Recommendations on strengthening stakeholder participation within the project

Stakeholder participation was crucial to gather expertise on each material, during the elaboration of the MSA and during the workshops organised for each material. The regular contacts and discussions with experts allowed the project team find new sources of information, fill data gaps, establish hypothesis, correct issues or validate the work carried out along the process of building the MSA.

An early engagement of the experts is deemed essential for the successful development of the MSA. The discussions with the experts in the first steps of the research allows the project team to increase the sources of data, understand the life cycle of the materials and identify new experts in different aspects of the MSA of the material.

However, one of the main limitations to stakeholder participation was the data confidentiality, which prevented some stakeholders from providing additional information on a material, and in some cases prevented them from participating at all in the project.

In particular, since this project was the first project aiming at the development of MSA database in the EU, the stakeholders were not aware of the outcome of the project, neither in terms of format of the database nor in terms of data disclosed and available to the public.

This would be less of a problem in any future project if the stakeholders have access to the first editions of the database. Nevertheless, it is strongly recommended that the future project team insist on a transparent and optimized communication when contacting stakeholders, by specifying that:

- Only aggregated data would be available to the public (input and output volumes in material content at the different life cycle steps). For instance in the manufacturing step, the exports from Europe of intermediate and finished products are provided as one flow. No information regarding the exports of a specific product would be publicly available.
- When accurate information cannot be provided due to confidentiality reasons, estimations are still considered useful.
- The Excel file (with all detailed information) used to calculate aggregated data is provided to the European Commission for internal use only. However if confidentiality is still considered to be an issue with the potential information shared, the project team can omit the source of such information provided.

If the stakeholders clearly understand the purposes and the outcomes of the project prior to their participation, they might be less reticent to provide sensitive data. However, parameters related to confidential data remain dependent on industrial stakeholders to share their knowledge.

4.3.2 Technical recommendations specific to each life cycle step of the MSA

4.3.2.1 Recommendations specific to the exploration and extraction steps

The main public available data sources for the exploration and extraction of raw materials can be found at the geological surveys like the British Geological Survey (BGS), the United States Geological Survey (USGS) or the German Geological Survey (BGR). These surveys continuously collect and analyse data of raw material stocks in the earth crust which are extracted or extractable under current

economic conditions (mineral reserves) or below current economic conditions (mineral resources). They also provide information on annual extraction by raw material and country.

It would be very time consuming and costly to try to gather these data individually, which are partly available also on public reporting schemes of extractive industries or personal communication. Hence the use of data from geological surveys is a reasonable approach for collecting data on exploration and extraction in an efficient way. This is most obvious since information for mineral resources and reserves is needed on a worldwide basis.

However, it is underlined that generating consistent and reliable data on mineral reserves and resources is very difficult, due to the following main reasons:

- First of all, the definition of mineral reserves and resources are not homogenous around the world. A homogenous code of definitions was recently developed by stakeholders of extracting activities but their adequate application for all mines and stocks may take long time.
- Secondly, the amounts of reserves and resources in stocks depend on the current price of a raw material which may turn a stock from under-economic to economic reserves and vice versa. So based on this mechanism the amounts of mineral reserves and resources may change accordingly.
- Finally, also according to prices of a certain raw material the exploration activities may increase and decrease and generate more or less knowledge about stocks.

Considering these aspects it is recommended to use data from a uniform data source of a geological survey which is hopefully based on a consistent approach. The most recent and most carefully operated data set on mineral reserves and resources shall be used. This must be evaluated for any future update of the MSA.

Parting from a unique data base of a geological survey or research activity like Mineral4EU it is also recommended to countercheck with corresponding data of other geological surveys or the knowledge of experts in the field.

Specific problems arise on issues like the desired information on extraction as main product or extraction as by-product or if different grades of a raw material have to be distinguished. In the first case geological and extraction engineering knowledge is needed to separate the origin of raw material as main exploited commodity or valuable by-product. For instance gold can be extracted solely from sedimentary origin or can be a by-product in copper ore, separated later in the processing step. Also the second case can be challenging. In a similar way, it was not possible to find reliable information on the reserves of coking coal in comparison to steam coal. Only total coal reserves were reported in surveys and literature. The difference between coking coal and steam coal⁴ is not made in the available statistics on coal reserves and resources. According to the time and financial budgets, these issues could be solved by investigating in more detail.

Another specific challenge regarding data about extraction is the content of the raw material in tailings and other extraction residues. This figure is needed to get the amount of a specific raw material in these stocks because it can be a major raw material source in the future. The expert knowledge of raw material content in a mineral and its marginal value for economic feasible extraction is needed to estimate these figures. The amount of tailings and marginal raw material content can be used to calculate the stocks of the raw material. It must be decided in any specific case if the corresponding information can be retrieved from data sources like geological surveys or if the knowledge of experts is necessary.

4.3.2.2 Recommendations specific to the processing step

The processing step includes the first steps of transformation of the raw materials. Nevertheless it is a matter of agreement where the processing step ends and the manufacture step starts.

⁴ All "black" coal is steam coal but a certain quality is needed to produce coke and this part of "black" coal is called coking coal.

A clear definition of the primary materials entering the processing step and the processed materials leaving the processing step is the basis for correctly assigning material flows to this step. As the clear demarcation of the processing boundaries might be different for each material under study no general recommendation shall be given.

Depending on the inputs and outputs assigned to the processing step, it might be difficult to find appropriate information for these materials in public databases. Production statistics from trade associations and key companies in the area could be valuable data sources if information from statistical offices is not available or not sufficient.

A similar problem arises if further differentiation of the processed materials is needed, as for example if steel has to be distinguished into construction steel and stainless steel. If statistical offices cannot provide this information, internal information from industry trade statistics or industry experts could be helpful. However, such information reveals facts about the market structure which enables market participants to plan their strategies. Thus, such information could be kept confidential or could be sold at a quite expensive price.

Besides, production waste from the processing step might contain considerable amounts of the raw material under study. This raw material might be diluted or transferred to chemical compounds which cannot be exploited anymore under economic conditions. If information of the type and material content of waste from the processing step is not available from waste statistics, it is necessary to analyse each process step to estimate the amount of the raw material in the waste stream.

4.3.2.3 Recommendations specific to the manufacture step

The manufacture step converts processed materials to finished products which are ready to be used in the use step. So in general the same issues apply which had been discussed for the previous "Processing" step.

In case of a bottom-up approach (see 2.3.1), the main challenges are the definition of a simplified value chain, the collection of data regarding the flows of semi-finished and finished products considered in the simplified value chain and the determination of average material contents for these typical products.

As the range of finished products could be very broad, it is recommended to define typical finished products representative of the main sectors. It is also recommended to take into account only one level of semi-finished products per finished product. However, the level of detail has to be adjusted to the variety of these products or according to their importance in the mass flow.

Regarding the average contents of materials in finished products, no public databases exist. Some bills of materials in products could be found in LCA databases, such as ELCD or ecoinvent. Otherwise, it is necessary to search for case studies in literature to estimate average composition of products. Also the help of experts is needed to address data gaps or verify information from literature.

In case of a top-down approach (see 2.3.2), which is the approach recommended, the main challenges are to find data on the total amount of the studied material in the finished products at the European level and to find data on the shares of use of the material within the main sectors in Europe. Then, the definition of typical finished products per main sector is also required.

