Management of Wastes from Primary Resources Processing: Identification, Environmental Evaluations

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Introduction

- The objective of Task 2.5 was to **present the waste management current practices** for the five refractory metals and to **state the required actions for future recovery** of the five refractory metals **from mining streams**.
- The initial vision in the proposal preparation was to **utilize LCA studies** for each of the five refractory metals, **in order to state those processes** in the mining value chain that **cause the main environmental burden**. However, this **proved to be an ambitious** objective, mainly **due to the lack of data** availability.
- The complexity of the raw materials value chains and the demand on inventory data over input and output flows within this chain is challenging for the sector. Given that refractory metals industry is even restricted in compiled production data per year in some cases makes evident the fact that a LCA analysis was not feasible within this study.
- The focus of the study is to **present the mining waste management** for the refractory metals in a **qualitative manner** and to depict those cases where valorization of mining wastes occurs and highlight the good practises. In addition, **LCA studies** per refractory metal **are analysed** with aggregated results for the mining boundaries.

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Waste Management EU Framework

- **RAW MATERIALS INITIATIVE – EIP SIP.**

EIP will among other focus on promoting innovation in such areas as:

  - ***Technologies to improve the recovery from waste***, including e.g. red mud and abandoned or closed mining waste facilities;
  - ***Turning wastes into valuable secondary raw materials by developing more efficient recycling/recovering processes***;
  - Furthermore, the **European Commission** in a 2012 communication stated that more ought to be done to help **reduce the wastage of materials throughout their life cycle**. It is thus clear that existing and future policy will support a comprehensive approach to waste management.

- **MINING WASTE DIRECTIVE**

In the EU, wastes deriving from the extraction and refining industries are regulated under the so-called Mining Waste Directive (2006/21/EC)

  - The **MWD does not specifically refer to secondary raw materials and excludes 'waste resulting from offshore' activities**. It is principally focused on 'waste management' to reduce the environmental and socio-economic impacts of extraction and processing of mineral resources, rather than the recovery of secondary raw materials or determining their stocks.

- **LANDFILL DIRECTIVE**

The objective of the Directive is to prevent or reduce as far as possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfills.

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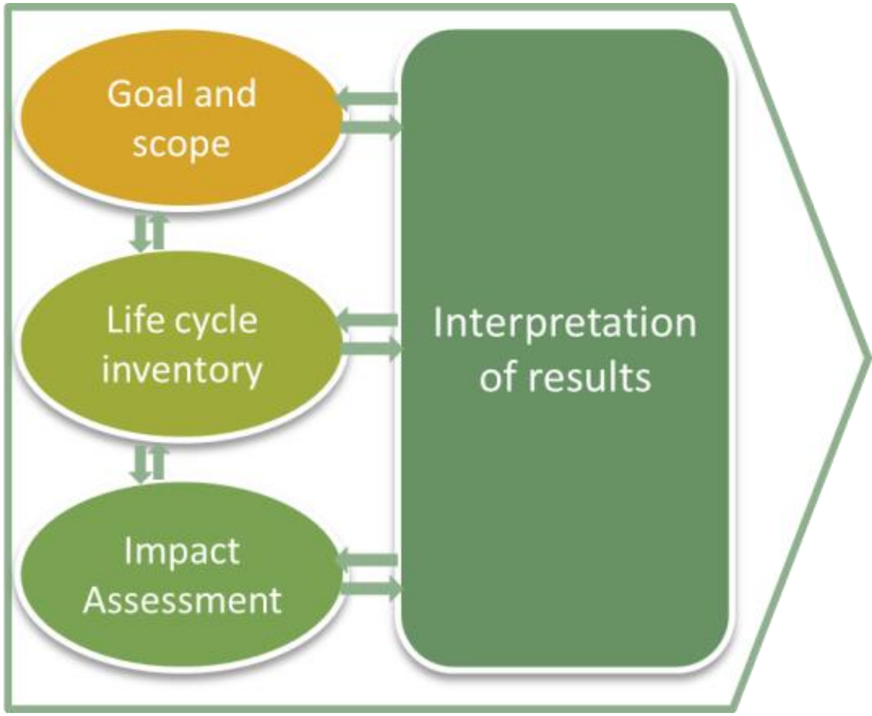
Life Cycle Assessment

