



MSP-REFRAM

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Management of waste from urban mines processing: identification, environmental evaluations

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Summary

Management of waste from urban mines processing: identification, environmental evaluations

Approval

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0. INTRODUCTION

The objectives of this task were very ambitious at the proposal phase. It was stated that several recovery processes from **urban mining** were going to be studied using the **Life Cycle Assessment** (LCA) methodology in order to determine the environmental impacts of those processes, assessing several scenarios and covering several impact categories, for the five metals studied. A brief description of how LCA is structured can be read below.

Life Cycle Assessment methodology

Life Cycle Assessment is an environmental tool that allows the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. The LCA methodology is clearly described by the following international standards:

- ISO 14040:2006¹. Environmental management. Life Cycle Assessment. Principles and framework.
- ISO 14044:2006². Environmental management. Life Cycle Assessment. Requirements and guidelines.

The LCA methodology is structured in four steps, as it can be seen in figure 1.

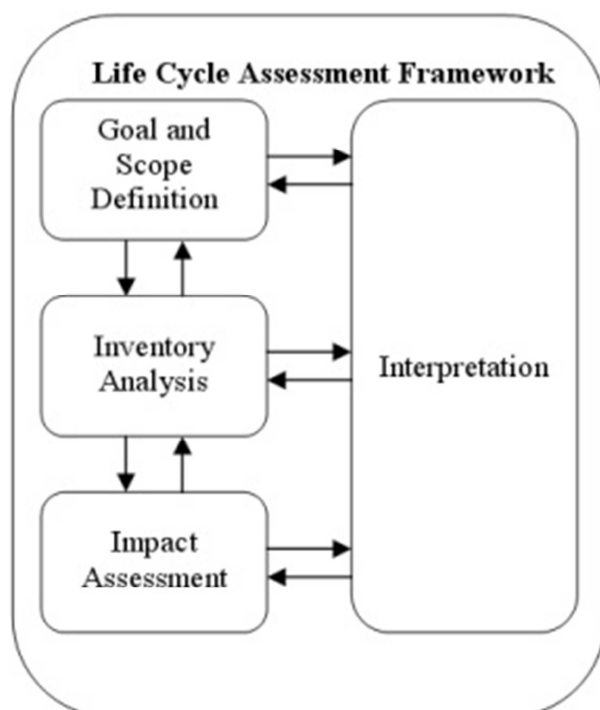


Figure 1. Life Cycle assessment framework. Source: ISO 14040

1. - *Goal and scope:*

The first stage of the LCA methodology defines why the assessment is developed, which the target audience is, and some important decisions, among others, as:

- Functional unit selection
- System boundaries
- Impact indicators selection

2. - *Inventory analysis:*

In this stage, the complete information about the system studied is collected, including energy and material inputs and outputs, as well as emissions to air, soil and water. Special attention must be paid to the data quality and the acquisition methods.

3. - *Impact assessment:*

After inventory compilation, classification and characterization are developed in this stage, in order to sort the inventory according to the effect on the environment and the multiplication by a factor in order to evaluate its contribution to that effect. Depending on the indicators selected, other stages (normalization or weighting are optional).

4. - *Interpretation:*

The final conclusions of the study are obtained in order to select strategies to improve the environmental performance of the system evaluated.

The deployment of this methodology in this context would provide useful information to incorporate to the global knowledge generated in this project in order to establish strategies for the selection of the best recycling and recovery options.

It would have provided also information about the environmental impact of recovery and recycling from the urban mining vs. the traditional extraction.

But at this stage of the Project, it is evident that the preliminary approach of the task was too ambitious and in many cases, unrealizable.

First of all, the on-going research and the info collected in the previous delis of this task (D4.2 and D4.3) has proved that it is only worth to study two metals, **Rhenium** and **Tantalum**, as time and human resources are limited, and considering also that these metals offer the most promising options for innovation

In the other hand, LCA is a methodology that needs a very complete data input (materials, energy, waste generation, etc.) and as it has been proven, that info is not available. There is a lot info missing in the recovery and recycling processes, which does not allow developing a LCA robust enough to be considered as representative.

So, the consortium has agreed to select one representative process for each metal in terms of urban mining, and the main objective of the task will be trying to identify and describe one Ta and one Re recovery process, and assess how that process meets the EU criteria in terms of environmental releases, waste fluxes, energy savings, etc.

As a first general approach, and as it has been identified in the previous deliverables of this Work Package, the next section will be a brief summary of the techniques identified for Ta and Re in Deliverables D4.2 and D4.3 of the project.

1. TA AND RE RECOVERY PROCESSES

1.1 TA RECOVERY PROCESSES

1.1.1 TA PRESENT RECOVERY PROCESSES

In this section, the information from Deliverable 4.2 “*State of the art on recovery of refractory metals from urban mines*” concerning Ta recycling-recovery techniques has been assessed and structured, including data about Tantalum source, the recycling-recovery process, waste identification and the potential environmental impact and risks associated to the waste management. As this deliverable is focused on waste management, further information about the refractory metal source or process can be found in the other deliverables from task 4.

Table 1. Ta present recovery sources and processes from urban mining. Source: Deliverable 4.2 REFRAM.