Regarding the total amount of the studied material in the finished products, one should pay attention to the representativeness of the data that could be found. Indeed, the available information can be representative of:

- the material input used in Europe to manufacture finished products (production sold in EU and imports of processed materials),
- the material output of the European manufacture industry (production sold in Europe and exports of finished products),
- or the final consumption in Europe at the use step (production sold in Europe and imports of finished products).

Depending on this representativeness, the data has to be handled in different ways.

Regarding the shares of use of the material within the main sectors, it is important to pay attention to the geographical perimeter of the data. Shares at the European level should be preferred. However, shares at world level could be used as a proxy when no other data is available.

Another aspect concerns the waste stream from the manufacture step. In many cases this waste stream is not considered as “waste” and not is reported in waste statistics. In the case of metals for instance this waste is called “new scrap” and directly delivered to recycling facilities without being reported. The information can only be based on the knowledge of the production process. Maybe in conjunction with the input into recycling facilities – e.g. at the processing step – it can be estimated which amounts of new scrap must come directly from the manufacturing.

If no specific information is available some general assumptions have to be made which are based on stoichiometry, general technology or even assuming that for the assembly no waste is generated at all. In those cases it should be clearly stated what had been assumed.

4.3.2.4 Recommendations specific to the use step

In the use step, the typical finished products representative of each main sector previously defined are analysed through their lifespan during use and their storage time at the consumer after use.

The MSA calculations at this step require having available several characteristics regarding these typical products such as: lifespan, in use dissipation rate, annual growth of consumption...

For the time being, only few study-based databases exist for material in anthropogenic stocks. Research on this aspect is emerging especially in the building sector and provides some information about stocks in buildings and roads. Nevertheless, many finished products like e.g. cars or electric appliances contain considerable amounts of material which are important to MSA but data on these stocks is missing.

Then, for the time being, average lifespans based on literature or assumptions were considered for the calculation of stocks of products per main sector. For many products used at home, some more specific information gathered by household polls exists at statistical offices. They probably could be used in future to improve the estimation of stocks in household if worth the effort.

Regarding the rate of dissipative use (distribution in fine particles, corrosive reactions...), it requires a one-by-one estimation of the product, the material and the use. Statistics will not be available for this issue due to the general character of dissipation. The in-use dissipation might be regarded as the gap between input and possible maximum collection of a material and treated as such in the material balance of the use phase.

4.3.2.5 Recommendations specific to the collection and recycling step

The use phase ends at a point where the consumer wants to hand over the end-of-life product to the collection services of that product. Collection and recycling statistics are part of waste management statistics and could be investigated together.

The composition of a waste is an overarching issue related to the material composition of a finished product and its modification in the use phase. Therefore, similar problems of lack of data are generally encountered for finished products and waste. Nevertheless, some waste statistics exist which also provide some information regarding material content, especially in the case of hazardous waste. It should be further investigated if this information is only historical or is kept updated and with which level of detail.

Besides, information about collection and recycling of post-consumer waste should normally exist as there are requirement of reporting at member State level and as it is generally handled within public service companies. However, the available data is often not detailed enough and there are lots of data gaps. In particular, the flows of waste from commercial uses are not consistently registered in statistics as end-of-life items are sometimes not considered as waste and directly transported to treatment facilities without entering waste statistics. Therefore, it is recommended to improve waste statistics, as explained in 4.2.2.

A possibility to overcome this problem of data gaps in MSA is to estimate the flows of waste collected for treatment based on EU consumption of finished products and characteristics of products such as lifespan, annual growth of consumption, in use dissipation... This approach, which was used for most

of the studied materials in this project, may lead to significant uncertainties but ensures mass balance consistency between the parameters at the use step and collecting step.

Then, for the update of the MSA, it is recommended to keep using this approach when information on waste flows is not detailed or reliable enough. However, if significant progress is made regarding waste statistics in the coming years, it could be interesting to make the calculation the other way round, that is to say to use the data on waste flows in order to deduce parameters at the use step, such as the in-use dissipation or the annual addition to stock.

Another aspect concerns the recycling step and in particular the need to distinguish functional and non-functional recycling and to determine recycling efficiencies for the different types of recycling and the different types of input flows. To this aim, it is recommended to use technical reports or to rely on expert knowledge to gather information. Then, it is recommended to put together all the available information (data on treatment efficiency, data on waste flows entering recycling facilities, data on production of secondary materials...) for reaching a plausible estimate of the material flows.

4.4 Conclusions

The previous sections list a number of recommendations for the European Commission and for MSA practitioners to take over the work carried out during this project.

This project has built a data inventory for a full Material System analysis on 28 raw materials in the EU. During this work, the project team has developed a comprehensive methodology and structure for this data inventory, which can be improved and completed in the future by the European Commission. The recommendations are therefore oriented to three main objectives:

1. To complete and update the present work,
2. To extend the scope of the MSA and explore new approaches to build the data inventory,
3. To integrate the present work with the existing data bases at EU level, and to harmonise them.

The first objective can be launched at short term, whereas the second and third objectives are proposed to be developed at medium and long term.

Cooperation at international level between industry, academia, policy makers and civil organisations, including those outside the EU, is key to complete a full Material System Analysis. This work will serve policy makers and industry as a valuable source of data to inform their decisions on raw materials in the EU.

5. Annex 1- Calculation of specific parameters of the Material System Analysis

5.1 Country concentration

This section aims to present the formulas used for the calculation of the following parameters:

- B.2.1 Country concentration at the extraction step,
- C.2.1 Country concentration at the processing step.

Those parameters assess to what extent the extraction or the processing of a material is subjected to a situation of monopoly at the country level. The situation of monopoly or high concentration is of great influence on the supply risk of a raw material, because dominant producing countries may be able to exert significant market power and to manipulate the end-user prices through strategic reductions in supply or price-fixing mechanisms.

According to the methodology used in the Report on *Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*, the parameter country concentration is calculated using the Herfindahl-Hirschman-Index (HHI). This index is given by the sum of the squared market shares of the countries involved in the extraction or processing market and can vary between 0 and 10,000. A value of 0 implies that the market is entirely fragmented and a value of 10,000 means that there is only one country which has 100% of the market.

5.1.1 Calculation formulas

The calculation formulas are given below:

$$\text{Country concentration at the extraction step} = HHI_{\text{Extraction, country}} = \sum_c (S_{\text{Extraction, country } c}^2)$$

$$\text{Country concentration at the processing step} = HHI_{\text{Processing, country}} = \sum_c (S_{\text{Processing, country } c}^2)$$

With:

$S_{\text{Extraction, country } c}$ = Share of the quantity of material extracted by country c within the global quantity of material extracted

$S_{\text{Processing, country } c}$ = Share of the quantity of material processed by country c within the global quantity of material processed

For the calculation of the HHI, the shares S need to be expressed in percentage (in the range 0-100 and not in the range 0-1).

5.1.2 Example

An example of calculation of country concentration at the extraction step is presented below for beryllium.