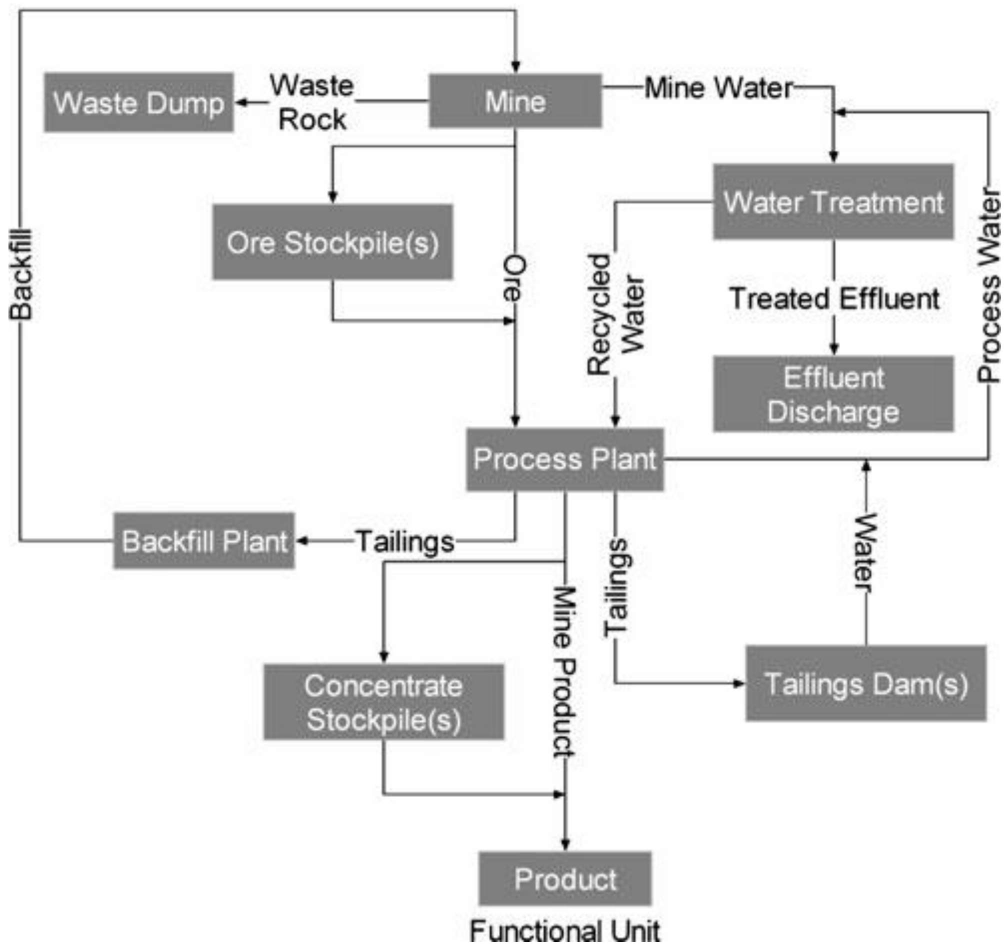
According to ISO 14044 an LCA is carried out in four distinct steps. These steps are often interdependent, meaning that the results of one step are used as necessary data for other steps. The methodology is characterized by a stepwise approach, being:

- Step 1: Goal and Scope Definition;
- Step 2: Life Cycle Inventory Analysis;
- Step 3: Life Cycle Impact Assessment;
- Step 4: Life Cycle Interpretation.



Life Cycle Assessment

- The initial scope of this report has been the evaluation of the mining production of the refractory metals in environmental terms with the utilization of LCA methodology. However, this proved to be ambitious since the limitation of data in mass and energy balances per unit process in the mining production of the refractory metals is evident and restricted only to LCA software companies and respective mining companies.
- The complexity of the raw materials value chains and the demand on inventory data over input and output flows within this chain is challenging for the sector. Given that refractory metals industry is even restricted in compiled production data per year in some cases makes evident the fact that a LCA analysis was not feasible within this study.