Source	Product	Product description	Process description
Electronic waste	Capacitors	Capacitors are the main source for Ta (13-33 wt %) Current recovery of Ta is focused on scraps generated during capacitors manufacturing process. Problems on EOL electronic devices containing Ta: - Ta is concentrated in components dispersed into PCBs - Ta compounds are covered by several layers of minerals - Ta easily oxidizes and migrates into the slag phases during pyro-metallurgical copper route used by e-waste recyclers	Recovery of Ta from capacitor scraps using an oxidation process followed by mechanical and chemical treatment. This process includes several options for Ta ₂ O ₅ reduction, including several reduction options (sodiothermic, calcium or alumina) and chlorination. Also a steam gasification process with sodium hydroxide was reported for recovery of tantalum sintered compact by destroying mold resin and stabilization of halogenated compounds in sodium hydroxide to prevent exhausting halogenated gas.
Non-Electronic waste	Cemented carbides	Tantalum carbide is used mostly in the manufacture of cemented carbide insert and tools, which typically contain about 3% Tantalum. The emphasis in recycling of cemented carbide scrap is to recover the contained tungsten, but the recovery of other metals such as tantalum is also considered.	The physical processes are less expensive than the chemical processes, generate no waste products, and produce a powder essentially ready for use. Tools are used as source material. Zinc process. Chemical processes are thus employed where direct recycling methods are not feasible, mostly because of contaminations. Chemical extraction. Oxide as final product for final transformation
	Metallurgical products and superalloys	Ta can be used either in: - Ta-based alloys (pure or with a low content of alloying element), where no information about recycling has been found, - Superalloys, where Ta is a minor element, with a content of 1 to 12 wt.%.	Ta recovery by remelting : In 1996, on the world scale, about 70% of the recycled superalloys scrap were remelted to regain the same alloy, while 20% was processed into low-grade materials (down-cycling). Ta recovery by extraction : A few methods, only developed at lab scale, aim at recovering Ta: - A pyrometallurgical method including alkaline fusion, leaching, and magnetic separation, - An electrochemical method, inorganic acid as electrolyte, and producing filterable Ta oxide

1.1.2 TA FUTURE RECOVERY PROCESSES

In this section, the information from Deliverable 4.3 “*Innovation potential in the recovery of refractory from urban mines*” concerning Ta has been assessed and summarized, and is briefly presented in table 2.

Table 2. Ta potential recovery sources and processes from urban mining. Source Deliverable 4.3 REFRAM.

Source	Process description	
Electronic waste	Project SILEXE aims to develop an effective method for extraction and purification of strategic metals such as indium, tantalum and gold from printed circuit boards	
	REMETOX project fits also into the context of the recycling of waste electrical and electronic equipment (WEEE) [11]. Alternative technology to recovery, based on the oxidation of printed circuit boards (PCBs) by water placed in conditions of pressure and temperature corresponding to supercritical state	
	The recovery of Ta from capacitor scraps using an oxidation process followed by mechanical and chemical Treatment sintered Ta electrodes inside the capacitor scraps are collected mechanically after the oxidation of the scraps in air and by combination with chemical treatment; tantalum oxide powder (Ta ₂ O ₅) with high purity was recovered by reducing the Ta ₂ O ₅ obtained through magnesiothermic reduction	
	Chlorination is another possibility to recover tantalum powder. Tantalum compounds are reacted with chloride wastes such as FeCl ₃ . It was found that tantalum was effectively separated and purified when tantalum powder is reacted with FeCl ₃ at 830°C under an argon atmosphere	
	According to Katano et al. [12], the recovery of tantalum sintered compact can be performed by using steam gasification with sodium hydroxide at 530°C under nitrogen atmosphere to destroy mold resin and stabilize the halogenated compounds in sodium hydroxide to prevent exhausting halogenated gas	
	Several metals can be recovered from Tantalum Capacitors with Ionic Liquids [13]. The dissolution of the whole tantalum capacitors can be performed in acidic AlCl ₃ based ionic liquids	
	It is also worth mentioning that there is a patent dealing with the recovery of high-content tantalum from tantalum sintered compact collected from a tantalum capacitor [14]. The method combines the acid and alkali treatments, thereby recovering tantalum. The acid treatment is performed using HCl and the alkali treatment is performed using NaOH or KOH.	
Non-Electronic waste	Cement carbide	The chemical process involves the recovery of tungsten oxide or ammonium paratungstate through an oxidation process combined with a purification process. The oxidation process can be one of many types, including thermal oxidation, chemical oxidation, mechanic-chemical oxidation, and electrochemical processes
	Metallurgical products & superalloys	One of the patented methods relates to a process for the digestion of superalloys , wherein both electrodes of an electrochemical cell are composed of superalloy. The considered superalloys contain as the main component 50 to 75 wt. % nickel, 3 to 15 wt. % of at least one of the elements cobalt, chromium, and 1 to 10 wt. % of one or more of the elements Tantalum, Niobium, Tungsten, Molybdenum, Rhenium, Platinum and Hafnium.
		Another patented method consists in digesting the superalloy in a salt melt . The salt melt contains 60-95 wt% of NaOH and 5-40 wt% of Na ₂ SO ₄ , and an additional oxidizing agent (e.g. NaNO ₃ or K ₂ S ₂ O ₈). The process is operated at 900-1050°C with a mixture of air and oxygen passed into the salt melt

1.2 RE RECOVERY PROCESSES

1.2.1 RE PRESENT RECOVERY PROCESSES

The information from Deliverable 4.2 “*State of the art on recovery of refractory metals from urban mines*” concerning Re recycling-recovery techniques has been assessed and structured in this section.

Table 3. Re present recovery sources and processes from urban mining. Source: Deliverable 4.2 REFRAM.