Table 6: Calculation of country concentration at the extraction step of beryllium, *data obtained from USGS (2014) Mineral commodity summaries and Beryllium Science and Technology Association (BeST) expertise*

Countries involved in extraction	Share (%)	Share ²
United States	70.98	5,038
China	6.94	48
Brazil	11.04	122
South Africa	11.04	122
Country concentration		5,330

With a Country concentration of 5,330, the beryllium mining industry is highly concentrated at country level.

5.2 Economic importance and substitutability Index

This section aims to present the formulas used for the calculation of the following parameters:

- D.2.3 Economic importance,
- D.2.2 Substitutability index.

According to the methodology used in the *Report on Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*, the parameter Economic importance is calculated based on the proportion of each material associated with industrial megasectors⁵ at EU level (Figure 117). These proportions are then combined with the megasectors' gross value added (GVA) to the EU's Gross domestic product (GDP). This total is then scaled according to the total EU GDP to define an overall economic importance for a material.

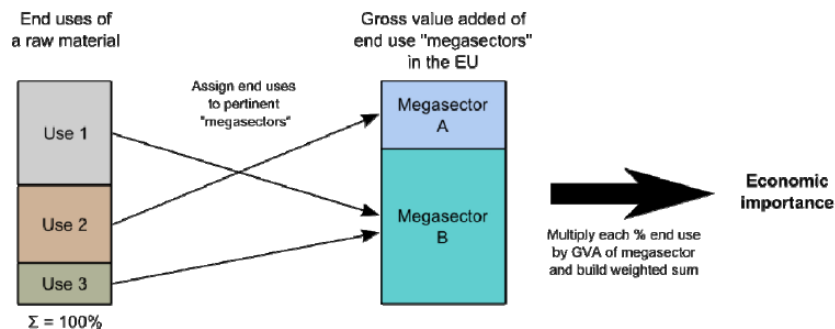


Figure 117: Illustration of the parameter economic importance (source: Report on CRM for the EU)

The potential for substitution, which is the estimated substitution potential for a raw material in a particular end-use sector, is used to build the substitutability index of a material. The potential for substitution of each use has been estimated by expert judgment in the CRM study. Possible values for substitutability are:

⁵ As defined in the 2014 Report on Critical Raw material for EU, each "megasector" is defined by a collection of related NACE sectors at the three and four digit level, as outlined in the Annex B of the Annexes to the Report on Critical Raw Materials for the EU.

- 0: Easily and completely substitutable at no additional cost,
- 0.3: Substitutable at low cost,
- 0.7: Substitutable at high cost and/or loss of performance,
- 1: Not substitutable.

A weighted sum (according to the share of the uses) is constructed to characterize the overall substitutability index of the raw material.

5.2.1 Calculation formulas

The calculation formula for economic importance is given below:

$$\text{Economic importance} = (\sum_s A_s * Q_s)$$

With:

A_s = Share of consumption of a raw material in an end-use sector s

Q_s = GVA of the corresponding megasector s (GVA is obtained from EUROSTAT's Structural Business Statistics for the EU)

The sum of the contribution to economic importance of each megasector has to be scaled to fit between 0 and 10, where 10 is the highest possible economic importance. The maximum possible economic importance is given when all end uses are assigned to the megasector with the highest GVA in a given year (i.e. Mechanical Equipment with 182.41 kEuros). Therefore, the relative economic importance EI has to be divided by 182,410; and finally multiplied by 10 to be scaled. Threshold for criticality is 5 according to the 2010 Critical raw materials for the EU Report of the European Commission.

The calculation formula for substitutability index is given below:

$$\text{Substitutability Index} = \sum_s A_s * \sigma_s$$

With:

A_s = Share of consumption of a raw material in an end-use sector s

σ_s = Potential for substitution of the material in this end-use sector s

5.2.2 Example

An example of calculation of economic importance and substitutability index is presented for beryllium.

Table 7: Calculation of economic importance and substitutability index of beryllium, data obtained from calculation based on EC (2014) Report on Critical Raw Materials for the EU and BeST expertise

Use	Share (%) A_s	Potential for Substitution σ_s	Megasector	Megasector GVA Q_s	Contribution to economic importance (Share x Megasector GVA)	Contribution to substitutability index (Share x Potential for substitution)
Mechanical equipment	20%	1	Mechanical Equipment	182 406	35 759	0,20
Electrical equipment and domestic appliances	13%	1	Electrical Equipment & Dom. Appliances	88 139	11 731	0,13

Use	Share (%) A_s	Potential for Substitution σ_s	Megasector	Megasector GVA Q_s	Contribution to economic importance (Share x Megasector GVA)	Contribution to substitutability index (Share x Potential for substitution)
Electronics & IT	16%	0.7	Electronics & ICT	104 855	17 058	0,11
Road transport	17%	1	Road Transport	147 442	25 286	0,17
Aircraft, shipbuilding and trains	6%	1	Aircraft, Shipbuilding, Trains	51 222	2 893	0,06
Rubber, plastics and glass	18%	0.7	Rubber, Plastic & Glass	98 135	17 599	0,13
Metals	10%	1	Metals	164 623	16 607	0,10
Total					126,932	0.90

European Economic importance of beryllium = $(126,932 / 182,410) * 10 = 6.96$

European Substitutability Index of beryllium = 0.90

5.3 Governance risk supply

This section aims to present the formulas used for the calculation of the following parameters:

- B.2.2 Governance risk supply at the extraction step,
- C.2.2 Governance risk supply at the processing step.

Risk supply is assumed to be mostly concentrated at the extraction step and at the processing step on supply from countries exhibiting poor governance (because the supply may be interrupted e.g. through political unrest).

According to the methodology used in the *Report on Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*, the parameter governance risk supply is calculated based on the production shares of each country and based on the country indicator for world governance performance (WGI). The parameter is calculated by using the Herfindahl-Hirschmann-Index (HHI).

In addition, the supply risk is considered to be reduced by the availability of secondary supply from end-of-life products. Furthermore, the risk is reduced by the existence of options for full substitution (price and performance). Therefore, the overall governance risk supply is considered to arise from a combination of several factors (see Figure 118), namely:

- high concentration of producing countries with poor governance performance,
- end-of-life recycling input rates at world level,
- substitutability.

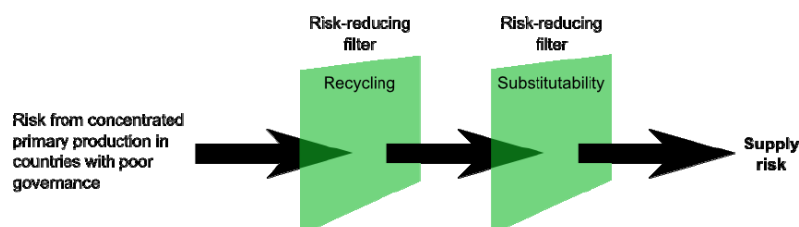


Figure 118: Illustration of the parameter governance risk supply (source: Report on CRM for the EU)

5.3.1 Calculation formulas

The calculation formulas are given below:

$$HHI_{Extraction,WGI} = \sum_c (S_{Extraction,c}^2 * WGI_{scaled,c})$$

$$\text{Governance Risk Supply at the extraction step} = HHI_{Extraction,WGI} * I_s * (1 - R)/10,000$$

$$HHI_{Processing,WGI} = \sum_c (S_{Processing,c}^2 * WGI_{scaled,c})$$

$$\text{Governance Risk Supply at the processing step} = HHI_{Processing,WGI} * I_s * (1 - R)/10,000$$

With:

$WGI_{scaled,c}$ = World governance performance indicator for the country c

$S_{Extraction,c}$ = Share of the quantity of material extracted by country c within the global quantity of material extracted

$S_{Processing,c}$ = Share of the quantity of material processed by country c within the global quantity of material processed

I_s = Substitutability Index of the material

R = End-of-life Recycling Input Rate at world level (measures the proportion of material that is produced from End-of-Life scrap worldwide)

For the calculation, the shares S_c need to be expressed in percentage (in the range 0-100 and not in the range 0-1).