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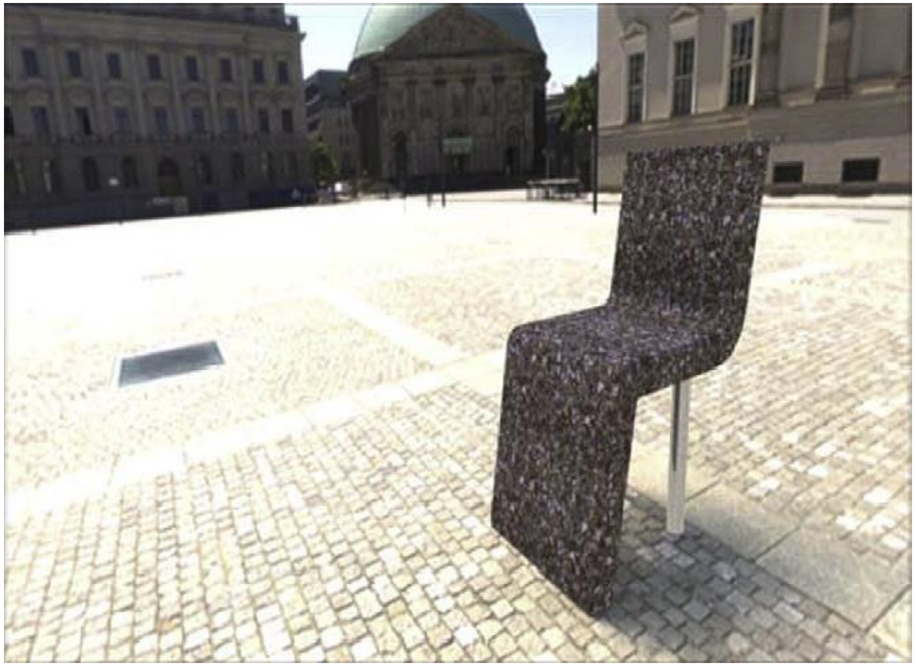
- One of the studies that provides LCA aggregated data for all the refractory metals is the "Life Cycle Assessment of Metals: A Scientific Synthesis", where environmental impact data for five different LCIA categories are available. The comparative Table does not lead to a single aggregated result on which metal is followed by the most environmental burden but is rather a category to category comparison. This is common in LCA studies and the overall result depends on the predefined goal and scope of the study and the assigned weighting factor for each LCIA category.
- In this case, Rhenium is causing the heaviest environmental impact in GWP and is followed by Tantalum with about 36% less GWP. Tungsten, Niobium and Molybdenum are causing almost 10 times less GWP compared to Rhenium. The same pattern is observed in the CED and Acidification LCIA. In Freshwater eutrophication and in Human Toxicity LCIA categories the impact is different with Molybdenum and Rhenium causing the heaviest environmental impact followed by Tantalum, Tungsten and Niobium.

IMPACT CATEGORY	UNITS	Ta	W	Re	Nb	Mo
Global warming potential	(kg CO2 eq / kg)	260	12.6	450	12.5	5.7
Cumulative energy demand	(MJ eq / kg)	4,360	133	9,040	172	117
Terrestrial acidification	(kg SO2 eq / kg)	1.7	0.29	11	0.053	0.16
Freshwater eutrophication	(kg P eq / kg)	0.15	9.3E-6	0.35	3.7E-03	0.54
Human toxicity	(CTUh/kg)	1.2E-04	3.4E-05	0.059	6.4E-06	9 E-04

Tungsten

Tailings

- A major problem resulted by the W mining activity is the large amount of waste-rock tailings. Panasqueira mining site have produced approximately 10 million m3 of mine wastes, over a period of more than 120 years
- It has been proved that rocks wastes from Panasqueira mine can be used for construction applications due to their chemical stability and mechanical durability. Among to potential application has been proposed a new polymer-based construction material in technical-artistic applications, particularly as terrazzo tiles for outdoor use, fulfilling CE marking requirements. Coarse waste fractions from Panasqueira mining are highly suited as a component in the polymer-based construction without any prior treatment. Sculpture and architecture applications present an important potential interest requirements for waste and landfills.



Prototype of urban furniture (outdoor bench) framed in a historical centre of a Portuguese city

Tungsten

Arsenic

- A significant cause of environmental hazard in case of tungsten mining is the presence of high arsenic concentrations in the W deposits. The As contamination can be easily spread to the soil of neighboring cultivation lands.
- Some innovative studies concerning the phyto- and bio-remediation of W mining wastes rich in As content have been made and are promising, but further research

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Tungsten

LCA Studies

- LCA studies in Tungsten are focused mainly on the post-mining fragment of the value chain and mainly connected to the production of Tungsten metal or Tungsten Carbide powder. Thinkstep company, owner of the Gabi LCA software has made a LCA study for the Tungsten mining, but is not available in commercial package. It is formed as data on demand with extra cost and with no information of the mine sites covered and if all the unit processes are included.