Source	Product	Product description	Process description
Non-Electronic waste	Super alloys and alloy scraps	It is not uncommon to find W and Re metals in alloys together.	<p>W-Re scrap may be recycled via an oxidative pyrometallurgical roasting technique.</p> <p>There is also a patent for a process for the elevated temperature digestion and recycling of rhenium-containing superalloys.</p> <p>Electrolytic decomposition of Rhenium superalloys using Titanium baskets as electrodes</p> <p>Shredded solid materials can be effectively processed by Toma Group, where it is oxidatively calcined and volatile Re_2O_7 is absorbed in ammonia solution</p>
	Spent Pt-Re catalysts	Petroleum-reforming catalysts containing rhenium and platinum for the improvement of the octane level of fuels. After being deactivated, an effective method for the recovery or rhenium and other PGM metals is necessary.	<p>Complete dissolution of the alumina substrate. Sulphuric acid may be used for dissolution of alumina, rhenium and, to some extent, platinum. The following processes involved are separation, elution, neutralization, evaporation, cooling, crystallization, precipitation, Rhenium recovery reached 97% for crushed catalysts, and 87% for uncrushed catalyst samples.</p> <p>Selective dissolution and recovery of rhenium and platinum This method varies from calcination of the catalysts to selective leaching in alkaline or acid conditions at ambient and elevated temperatures. By calcination of the catalyst at temperatures up to 1,150° C, the Platinum and Rhenium can then be selectively leached in concentrated (5 mol/L) sulphuric acid solutions It is reported Rhenium and Platinum recoveries are as high as 95.5% and 97%.</p>

1.2.2 RE FUTURE RECOVERY PROCESSES

In this section, the information from Deliverable 4.3 “Innovation potential in the recovery of refractory from urban mines” concerning Re has been assessed and summarized, and is briefly presented in table 4. It is important to remark that in the recent years, 80-90% of rhenium has been produced from primary sources and waste from the processing of ore concentrates of copper and uranium, and only 10-20% comes from recycling.

Table 4. Re future recovery sources and processes from urban mining. Source: Deliverable 4.3 REFRAM.

Source	Process description
Different sources	<p>Process of leaching at elevated pressures and temperatures represents a very promising direction while increasing the share of recycling of rhenium in its total production, especially with such a large variety of materials, so difficult to process, and small amount of rhenium contained in them</p> <p>Dissolving of superalloys and rhenium containing alloys scraps with application of an electrolyser of a special design</p> <p>Rhenium-containing wire scrap the W-Re wire scrap containing 3.27 % Re has been subjected to high-temperature oxidation to volatilize Re as Re₂O₇.</p> <p>Recovery from Ni-based super-alloys is possible by oxidative leaching with HCl-HNO₃ mixtures and by sulphide precipitation, adsorption or solvent extraction.</p>

2. EUROPEAN INFORMATION ABOUT WASTE ELECTRICAL AND ELECTRONIC EQUIPMENTS (WEEE)

In the same way as it has been reported in Deliverable 3.4, info about the European strategies and tendencies regarding to the WEEE is explained in this section, considering that the major end use of **Tantalum** is represented by more than 60% in the production of electronic components (Ta capacitors), so it can be considered an important source in urban mining.

2.1 EU POLICY ON WEEE

The EU has a series of waste-related Directives and Regulations. Management of WEEE was especially initiated based on the obligation on the producers of EEE to take back EoL or waste products free of charge in an effort to reduce the amount of waste going to landfills. This initiative is outlined in the WEEE Directive. However, it is important to understand the inter-linkages between other EU waste legislations applicable to WEEE, in particular the following:

- Waste Framework Directive (2008/98/EC)³
- Directive on waste electrical and electronic equipment (WEEE) 2012/19/EU⁴

- Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)⁵
- Waste Shipment Regulation “WSR” (EC) No 1013/2006⁶
- The Industrial Emissions Directive (2010/75/EU)⁷ and BAT for Waste Treatment⁸

2.1.1 WASTE FRAMEWORK DIRECTIVE (2008/98/EC)

The Waste Framework Directive (WFD) of 2008 (2008/98/EC) sets the basic concepts and definitions related to waste management such as definitions of waste, recycling, and recovery. It thus provides a general framework of waste management requirements and sets the basic waste management definitions for the EU. Along with the waste management definitions, the WFD applies a waste management hierarchy as follows: prevention, preparing for re-use, recycling, recovery and disposal. Further, it establishes a legal framework for the treatment of waste, where waste treatment facilities must obtain permits and registrations to operate (Article 23). Further, the WFD includes requirements regarding the control of hazardous waste (Art. 17), mixing ban (Art. 18), labelling (Art. 19) and record keeping of hazardous waste (Art. 21).

2.1.2 WEEE DIRECTIVE (2012/19 / EU)

The purpose of this Directive is to contribute to sustainability in production and consumption by preventing the generation of WEEE. It also includes reuse, recycling and other forms of recovery of such waste, with the aim of reducing their disposal and contributing to the efficient use of resources and the recovery of secondary raw materials. On the other hand, it aims to improve the environmental performance of the main players involved in the life cycle of electrical and electronic equipment, such as producers, distributors and consumers.

The first WEEE Directive (2002/96/EC)⁹ was adopted on 27 January 2003 and has since been revised. The new WEEE Directive 2012/19/EU (‘WEEE Directive’) covers all types of EEE, for which it establishes different categories and sets targets for their collection, recovery and recycling.