The values for $WGI_{scaled,c}$ are taken from Annex B (Table 1.6) of the *Report on Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*. These indexes range from 0 to 10.

HHI ranges from 0 to 100,000. Indeed, the upper bound refers to a monopoly situation ($100^2 = 10,000$) in a country with the worst possible WGI_{scaled} (10), which gives the highest possible HHI of 100,000 ($10,000 \times 10 = 100,000$).

The factor $(1-R)$ corresponds to the fraction of world supply covered by primary resources. It ranges from 0 to 1. The value of R is taken from Annex C of the *Report on Critical Raw Materials for the EU - Report of the Ad hoc Working Group on defining critical raw materials (2014, European Commission)*. The substitutability index I_s ranges from 0 to 1 (with 1 corresponding to the least substitutable situation) and is taken from the same source.

After division by 10,000, the governance risk supply is scaled to lie between 0 and 10. The threshold for criticality is 1 according to the 2010 Critical raw materials for the EU Report of the European Commission.

5.3.2 Example

An example of calculation of governance risk supply at extraction is presented below for beryllium.

Table 8: Calculation of governance risk supply at the extraction step for beryllium, *data obtained from USGS (2014) Mineral commodity summaries, EC (2014) Report on Critical Raw Materials for the EU and BeST expertise*

Country involved in extraction	Share (%)	Share ²	WGI _{scaled}	Contribution to HHI _{Extraction,WGI}
United States	70.98	5,038	2.53	12,746
China	6.94	48	6.18	298
Brazil	11.04	122	4.73	577
South Africa	11.04	122	4.49	547
HHI	HHI_{Extraction,WGI} = 14,167			

$I_s = \text{World Substitutability Index of beryllium} = 0.85$

$(1-R) = (1-\text{World Recycling Input Rate of beryllium}) = 1 - 0.19 = 0.81$

Governance Risk Supply at the extraction step = $\frac{14,167 * 0.85 * (1-0.19)}{10,000} = 0.98$

5.4 Stock and flow parameters at the Use step and stock in landfill

This section aims to present the formulas used for the calculation of the following parameters:

- E.1.1 Stock of manufactured products in use in EU,
- E.1.2 Stock of manufactured products at end of life in EU,
- E.1.3 Exports from EU of manufactured products for reuse,
- E.1.5 In use dissipation in EU,
- E.1.6 Products at end of life in EU collected for treatment,
- E.1.7 Annual addition to in use stock of manufactured products in EU,
- E.1.8 Annual addition to end of life stock of manufactured products in EU,
- F.1.5 Stock in landfill.

These parameters are calculated based on several data and notably on the following parameters:

- D.1.1 Production of manufactured products in EU sent to use in EU,
- E.1.4 Imports to EU of manufactured products.

For each parameter, the calculation formulas described below are defined for a specific end-use, that is to say a specific type of product i containing the studied material X. The global parameter for all the types of products containing the material X is the sum of the parameters calculated for each product i.

In addition, the parameters are defined for a specific year, which is different according to the materials. Indeed, the majority of materials have their reference year of 2012, and some of 2013.

For example:

$$E.1.1_{year N} = \sum_{product i} E.1.1_{product i, year N}$$

One considers a specific product i containing the studied material X and one defines the following parameters. In order to ease the understanding, one considers a fictive example with fictive values indicated in blue.

$year N = \text{Reference year for the MSA} = 2012$

$L_{use} = \text{Lifespan of product i in Europe} = 6 \text{ years}$

$R_{eol} = \text{Rate of product i kept by users after end of life in Europe}$

L_{eol} = Time during which products i kept by users after end of life are kept by users in Europe = 2 years

R_D = In use dissipation rate of product i in Europe

AG = Annual Growth rate of consumption of product i in Europe

Input flow i year N = input flow of product i in year N = Production of product i in EU sent to use in EU in year N + Imports to EU of product i in year N = $D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N}$

Output flow i year N = Flow of product i reaching end of life in 2012 and not kept by users + Flow of product i already at end of life and no longer kept by users in 2012)

R_R = Rate of products i exported for reuse

Some flows and stocks defined above are illustrated in the figure below for the fictive example.

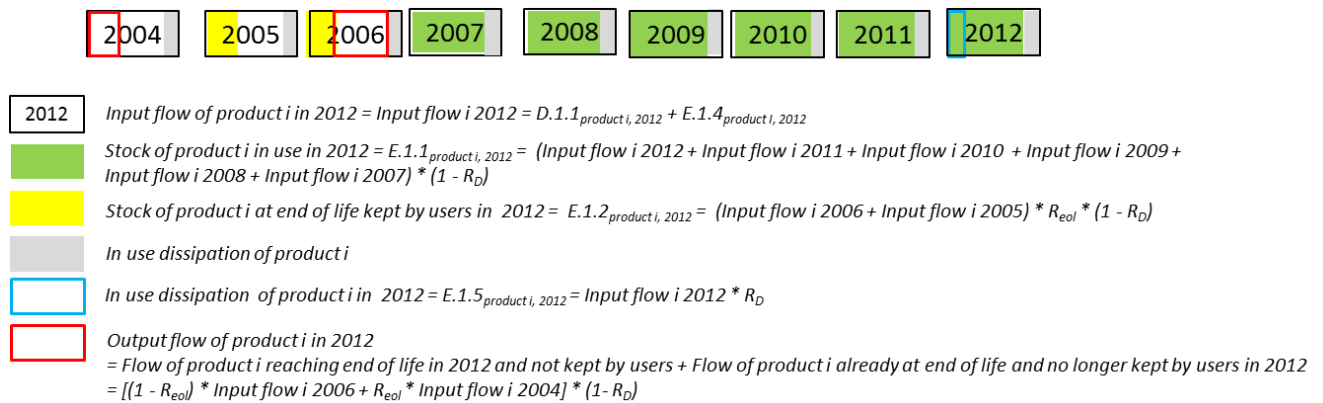


Figure 119: Illustration of the calculation of stocks and flows at the Use step, with fictive values