PROCESSING STEP	ENERGY (kWh/ t ore)	COMMENTS
Ore mining &extraction		
Drilling	0.4	USA best practice across the whole metals sector
Blasting	2.2	
Digging	1.5	
Ventilation	1.3	
Dewatering	0.2	
Materials handling	14.7	
Beneficiation & processing		
Crushing	0.4	USA best practice
Grinding	14.4	USA best practice
Beneficiation general	12.8	Wolframite ore in India

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Niobium-Tantalum

Environmental Challenge

- The existence of TENORMS (technologically enhanced natural radiation materials) in waste-processing of Ta-Ni ores has been described in Brazil and in Nigeria.
- The environmental hazard is extremely intense in case of Nigeria where generated large quantities of tailings that are rich in these radioactive minerals and are mostly dumped haphazardly in the environment.

Niobium-Tantalum

LCA Studies

- An energy consumption flow for all the incorporated processes required to produce 1 tonne of Niobium is depicted in the following Table, where the mining contribution is only 10% compared to total and is equal to 37.5GJ/t.

Niobium production process	GJ/t	%	Probable energy type
Mining	37.5	10.17	Diesel Fuel
Beneficiation	15.7	4.26	Electricity
Chemistry	87.2	23.65	Coal
Reduction	151.8	41.17	Coal
Refinery	76.5	20.75	Electricity
Total	369	100.00	

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Rhenium

Environmental Challenge

- Rhenium extraction is usually performed as a byproduct in large scale sulfide polymetallic mines. **The main environmental impact of sulfide deposits is the existence of drainage phenomena. Acid Rock Drainage (ARD)** in some polymetallic sites from the waste rock dumps has been observed causing serious environmental issues.
- Island Cooper mine in Canada is a polymetallic ore deposit containing also rhenium. Island Copper Mine is located on northern Vancouver Island. The mine began production in 1971, and was the third largest copper mine in Canada when it was closed in 1995 due to resource depletion. An estimated 1.3 million tonnes of copper, 31,000 tonnes of molybdenum, 31.7 tonnes of gold, 336 tonnes of silver, and 27 tonnes of rhenium were extracted over the lifetime of the mine. More than a billion tonnes of material was excavated, which produced an oval-shaped pit with a depth 400 metres below sea level. During mining operations, the excavated ore was ground up and processed in a slurry by floatation to remove the copper and molybdenum. Waste rock was dumped in piles on site and along the shore, and the tailings produced from the copper processing operations were placed on the seabed. However, in 1986, acid rock drainage (ARD) from the waste rock dumps was observed, and considerable effort was put into monitoring and evaluating stream flow volumes and dissolved metal content.

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Molybdenum

Environmental Challenge

- Leaching of metals during sulfide oxidation reactions in mining waste rock dumps presents a global environmental challenge.
- Molybdenum consist a metal which can be released at elevated concentrations during weathering of sulfidic waste rock while it can cause **toxic effects** at elevated environmental concentrations.
- **Molybdenum is particularly harmful to ruminants which are susceptible to molybdenosis.**

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Molybdenum

LCA Studies

- LCA studies in Molybdenum are more vast and open compared to the other refractory metals. However, they are restricted mainly on the post-mining fragment of the value chain and mainly connected to the processing stages for the metal production. In the Mo case, Ecoinvent Database has data for the production of Molybdenum mining (concentrate), but the mass and energy balances for the unit processes are not open, which leads to aggregated results of the mining production as a whole.
- The International Molybdenum Association (IMOA) has an ongoing initiation over a life cycle assessment (LCA) program performing cradle-to-gate life cycle inventories (LCIs) of three molybdenum metallurgical products, followed by LCIs of eight molybdenum chemicals and an update to the metallurgical LCIs. From 2012 to 2014, IMOA participated in a multi-metal industry initiative to harmonize the methodological approach to metal-related LCAs.

Molybdenum

LCA Studies

- Rio Tinto has published a LCA study for the Molybdenum Oxide Environmental Profile and described the whole value chain of the oxide production . The Kennecott LCA project included a complete cradle to gate LCA study for copper cathode, gold, silver, molybdenum oxide and sulfuric acid produced by the mining operation. The results of the study are analysed in the following for the selected LCIA categories.