2.1.2.1 DEFINITION OF WEEE AND CATEGORIES SUBJECT TO WEEE DIRECTIVE

Article 3(1)(a) of the WEEE Directive defines EEE as “equipment which is dependent on electric currents or electromagnetic fields in order to work properly and equipment for the generation, transfer and measurement of such currents and fields and designed for use with a voltage rating not exceeding 1 000 volts for alternating current and 1 500 volts for direct current”. WEEE is in turn defined (Article 3(1)(e)) as “electrical or electronic equipment which is waste within the meaning of Article 3(1) of Directive 2008/98/EC, including all

components, sub-assemblies and consumables which are part of the product at the time of discarding”.

There are two lists of categories of products covered by the WEEE Directive:

- The current 10 categories, with the inclusion of photovoltaic panels, which are covered from 13 August 2012 to 14 August 2018 (transitional period), and
- 6 categories (open scope), which will be covered from 15 August 2018.

The 10 transitional categories have been compiled into the 6 open scope categories (Annex III of the WEEE Directive) as illustrated below:

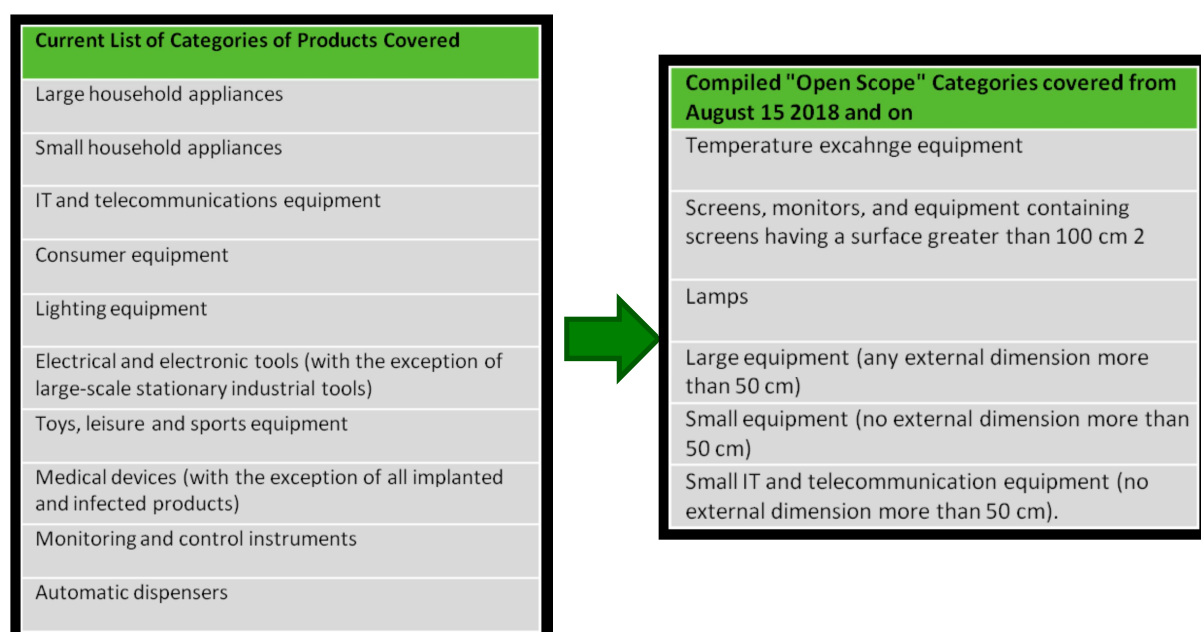


Figure 2. Current list and future list of categories covered by the WEEE Directive.

2.1.2.2 EXPORT OF WEEE

Article 10(1) of the WEEE Directive provides that shipments of WEEE must comply with the WSR and the corresponding Regulation (EC) No 1418/2007¹⁰, in terms of limitations on the hazardous and non-hazardous waste shipped to OECD and non-OECD countries as defined by WSR Annexes.

From 2016, Member States (MS) will be required to collect 45% of the average weight of EEE placed on the market. From 2019 onwards, MS will be required to collect 85% of WEEE generated on the territory of that MS. Currently, the EU collects about 4kg of WEEE per capita; by 2020 the target for the collection of WEEE is 20 kg per capita (as e-waste is expected to rise).

Recovery targets are highly relevant to the export of WEEE. Starting in 2014, WEEE exporters will have to prove that the treatment of WEEE outside the EU takes place in conditions equivalent to those required by the Directive for the waste to be counted towards their collection and recovery target rates (Article 10(2)).

2.1.2.3 PROPER TREATMENT AND DISPOSAL OF WEEE

Article 8 of the WEEE Directive provides that MS must ensure that all separately collected WEEE undergoes proper treatment. At a minimum, this includes the removal of all fluids and a selective treatment in accordance to Annex VII and Annex VIII of the Directive.

Table below lists the technical requirements for storage and treatment of WEEE:

Table 5. Technical requirements for storage and treatment of WEEE.

WEEE Directive, Annex VIII Technical Requirements	
1. Sites for storage (including temporary storage) of WEEE prior to its treatment requirements	
impermeable surfaces for appropriate areas with the provision of spillage collection facilities and, where appropriate, decanters and cleanser-degreasers	
weatherproof covering for appropriate areas	
2. Sites for treatment of WEEE	
scales to measure the weight of the treated waste	
impermeable surfaces and waterproof covering for appropriate areas with the provision of spillage collection facilities and, where appropriate, decanters and cleanser-degreasers	
appropriate storage for disassembled spare parts	
appropriate containers for storage of batteries, PCBs/PCTs containing capacitors and other hazardous waste such as radioactive waste	
equipment for the treatment of water in compliance with health and environmental regulations	

Annex VII outlines the minimum selective treatment for materials and components of WEEE. This is summarised in Table below.