5.4.1 Stock of manufactured products in use in EU (E.1.1)

In the fictive example for product i , the stock of product i in use in 2011 can be calculated as follows:

$$\begin{aligned}
 & E.1.1_{product\ i, 2012} \\
 & = (Input\ flow\ i\ 2012 + Input\ flow\ i\ 2011 + Input\ flow\ i\ 2010 + Input\ flow\ i\ 2009 + Input\ flow\ i\ 2008 + Input\ flow\ i\ 2007) * (1 - R_D) \\
 & = (Input\ flow\ i\ 2012 + \frac{Input\ flow\ i\ 2012}{(1+AG)} + \frac{Input\ flow\ i\ 2012}{(1+AG)^2} + \frac{Input\ flow\ i\ 2012}{(1+AG)^3} + \frac{Input\ flow\ i\ 2012}{(1+AG)^4} + \frac{Input\ flow\ i\ 2012}{(1+AG)^5}) * (1 - R_D) \\
 & = Input\ flow\ i\ 2012 * (1 + \frac{1}{1+AG} + \frac{1}{(1+AG)^2} + \frac{1}{(1+AG)^3} + \frac{1}{(1+AG)^4} + \frac{1}{(1+AG)^5}) * (1 - R_D)
 \end{aligned}$$

The general formula is given below:

$$\begin{aligned}
 & E.1.1_{product\ i, year\ N} \\
 & = Input\ flow\ i\ year\ N * \sum_{n=0}^{L_{use}-1} \frac{1}{(1+AG)^n} * (1 - R_D) \\
 & = (D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N}) * [\frac{1 - (\frac{1}{1+AG})^{L_{use}}}{1 - \frac{1}{1+AG}}] * (1 - R_D)
 \end{aligned}$$

5.4.2 Stock of manufactured products at end of life in EU (E.1.2)

In the fictive example for product i , the stock of product i at end of life kept by users in 2012 can be calculated as follows:

$$\begin{aligned}
& E.1.2_{product\ i, 2012} \\
& = (Input\ flow\ i\ 2006 + Input\ flow\ i\ 2005) * R_{eol} * (1 - R_D) \\
& = Input\ flow\ i\ 2006 * \left(1 + \frac{1}{1+AG}\right) * R_{eol} * (1 - R_D) \\
& = Input\ flow\ i\ 2012 * \frac{1}{(1+AG)^6} * \left(1 + \frac{1}{1+AG}\right) * R_{eol} * (1 - R_D)
\end{aligned}$$

The general formula is given below:

$$\begin{aligned}
& E.1.2_{product\ i, year\ N} \\
& = Input\ flow\ i\ year\ N * \frac{1}{(1+AG)^{L_{use}}} * \sum_{n=0}^{L_{eol}-1} \frac{1}{(1+AG)^n} * R_{eol} * (1 - R_D) \\
& = (D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N}) * \frac{1}{(1+AG)^{L_{use}}} * \left[\frac{1 - \left(\frac{1}{1+AG}\right)^{L_{eol}}}{1 - \frac{1}{1+AG}} \right] * R_{eol} * (1 - R_D)
\end{aligned}$$

5.4.3 Exports from EU of manufactured products for reuse (E.1.3)

In the fictive example for product i, the export for reuse of product i in 2012 can be calculated as follows:

$$\begin{aligned}
& E.1.3_{product\ i, 2012} \\
& = Output\ flow\ I\ 2012 * R_R \\
& = (Flow\ of\ product\ i\ reaching\ end\ of\ life\ in\ 2012\ and\ not\ kept\ by\ users + Flow\ of\ product\ i\ already\ at\ end\ of\ life\ and\ no\ longer\ kept\ by\ users\ in\ 2012) * R_R \\
& = [(1 - R_{eol}) * Input\ flow\ i\ 2006 + R_{eol} * Input\ flow\ i\ 2004] * (1 - R_D) * R_R \\
& = \left[(1 - R_{eol}) * \frac{Input\ flow\ i\ 2012}{(1+AG)^6} + R_{eol} * \frac{Input\ flow\ i\ 2012}{(1+AG)^8} \right] * (1 - R_D) * R_R \\
& = Input\ flow\ i\ 2012 * \left(\frac{1 - R_{eol}}{(1+AG)^6} + \frac{R_{eol}}{(1+AG)^8} \right) * (1 - R_D) * R_R
\end{aligned}$$

The general formula is given below:

$$\begin{aligned}
& E.1.3_{product\ i, year\ N} \\
& = (D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N}) * \left(\frac{1 - R_{eol}}{(1+AG)^{L_{use}}} + \frac{R_{eol}}{(1+AG)^{L_{use} + L_{eol}}} \right) * (1 - R_D) * R_R
\end{aligned}$$

5.4.4 In use dissipation in EU (E.1.5)

In the fictive example for product i, the in use dissipation of product i in 2012 can be calculated as follows:

$$\begin{aligned}
& E.1.5_{product\ i, 2012} \\
& = Input\ flow\ i\ 2012 * R_D
\end{aligned}$$

The general formula is given below:

$$\begin{aligned}
& E.1.5_{product\ i, year\ N} \\
& = (D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N}) * R_D
\end{aligned}$$

5.4.5 Products at end of life in EU collected for treatment (E.1.6)

In the fictive example for product i, the flow of product i at end of life collected for treatment in 2012 can be calculated as follows:

$$E.1.6_{product\ i, 2012}$$

$$\begin{aligned}
&= \text{Output flow } i \text{ 2012} * (1 - R_R) \\
&= (\text{Flow of product } i \text{ reaching end of life in 2012 and not kept by users} + \text{Flow of product } i \text{ already at end of life and no longer kept by users in 2012}) * (1 - R_R) \\
&= [(1 - R_{eol}) * \text{Input flow } i \text{ 2006} + R_{eol} * \text{Input flow } i \text{ 2004}] * (1 - R_D) * (1 - R_R) \\
&= [(1 - R_{eol}) * \frac{\text{Input flow } i \text{ 2012}}{(1+AG)^6} + R_{eol} * \frac{\text{Input flow } i \text{ 2012}}{(1+AG)^8}] * (1 - R_D) * (1 - R_R) \\
&= \text{Input flow } i \text{ 2012} * (\frac{1-R_{eol}}{(1+AG)^6} + \frac{R_{eol}}{(1+AG)^8}) * (1 - R_D) * (1 - R_R)
\end{aligned}$$

The general formula is given below:

$$\begin{aligned}
&E.1.6_{\text{product } i, \text{ year } N} \\
&= (D.1.1_{\text{product } i, \text{ year } N} + E.1.4_{\text{product } i, \text{ year } N}) * (\frac{1-R_{eol}}{(1+AG)^{L_{use}}} + \frac{R_{eol}}{(1+AG)^{L_{use}+L_{eol}}}) * (1 - R_D) * (1 - R_R)
\end{aligned}$$

5.4.6 Annual addition to in use stock of manufactured products in EU (E.1.7)

$$\begin{aligned}
&E.1.7_{\text{product } i, \text{ year } N} \\
&= \Delta E.1.1_{\text{product } i, \text{ year } N} \\
&= E.1.1_{\text{product } i, \text{ 2012}} - E.1.1_{\text{product } i, \text{ 2011}} \\
&= \frac{1 - \frac{1}{(1+AG)^{L_{use}}}}{1 - \frac{1}{1+AG}} * (1 - R_D) * (\text{Input flow } i \text{ 2012} - \text{Input flow } i \text{ 2011}) \\
&= \frac{1 - \frac{1}{(1+AG)^{L_{use}}}}{1 - \frac{1}{1+AG}} * (1 - R_D) * \text{Input flow } i \text{ 2012} * (1 - \frac{1}{1+AG}) \\
&= (D.1.1_{\text{product } i, \text{ year } N} + E.1.4_{\text{product } i, \text{ year } N}) * (1 - \frac{1}{(1+AG)^{L_{use}}}) * (1 - R_D)
\end{aligned}$$