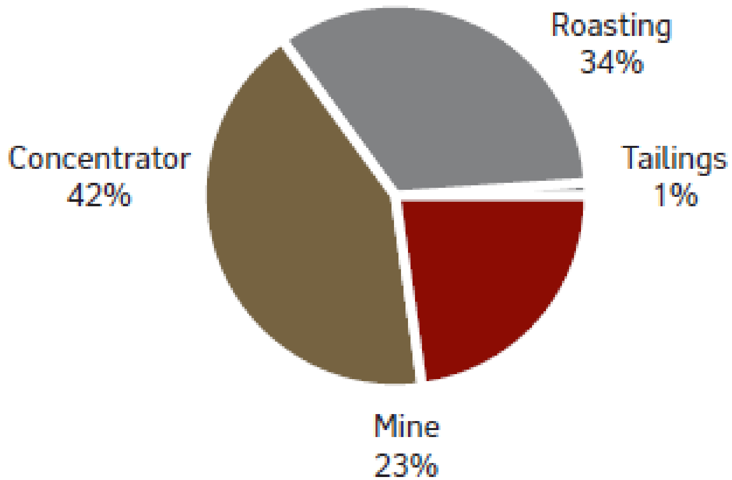

Figure 1: Breakdown of PED by process group for molybdenum

In molybdenum oxide production, the concentrator contributes most to PED, drawing most of its energy for the milling process. The mining accounts for 23% of the total burden, while tailings only for 1%.

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Molybdenum

Concentrator dominates the GWP results for molybdenum oxide production system. Emissions associated with the concentrator are the result of greenhouse gases emitted through on-site and off-site electricity production. **Diesel combustion and electricity consumption at the mine is second largest contributor of greenhouse gases in the molybdenum production system.** In the GWP breakdown for mining hauling and overburden is having the higher impact followed by electricity and hauling of ore.

Global warming Potential (GWP)

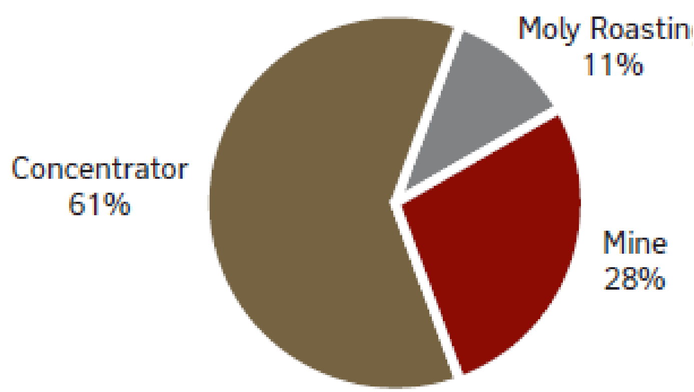

Figure 1: Breakdown of GWP by process group for molybdenum

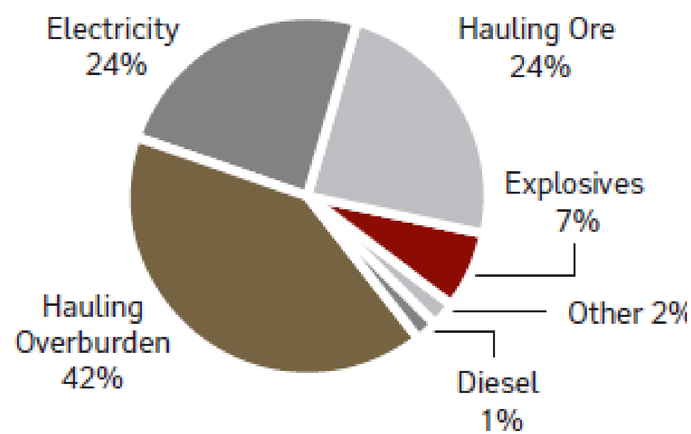

Figure 2: Breakdown of GWP in the mining process for molybdenum

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Conclusions-Challenges

- **Challenge 1.** Creation of LCI datasets for the mining boundaries of the refractory metals with specific focus on waste management.
- **Challenge 2.** The lack of data in both LCA and MFA forms a gap in a Life Cycle Thinking approach and in a Circular Economy mindset. This is a clear challenge for the stakeholders of the refractory metals and needs to be addressed.
- **Challenge 3.** Tungsten waste management to prevent arsenic pollution and development of actions/technologies to remediate W mining waste rich in As.
- **Challenge 4.** Environmental regulations in low developed countries, where W mines operate to meet EU standards and avoid causing bad examples that cause bad name for the RM sector.
- **Challenge 5.** Tailings and mining waste valorization of W primary production.
- **Challenge 6.** Waste management of hazardous tailings in niobium-tantalum primary production.