Table 6. Selective treatment for materials and components of WEEE.

Selective treatment for materials and components of WEEE	
1. As a minimum the following substances, mixtures and components have to be removed from any separately collected WEEE:	
PCB containing capacitors in accordance with Council Directive 96/59/EC of 16 September 1996	
Mercury containing components, such as switches or backlighting lamps	
Batteries	
Printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres	
Toner cartridges, liquid and paste, as well as colour toner plastic	
Plastic containing brominated flame retardants	
Asbestos waste and components which contain asbestos	
CRTs	
Chlorofluorocarbons (CFC), hydro chlorofluorocarbons (HCFC) or hydro fluorocarbons (HFC), hydrocarbons (HC)	
Gas discharge lamps	
LCDs (together with their casing where appropriate) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps	
External electric cables	
Components containing refractory ceramic fibres as described in Commission Directive 97/69/EC of 5 December 1997	
Components containing radioactive substances with the exception of components that are below the exemption thresholds set in Article 3 of and Annex I to Council Directive 96/29/Euratom	
Electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume). These substances, mixtures and components shall be disposed of or recovered in compliance with the WFD	
2. The following components of WEEE that is separately collected have to be treated as indicated:	
CRT: the fluorescent coating has to be removed	
Equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009	
Gas discharge lamps: the mercury must be removed.	

The WEEE Directive does not specifically provide standards for the treatment of WEEE beyond the preceding lists. However, it does provide (Article 9) that MS must ensure that any establishment or undertaking carrying out WEEE treatment operations obtains a permit from the competent authority in compliance with Article 23 of the WFD.

This means that the permit shall specify at least the following:

- (a) the types and quantities of waste that may be treated;
- (b) for each type of operation permitted, the technical and any other requirements relevant to the site concerned;
- (c) the safety and precautionary measures to be taken;
- (d) the method to be used for each type of operation;
- (e) such monitoring and control operations as may be necessary; and
- (f) such closure and after-care provisions as may be necessary.

MS shall also ensure that the permit includes all conditions that are necessary for the compliance with the requirements of Article 8 (2), (3) and (5) and for the achievement of the recovery targets set out in Article 11 of the WEEE Directive.

On 4 February 2013, the Commission requested the European Standardization Organizations to develop European standards for the treatment of WEEE. European standards relevant for WEEE include the following:

- EN 50419 on the marking of electrical and electronic equipment
- EN 50574 on the collection, logistics & treatment requirements for end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons
- EN 50625-1: Collection, logistics & treatment requirements for WEEE - Part 1: General treatment requirements

2.1.3 ROHS DIRECTIVE (2011/65/EU)

The Directive of the European Parliament and of the Council on the Restriction of Hazardous Substances (RoHS) in Electrical and Electronic Equipment (EEE) and promoting the collection and recycling of such equipment was initially adopted on 27 January 2003 (2002/95/EC) ¹¹. The Directive provides for the creation of collection schemes where consumers return their used e-waste free of charge. The objective of these schemes is to increase the recycling and/or re-use of such products. It also requires heavy metals such as lead, mercury, cadmium, and hexavalent chromium and flame retardants such as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) to be substituted by safer alternatives.

A number of substantial changes to this Directive were introduced through the new Directive 2011/65 / EU, which entered into force on 21 July 2011 (RoHS 2) with the aim to

increase the amount of e-waste that was appropriately treated and to reduce the volume that goes to disposal. The aim of the RoHS recast was also to reduce administrative burdens and ensure coherency with newer policies and legislation covering, for example, chemicals and the new legislative framework for the marketing of products in the European Union. The RoHS Recast Directive (RoHS 2) was published in the Official Journal on 1 July 2011.

2.1.4 IPPC DIRECTIVE/INDUSTRIAL EMISSIONS DIRECTIVE AND BAT FOR WASTE TREATMENT

The IPPC Directive (codified by Directive 2008/1/EC), which was repealed by the 2010 Industrial Emissions Directive (IED, 2010/75/EU) with effect from 7 January 2014, sets out minimum requirements through their BREFs for MS. This will likely impact the treatment conditions of WEEE as (i) the IED expressly provides that “BAT conclusions shall be the reference for setting the permit conditions” (Article 14(3)), and (ii) BAT may be defined for the treatment of WEEE in accordance with the IPPC/IED, as contemplated by the WEEE Directive. However, it is specially noted that the requirements under this Directive are relevant only for the treatment facilities that fall within its scope; they are not relevant for all WEEE treatment facilities in the EU.

2.1.5 WASTE SHIPMENT REGULATION (EC) NO 1013/2006

The Waste Shipment Regulation (WSR) adopted by the EU in 2006 sets out legal procedures and control regimes for the shipment of waste to ‘harmonise’ (recital 5 of the WSR) the Basel Convention and the OECD Decision (referenced in Annex VIII of the Regulation). It is a legally binding legislation, with its waste categories derived from the two international agreements. Table 7 provides an overview of WSR objectives and waste codes.

Table 7. WSR objectives and waste codes.