5.4.7 Annual addition to end of life stock of manufactured products in EU (E.1.8)

$$\begin{aligned}
&E.1.8_{\text{product } i, \text{ year } N} \\
&= \Delta E.1.2_{\text{product } i, \text{ year } N} \\
&= E.1.2_{\text{product } i, \text{ 2012}} - E.1.2_{\text{product } i, \text{ 2011}} \\
&= \frac{1}{(1+AG)^{L_{use}}} * \frac{1 - \frac{1}{(1+AG)^{L_{eol}}}}{1 - \frac{1}{1+AG}} * (1 - R_D) * R_{eol} * (\text{Input flow } i \text{ 2012} - \text{Input flow } i \text{ 2011}) \\
&= \frac{1}{(1+AG)^{L_{use}}} * \frac{1 - \frac{1}{(1+AG)^{L_{eol}}}}{1 - \frac{1}{1+AG}} * (1 - R_D) * R_{eol} * \text{Input flow } i \text{ 2012} * (1 - \frac{1}{1+AG}) \\
&= (D.1.1_{\text{product } i, \text{ year } N} + E.1.4_{\text{product } i, \text{ year } N}) * \frac{1}{(1+AG)^{L_{use}}} * (1 - \frac{1}{(1+AG)^{L_{eol}}}) * (1 - R_D) * R_{eol}
\end{aligned}$$

5.4.8 Stock in landfill (F.1.5)

For the parameter F.1.5 Stock in landfill in EU, the waste considered are the processing waste, the manufacturing waste, the products at end of life and the recycling waste that are sent for disposal (C.1.5, D.1.4, F.1.3 and G.1.5). For the calculation of the stock, one considers the amount of material accumulated in landfill over the last 20 years as a maximum level. However, in some cases, this period of 20 years can be reduced if the material is used in specific products that did not exist 20 years ago.

For example, steels with niobium have been used for construction for more than 20 years but buildings and bridges have not yet reached end of life so F1.3 and G1.5 are both zero. Indium has also been used to make flat panel Liquid Crystal Displays (LCD) in computers, televisions and mobile phones for about 18 years. Waste from these started to arise about six years later (i.e. 12 years ago).

The stock is calculated with two parts.

The stock due to manufacturing waste, products at end of life and recycling waste is calculated for each specific end-use, that is to say for each specific type of product *i* containing the studied material *X*.

The stock due to processing waste is calculated at a global level for all the types of processed materials supplied at the manufacture step.

For the stock due to manufacturing waste, products at end of life and recycling waste, the general formula is given below. The period of 20 years can be reduced depending on the product *i*.

$$\begin{aligned}
 F.1.5_{product\ i, year\ N} &= \text{Flow going to landfill year } N \text{ for product } i * \left(1 + \frac{1}{1+AG} + \frac{1}{(1+AG)^2} + \dots + \frac{1}{(1+AG)^{19}}\right) \\
 &= \text{Flow going to landfill year } N \text{ for product } i * \left(\frac{1 - \left(\frac{1}{1+AG}\right)^{20}}{1 - \frac{1}{1+AG}}\right) \\
 &= (D.1.4_{product\ i, year\ N} + F.1.3_{product\ i, year\ N} + G.1.5_{product\ i, year\ N}) * \left(\frac{1 - \left(\frac{1}{1+AG}\right)^{20}}{1 - \frac{1}{1+AG}}\right)
 \end{aligned}$$

For the stock due to processing waste, the general formula is given below. The annual growth rate *AG'* of the consumption of processed materials can be different from the one (*AG*) of end-products.

$$F.1.5_{processed\ waste, year\ N} = C.1.5_{year\ N} * \left(\frac{1 - \left(\frac{1}{1+AG'}\right)^{20}}{1 - \frac{1}{1+AG'}}\right)$$

Finally, the parameter F.1.5 Stock in landfill in EU is calculated as follows:

$$F.1.5_{year\ N} = \left(\sum_{product\ i} F.1.5_{product\ i, year\ N}\right) + F.1.5_{processed\ waste, year\ N}$$

5.4.9 Verification of mass balance at the use step

In order to check the mass balances, the following equation needs to be verified:

$$\begin{aligned}
 D.1.1_{product\ i, year\ N} + E.1.4_{product\ i, year\ N} - E.1.3_{product\ i, year\ N} - E.1.5_{product\ i, year\ N} - E.1.6_{product\ i, year\ N} \\
 = E.1.7_{product\ i, year\ N} + E.1.8_{product\ i, year\ N}
 \end{aligned}$$

5.5 Recycling rates at the recycling step

This section aims to present the formulas used for the calculation of the following parameters:

- G.2.1 European Functional Recycling Rate,
- G.2.2 European Non Functional Recycling Rate.

Those parameters are calculated on the basis of other flow parameters at the EU level:

- E.1.6 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.1.2 Imports to the EU of manufactured products at end of life,
- 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.1.4 Production of secondary material from post-consumer non-functional recycling in the EU.

The calculation formulas are the following:

$$G.2.1 = \frac{G.1.1+G.1.2}{E.1.6+F1.2-F.1.1}$$

$$G.2.2 = \frac{G.1.4}{E.1.6+F1.2-F.1.1}$$

6. Annexes 2– data sources

This annex presents the list of data sources used and the main stakeholders who contributed to the development of the MSA for each material.

These stakeholders provided important insights and helped through confirming or infirming some preliminary results. However please note that these stakeholders did not always validate the overall MSA for their material of interest.

6.1 Aggregates

List of the main stakeholders who contributed to the MSA

- Union Européenne de Producteurs de Granulats
- British Geological Survey
- Industrial Minerals Association Europe

Table of data sources used

Table 9 : Data sources used for the MSA of Aggregates

Data sources used for the MSA on Aggregates
Aggregates Levy Sustainable Fund (2007) Optimising The Efficiency Of Primary Aggregate Production
Eurostat database. Production in construction - annual data, percentage change [sts_coprgr_a]. Accessed in December 2014
Eurostat PRODCOM database. http://ec.europa.eu/eurostat/data/database , accessed in April 2014
Mitchell (2009) Quarry Fines and Waste
NRMCA (2002) Environmental LCI of portland cement concrete
RockProducts website. http://www.rockproducts.com/features/13045-world-aggregates-market.html#.VJh43sHDk . Accessed in December 2014
Roskill (2014) Study on CRM at EU level - Critical material profiles issue
UEPG (2011) Recycling of C&D Materials. European Perspectives. Presentation July 2011
UEPG (2012) A sustainable industry for a sustainable Europe
UEPG (2014) Annual review
UEPG statistics of aggregates production http://www.uepg.eu/statistics/estimates-of-production-data/data-2012 , accessed in December 2014
USGS (2014) Mineral commodity summary - Crushed Stone
USGS (2014) Mineral commodity summary - Sand and gravel, construction