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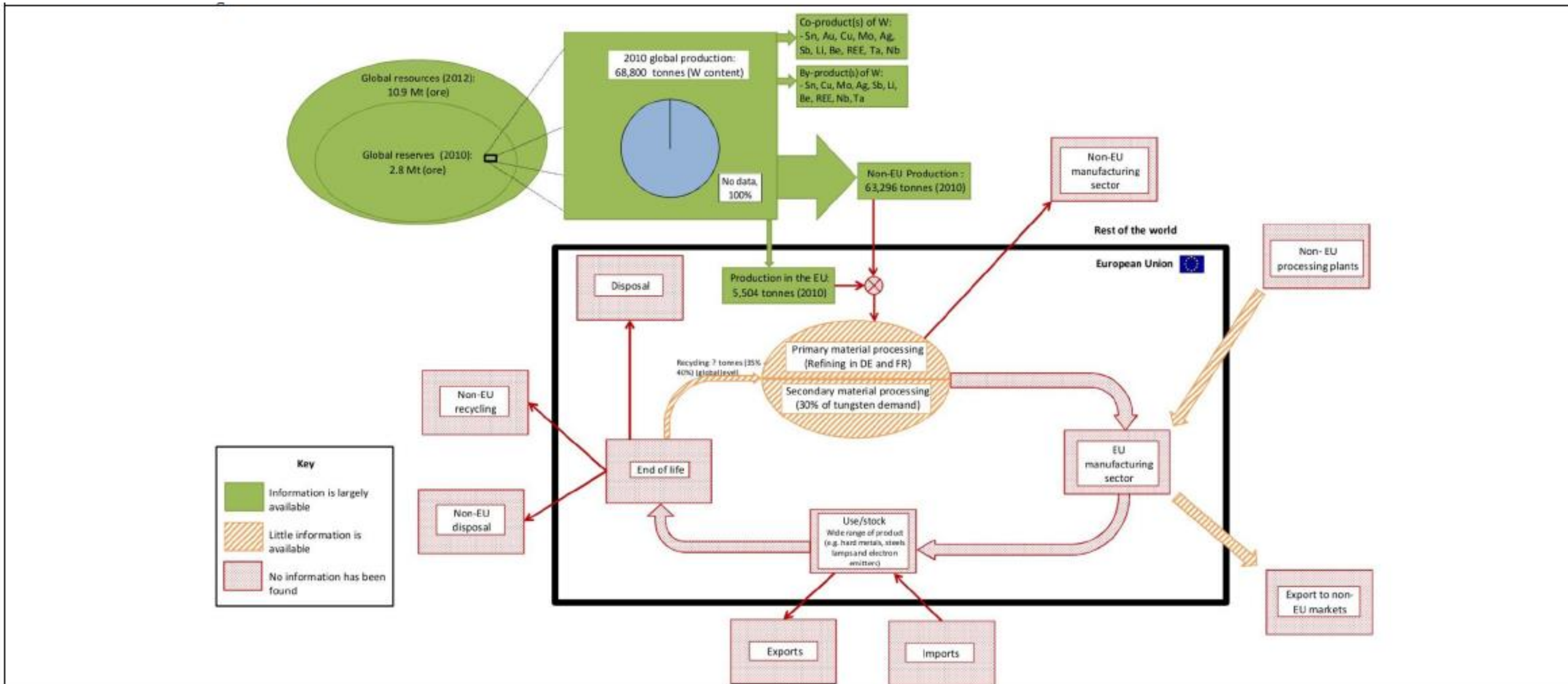
Material Flow Analysis



Structure of the relevant sectors		*Future trends*	
Exploration	Limited number	**Exploration**	New mines opening in Spain and the UK
Extraction	8% in the EU, China: 85%	**Extraction**	Underground, max 2.000 ores per day
Refining	FR, DE, China and the USA	**Refining**	Increase in processing outside the EU
Manufacturing	Insufficient information	**Manufacturing**	Insufficient information
Collection	Insufficient information	**Collection**	Insufficient information
Recycling	Only known for specific sub-sectors	**Recycling**	Only known for specific sub-sectors

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