EU WSR objectives and waste codes
Ensure shipment and disposal/recovery without endangering human health and the environment
Require ESM in case of export from the EU
Prohibit export and import if reason to believe that waste will not be managed accordingly (‘management’ of waste is referring to the best available techniques reference documents (BREFs) from the IPPC Directive which should be used as a reference)
Annex III: ‘Green list’ made up of G codes from OECD Decision and B Codes of Basel Convention – shipment of waste subject to general information requirements.
Annex IV: ‘Amber List’ includes a list of selected A Codes of the Basel Convention – shipment of waste subject to the procedure of prior written notification and consent
Annex V: defines ‘dangerous’ waste subject to an export prohibition in article 36 of the WSR. There are two lists: List A (from Annex VIII to the Basel Convention) and List B (Annex IX to the Basel Convention). Wastes in List A are completely prohibited from being exported. Wastes listed in List B are potentially permitted to be exported.

Article 36 of the WSR prohibits the export of waste for disposal and export of dangerous wastes to non-OECD countries (listed in Annex V). Within the 'Green' list of waste are categories of WEEE that are considered to be non-hazardous. The export of 'Green Waste' is permitted, as long as the importing country allows it, or allows it with specific controls (Article 37 of the WSR).

Despite specific waste being listed under the 'Green List,' third countries and MS have the legal right to ban or limit waste. The corresponding Regulation 1418/2007 provides a list of these countries and the types of waste they limit, which for some countries includes WEEE (for example, China completely bans the importation of electronic scrap, despite it being considered a "Green" Listed Waste in the WSR)

The WSR provides waste codes for WEEE-related wastes and not for WEEE as defined in the WEEE Directive. For example, there are codes for electronic scrap, for assemblies, for cathode-ray tubes, for waste lead-acid batteries, copper alloys etc. Such codes have been identified in the Correspondents' Guideline No. 1 on the shipments of WEEE, as well as in the draft technical guidelines on e-waste of the Basel Convention.

In its article 49, the WSR provides that for exported waste that is to be recovered outside the EU, the MS are required to ensure that the facility which receives the waste will be operated in accordance with human health and environmental protection standards that are "broadly equivalent to standards established in Community legislation".

3 ENVIRONMENTAL IMPACTS FOR TA AND RE (PRIMARY EXTRACTION)

According to the paper *Life Cycle Assessment of Metals: A Scientific Synthesis*¹², the following results for the Ta and Re have been reported, considering a cradle to gate approach and considering a primary extraction of the metal (table 8).

Table 8. Ta and Re environmental comparison for the virgin primary extraction.

Impact category	Ta	Re
Global warming potential (kg CO ₂ eq / kg)	260	450
Cumulative energy demand (MJ eq / kg)	4,360	9,040
Terrestrial acidification (kg SO ₂ eq / kg)	1.7	11
Freshwater eutrophication (kg P eq / kg)	1.5E-01	3.5E+01
Human toxicity (CTUh/kg)	1.2E-04	5.9E-02

These results can be considered as reference in terms of environmental impact, and in case that environmental result for the Ta and Re are obtained, they will be compared to these results.

4. TA RECYCLING TECHNOLOGIES SELECTED FOR THE ENVIRONMENTAL STUDY

One process was selected for the environmental study in this Work package, based in a scientific paper ⁽¹³⁾:

Title:

Recovery of Tantalum Sintered Compact from Used Tantalum Condenser Using Steam Gasification with Sodium Hydroxide

Authors:

Shigeyuki Katanoa, Takaaki Wajimaa and Hideki Nakagomea)

Abstract:

A recycling process for tantalum from capacitor scraps using an oxidation process followed by mechanical separation and chemical treatment was investigated. This study demonstrates that sintered tantalum electrodes inside the capacitor scraps can be mechanically collected after the oxidation of the scraps in air, and high-purity tantalum oxide powder (Ta_2O_5) was efficiently recovered after chemical treatment. By reducing the Ta_2O_5 obtained through magnesiothermic reduction, tantalum powder with 99 % mass purity was obtained. Using the chlorination for tantalum recovery was also investigated, and the tantalum or tantalum compounds were reacted with chloride wastes such as $FeCl_x$. It was found that tantalum was effectively separated and purified when tantalum powder is reacted with $FeCl_x$ at 1100 K under an argon atmosphere.

Unfortunately, no data about this process has been obtained, neither any other process of Ta recovery from urban mining process.

Considering this situation, the authors' option has been not to develop any study due to no data availability.

The authors have developed a Ta recovery study included in the Work package 3 of the project, where info about Ta secondary process were obtained, and it should be interesting to assess the possibility of using that process in some urban mining Ta source.

5. RE RECYCLING TECHNOLOGIES SELECTED FOR THE ENVIRONMENTAL STUDY

5.1 RE RECYCLING TECHNOLOGY

According to the data provided by the partners involved in the **Re** recovery processes, the selected method to be study for **Re** will be a technology of treatment of rhenium wastes from **superalloys** production and processing, with a grain size ≤ 10 mm. It is a currently used technology for production of ammonium perrehenate.

A multistage hydrometallurgical process is used to process Rhenium wastes from superalloys production and processing with a grain size ≤ 10 mm.

Such a process comprises materials preparation and leaching, rhenium ions sorption on a weak base anion exchange resin, elution of adsorbed ReO_4^- ions with ammonia solution and eluates production with ammonium perrehenate production. It was assumed to use rhenium wastes with rhenium content 1-3 %. Rhenium content in a feed was taken to be at the level of 1.5 %. The main scheme of the process can be seen in figure 3.