6.2 Antimony

List of the main stakeholders who contributed to the MSA

- International Antimony Association
- Plastics Europe
- Eurobat
- Umicore

Table of data sources used

Table 10: Data sources used for the MSA of Antimony

Data sources used for the MSA on Antimony
ACEA Trade Association website: http://www.acea.be/ , accessed March 2015
Boliden Mines (2013) Mines Technology
Defra (2007) Trial to establish waste electrical and electronic equipment (WEEE) protocols
Defra (2009) Maximising Reuse and Recycling of UK clothing and textiles
EC (2004) Advantages and drawbacks of restricting the marketing and use of lead in ammunition, fishing sinkers and candle wicks
EC (2014) Report on Critical Raw Materials for the EU - Critical material profiles
EEA (2012) Movements of waste across the EU's internal and external borders
Euratex (2013) Key Figures 2013
Eurobat (2014) The availability of automotive lead-based batteries for recycling in the EU
European Parliament (2010) End of life vehicles: Legal aspects, national practices and recommendations for future successful approach
Eurostat Database, http://ec.europa.eu/eurostat/data/database
Federal Office for the Environment FOENBern (2007) Antimony in Switzerland, A substance flow analysis
Gunn et al. (2014) Critical Metals Handbook
Horrocks and Price (2008) Advances in fire retardant materials
IfM (2006) Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom
Matthews et al. (1999) Disposition and End-of-Life Options for Products: A Green Design Case Study
Mining website: http://www.mining.com/adroit-updates-antimony-soil-sampling-in-italy/
Morf et al. (2007) Metals, non-metals and PCB in electrical and electronic waste – Actual levels in Switzerland
Öko Institut (2010) Adaptation to scientific and technical progress of Annex II to Directive 2000/53/EC (ELV) and of the Annex to Directive 2002/95/EC (RoHS)
Ouvertes Project (2005) Report by textile reuse and recycling players on the status of the industry in Europe
Petcore website: www.petcore.org
PETRA website: http://www.petresin.org/aboutpet.asp
Plastics Europe (2013) Plastics – the Facts 2013. An analysis of European latest plastics production, demand and waste data
Rahn and Sturdivan (2004) Neutron activation and the JFK assassination, Part I. Data and interpretation
Roskill Mineral Services (2007) Antimony: Global markets and outlook
Roskill Mineral Services (2011) Study of the Antimony Market
Roskill Mineral Services (2012) Antimony: Changes in the pattern of supply and demand
Schönwald Consulting (2007) The Market for Barrier Enhanced PET Bottles in Western, Central and Eastern Europe 2006 and Outlook 2011

Swiss Federal Office of Public Health (?) Diffusion coefficient of antimony catalysts in polyethylene terephthalate (PET) materials
Tri-Star Resources (2012) Antimony uses, production & prices
UK Government website: https://www.gov.uk/government/statistics/composition-of-local-authority-waste
USGS (2002) Antimony recycling in the United States in 2000
USGS website, Antimony market data: http://minerals.usgs.gov/minerals/pubs/commodity/antimony/ , accessed in 2014 and 2015
Wire & Cable India website: http://www.wirecable.in/2014/07/global-cable-market-grew-by-3-in-2013/

6.3 Beryllium

List of the main stakeholders who contributed to the MSA

- Beryllium Science & Technology Association
- NGI
- IBC Advanced Alloys
- NGK BerylCo
- Materion
- www.tropag.de

Table of data sources used

Table 11: Data sources used for the MSA of Beryllium

Data sources used for the MSA on Beryllium
Beryllium Science and Technology Association (BeST) website: http://beryllium.eu/ , accessed in May 2015
Beryllium Science and Technology Association (BeST) website: http://beryllium.eu/health-environment-legislation/recycling/ , accessed in May 2015
Boeing (2013) Key Findings on Airplane Economic Life
BRGM (2011) Panorama 2010 du marché du Béryllium
Committee on Assessing the Need for a Defense Stockpile, National Research Council (2008) Managing materials for a 21st century Military
Cowi (2011) European second-hand car market analysis
EC (2014) Report on Critical Raw Materials for the EU - Critical material profiles
EEA (2012) Movements of waste across the EU's internal and external borders
Eurostat Database - Data on Waste of Electric and Electronic Equipment (WEEE). http://ec.europa.eu/eurostat/data/database , accessed in May 2015
Eurostat Database - Data on Waste of End-of-life-vehicles. http://ec.europa.eu/eurostat/data/database , accessed in May 2015
Eurostat PRODCOM database. Data on Mould tools, Cell phones, Computers, Cars, X-ray machines & Sound systems. http://ec.europa.eu/eurostat/data/database , accessed in May 2015
Eurostat PRODCOM database. http://ec.europa.eu/eurostat/data/database , accessed in May 2015
Gunn (2014) Critical Metals Handbook
IBC website: http://www.ibcadvancedalloys.com/ , accessed in May 2015
IDQ Frequency - Contrôle fréquentiel pour les télécommunications - Antennes relais pour téléphonie

mobile http://www.iqdfrequencyproducts.fr/app-notes/telecommunications/ , accessed in May 2015
Ken Rehbehn (2014) Vibrant LTE Antenna Market Adapts to Growth, 451 Research Yankee Group
Messagie et al. (2014) A Range-Based Vehicle Life Cycle Assessment Incorporating Variability in the Environmental Assessment of Different Vehicle Technologies and Fuels
Ohio CEA (2011) Medical Equipment Life Expectancy List
Öko-Institut (2011) Preparatory Study For Ecodesign of Energy using Products: Lot 24 - Professional washing machines, dryers and dishwashers - Task 2 report
ISIS (2007) Preparatory Study For Ecodesign of Energy using Products: Lot 14 - Domestic washing machines and dishwashers - Task 2 report
Rauch et al. (2007) Copper recycling in the State of Connecticut
Roskill Mineral Services (2005) Beryllium
TNS-Sofres (2011) Etude sur la durabilité des gros appareils ménagers
USGS (2013) Mineral Commodity Summaries, Beryllium
USGS (2014) Mineral commodity summaries