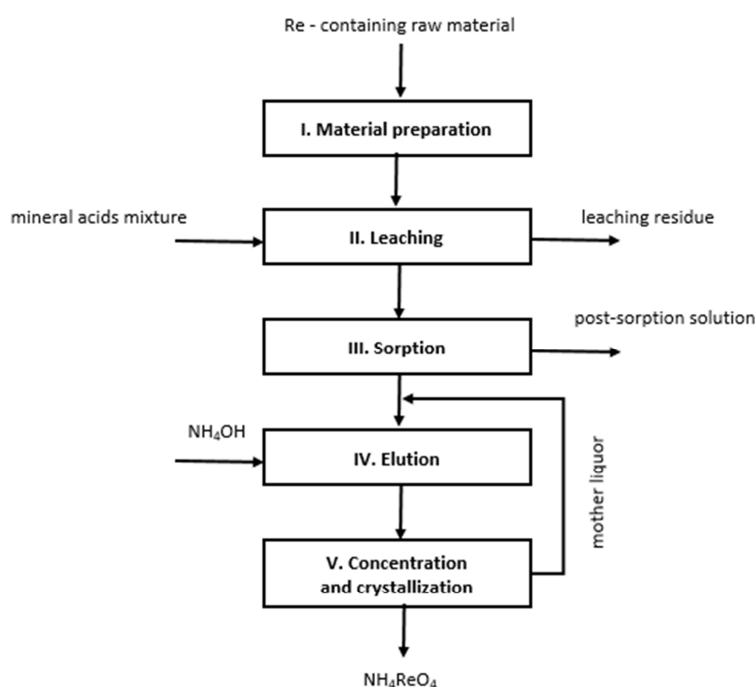


Figure 3. Diagram of Rhenium recovery from wastes < 10mm

The process stages are described below:

Stage I. Material preparation for leaching tests. Varied rhenium content, size and type are the main features of materials from superalloys production and processing. Therefore the key parameter enabling its further processing in the second Leaching stage is

type and composition. Powder materials with grain size $\leq 10\text{mm}$ with above 1 % rhenium are used in stage II.

Stage II. Leaching. Leaching of materials is carried out in an acidic environment favourably in a mixture of mineral acids with a small addition of oxidizers, in a specially-prepared reactor with vapour heating, a proper solid – liquid ratio and intensive mixing.

In one batch 200 kg of material is leached in a 2-3m³ of acids. Leaching is carried out for 6h till the end of hydrogen evolution. Then solution is filtered and sent to next stage.

Stage III. Re sorption. Leaching residue containing $<0.01\%$ Re and other refractory metals is managed. The solutions of temperature 20-25°C and containing above 0.5 g/dm³ Re are used in a stage III.

Re sorption is accomplished in at least four ion exchange columns connected in series. When the rhenium concentration in an eluate from the first column equals concentration in a feed then the column is separated from the rest and stage IV Re elution is performed.

Solutions containing nickel, cobalt and other metals from sorption stage are sent to recovery.

Stage IV. Re elution is performed using 6 - 9 % ammonia solution in a three steps process. The first part of the eluate with $\text{pH} < 5.5$ is recycled to a sorption stage while the second part is directed to the stage V.

Stage V. Concentration and crystallization and the third one to eluting agent preparation. In this technology ammonium perrhenate with the following elements content is crystallized:

min. 69.4% Re;

moisture content: 0.1 %;

Hg $< 1\text{ppm}$;

Al, Cu, Fe, Mg, Mn, Mo, Na, Ni, Pb, Zn $< 5\text{ ppm}$;

Ag, Ba, Ca, Cd, Co, Cr, Pd, Rh, Ru, Sb, Sn, Tl $< 10\text{ ppm}$;

As, Se, Si, W $< 20\text{ ppm}$;

V, P, Ir $< 50\text{ ppm}$.

A clarifying mass flowchart is shown in figure 4. That flowchart will be the basis for the data inventory of the process, taking into account that the flowchart only presents data for the mass balance and **no energy flow has been collected**.