6.4 Borate

List of the main stakeholders who contributed to the MSA

- Etiproducts Oy, Turkey
- European Borate Association

Table of data sources used

Table 12: Data sources used for the MSA of Borate

Data sources used for the MSA on Borate
Boron: Global Industry Markets and Outlook. Thirteenth Edition, Roskill 2015
Business Recycling: Ceramics. Website: http://businessrecycling.com.au/recycle/ceramics , accessed in May 2015.
Centre for Life Cycle Inventories. The ecoinvent database. Website: http://www.ecoinvent.org/database/database.html , accessed in May 2015
Container Recycling Institute: End-markets for collected glass. Website: http://www.container-recycling.org/index.php/end-markets-for-collected-glass , accessed in May 2015
Czech Statistical Office (2011). Waste production, use and disposal. Website: https://www.czso.cz/csu/czso/produkce-vyuziti-a-odstraneni-odpadu-2011-7zwxkdx7ip6 , accessed in May 2015
EC (2014). Report on critical raw materials for the EU. Critical raw material profiles. DG Enterprise and Industry.
Ecochem. Manure is an excellent fertilizer. Website: http://www.ecochem.com/t_manure_fert.html , accessed in May 2015
Eriksson, J. (2001). Concentrations of 61 trace elements in sewage sludge, farmyard manure, mineral fertiliser, precipitation and in oil and crops. Vol. 5159. Stockholm, Sweden: Swedish Environmental Protection Agency
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Gesing, A. J., Dubreuil, A. (2008). Recycling of post-consumer Mg scrap. 65th Annual World Magnesium Conference, Warsaw, Poland
Glass Alliance Europe. Statistical data. Website: http://www.glassallianceeurope.eu/en/statistical-data , accessed in May 2015
International Fertilizer Industry Association. Production and International Trade. Website: http://www.fertilizer.org//En/Statistics/PIT_Excel_Files.aspx , accessed in May 2015
Messagie, M. et al. (2014). A range-based vehicle life cycle assessment incorporating variability in the environmental assessment of different vehicle technologies and fuels. <i>Energies</i> 7.3: 1467-1482.
Sommer, S.G. (2001). Effect of composting on nutrient loss and nitrogen availability of cattle deep litter." <i>European Journal of Agronomy</i> 14.2: 123-133
USGS, Mineral commodity summaries - Boron, 2013 (http://minerals.usgs.gov/minerals/pubs/commodity/boron/)
Wadhwa, M., Bakshi, M. (2013). Utilization of fruit and vegetable wastes as livestock feed and as substrates for generation of other value-added products." <i>RAP Publication</i> 4.
Waste 360. Profiles in Garbage. Food waste. Website: http://waste360.com/mag/waste_profiles_garbage_food , accessed in May 2015

6.5 Chromium

List of the main stakeholders who contributed to the MSA

- International Chromium Development Association
- International Stainless Steel Forum
- Steel & Metals Market Research
- DCX Chrome
- Lanxess
- Cronimet
- Oryx Stainless

Table of data sources used

Table 13: Data sources used for the MSA of Chromium

Data sources used for the MSA on Chromium
Afarak (2014) Afarak Group Annual Report 2014
BREF (2014) Best Available Techniques (BAT) Reference Document for the Non-Ferrous Metals Industries, Final Draft 2014
British Geological Survey (2015) Chromium ore and concentrate production, Finland, 1970 – 2013
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Indian Standard (1999) IS 10819 Chromite for Refractory Industry - Specification
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JRC-EC 2005: CHROMIUM TRIOXIDE, SODIUM CHROMATE, CHROMIUM TRIOXIDE, AMMONIUM DICHROMATE AND POTASSIUM DICHROMATE - Summary Risk Assessment
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Yildirim (2014) Yildirim Annual Report 2013

6.6 Cobalt

List of the main stakeholders who contributed to the MSA

- Cobalt Development Institute

- Yale university
- US Geological Survey
- Recharge aisbl

Table of data sources used

Table 14: Data sources used for the MSA of Cobalt

Data sources used for the MSA on Cobalt
Avicenne (2010) The Portable Rechargeable Battery (PRB) market in Europe (2008-2015)
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CDI (2014) Cobalt Facts
EC (2010) Critical Raw Materials for the EU, Report of the Ad-hoc Working Group on Defining Critical Raw Materials
EC (2014) Report on Critical Materials for the EU - Critical Materials Profiles
Eurostat PRODCOM data on trade of cobalt ores and compounds
Eurostat PRODCOM data on trade of cemented carbides
Eurostat PRODCOM data on trade of cordless tools
Eurostat PRODCOM data on trade of Digital cameras
Eurostat PRODCOM data on trade of laptop PCs
Eurostat PRODCOM data on trade of metallurgy products of cobalt
Eurostat PRODCOM data on trade of pigments
Eurostat PRODCOM data on trade of Telephones for cellular networks or for other wireless networks
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6.7 Coking Coal

List of the main stakeholders who contributed to the MSA

- Euromines
- Euracoal
- Eurofer

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6.8 Fluorspar

List of the main stakeholders who contributed to the MSA

- CEFIC - The European Chemical Industry Council
- LMT Services
- Plastic Europe
- Dupont Chemicals
- Euromines
- Umicore

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6.9 Gallium

List of the main stakeholders who contributed to the MSA

- Freiberger Compound Materials GmbH
- Soitec
- Indium Corporation

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6.10 Germanium

List of the main stakeholders who contributed to the MSA

- Indium Corporation
- OMG Finland
- International Lead and Zinc Study Group
- Nyrstar
- Umicore

Table of data sources used

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6.11 Indium

List of the main stakeholders who contributed to the MSA

- Indium Corporation
- Nyrestar
- Umicore
- Atlantic Strategy

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6.12 Lithium

List of the main stakeholders who contributed to the MSA

- Rockwood lithium
- SQM – Sociedad Química y Minera de Chile
- Recharge aisbl
- British Geological Survey
- Bureau de Recherches Géologiques et Minières
- Bike Europe magazine

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6.13 Magnesite

List of the main stakeholders who contributed to the MSA

- Euromines
- Grecian Magnesite
- Magnesitas Navarras
- PRE – European Refractories Producers Federation
- RHI AG

Table of data sources used

Table 20: Data sources used for the MSA of Magnesite

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6.14 Magnesium

List of the main stakeholders who contributed to the MSA

- Magontec
- International Magnesium Association

Table of data sources used

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6.15 Natural graphite

List of the main stakeholders who contributed to the MSA

- Euromines
- IMERYYS S.A.
- Recharge aisbl
- Graphitbergbau Kaiserberg
- AMG Mining
- Schaeffler Friction

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USGS (2015) Graphite Mineral Commodity Summary

6.16 Niobium

List of the main stakeholders who contributed to the MSA

- Beta Technology
- ERA Technology
- AeroSpace and Defence Industries Association of Europe
- COCIR - European Trade Association representing the medical imaging, health ICT and electromedical industries

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6.17 Platinum Group Metals – Palladium, platinum and rhodium

List of the main stakeholders who contributed to the MSA

- British Geological Survey
- Bureau de Recherches Géologiques et Minières
- International Platinum Group Metals Association

Table of data sources used

Table 24: Data sources used for the MSA of Platinum Group Metals

Data sources used for the MSA on Platinum Group Metals
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ASTER (2015) Material flow analysis applied to rare earth elements in Europe
BGS (2009) Platinum commodity profile
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6.18 Phosphate rock

List of the main stakeholders who contributed to the MSA

- Wageningen University
- International Fertilizer Industry Association
- European Sustainable Phosphorus Platform

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Table 25: Data sources used for the MSA of Phosphate rock

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6.19 Rare Earth Elements – Erbium, europium, dysprosium, neodymium, terbium, yttrium

List of the main stakeholders who contributed to the MSA

- Bureau de Recherches Géologiques et Minières
- Solvay
- Recharge aisbl
- ACEA - European Automobile Manufacturers' Association

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6.20 Silicon

List of the main stakeholders who contributed to the MSA

- Elkem
- Euroalliages
- First Solar
- Industrial Minerals Association - Europe
- PV Cycle Association
- Wacker
- Wambach Consulting

Table of data sources used

Table 27: Data sources used for the MSA of Silicon

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6.21 Tungsten

List of the main stakeholders who contributed to the MSA

- Betek
- British Geological Survey
- Element Six
- ERAMET Group
- International Tungsten Industry Association
- Wolfram Bergbau und Hütten AG

Table of data sources used

Table 28: Data sources used for the MSA of Tungsten

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