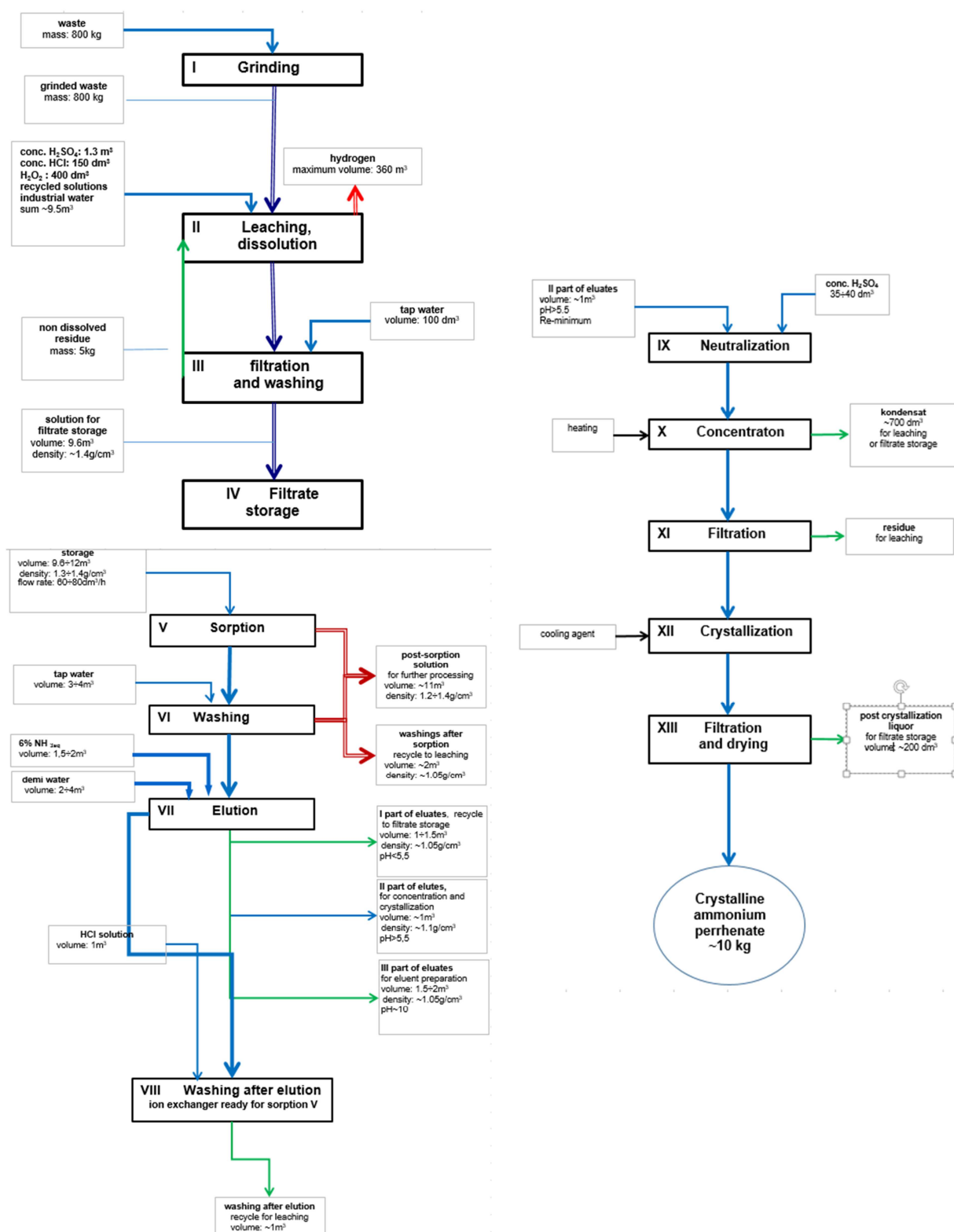


Figure 4. Flow chart mass balance for leaching (I-IV), ion-exchange (V-VIII) and concentration and crystallization (IX-XIII). All values for 800 kg of waste with Re content of 1.3 %.

Table 9. Inventory of the Re recovery process (only for materials).

Stage	INPUTS			OUTPUTS		
	Input	Value	Unit	Output	Value	Unit
I Grinding	Waste	800	kg	Waste grinded	800	kg
II Leaching, dissolution	H_2SO_4	1.3	m ³	Hydrogen	360	m ³
	HCl	150	dm ³			
	H_2O_2	400	dm ³			
	Recycled solutions	?	m ³			
	Industrial water	?	m ³			
	Total amount	9.5	m ³			
III Filtration and washing	Tap water	100	dm ³	Non dissolve residue	5	kg
IV Filtrate storage	Solution for filtrate storage	9.5	m ³			
V Sorption	Solution for filtrate storage	9.5-12	m ³	Post sorption solution for further processing	11	m ³
VI Washing	Tap water	3-4	m ³	Washing after sorption. Recycle for leaching	2	m ³
VII Elution	NH ₃ 6%	1,5-2	m ³	Eluate I, recycled to filtrate storage	1-1.5	m ³
	Demineralized water	2-4	m ³	Eluate II, for concentration and crystallization	1	m ³
				Eluate III, for eluent preparation	1.5-2	m ³
VIII Washing after elution	HCl solution	1	m ³	Washing after elution. Recycling for leaching	1	m ³
IX Neutralization	Eluate II, for concentration and crystallization	1	m ³			
	H ₂ SO ₄	35-40	dm ³			
X Concentration	Heating			Condensate for leaching or filtrate storage	700	dm ³
XI Filtration				Residue for leaching		
XII Crystallization	Cooling agent					
XIII Filtration and drying	Crystalline ammonium perrhenate	10	kg	Post crystallization liquor for filtrate storage	200	dm ³

Data collected has been reported for the recovery of 10 kg of ammonium perrhenate, 69.4 % Re content. So the results must be normalized to taking into account that value (6.94 kg of Re).

As it can be seen, only material inputs will be considered, because no energy input has been reported.

No data for the liquid effluents will be included, because it is reported that all the effluents are reused and recycled in the process. It is important to keep in mind that some values about effluents treatment are missed in the mass balance.

Table 10 shows the environmental impacts referred only to the material input of the process.

Table 10. Environmental results (only considering material inputs)

Stage	Material input			Impact category				
				Global warming potential	Cumulative energy demand	Terrestrial acidification	Freshwater eutrophication	Human toxicity
				(kg CO ₂ eq / kg)	MJ	(kg SO ₂ eq / kg)	(kg P eq / kg)	(CTUh/kg)
II Leaching, dissolution	H ₂ SO ₄	187.32	kg	2.06E+01	3.24E+02	1.25E+00	2.14E-02	1.41E-09
	HCl	21.61	kg	1.32E+01	2.79E+02	4.88E-02	4.69E-03	5.31E-09
	H ₂ O ₂	57.64	kg	5.71E+01	1.03E+03	1.53E-01	1.16E-02	2.41E-09
III Filtration and washing	Tap water	14.41	kg	7.45E-03	1.36E+02	3.27E-05	4.18E-06	3.85E-13
VI Washing	Tap water	504.32	kg	2.61E-01	4.77E+03	1.14E-03	1.46E-04	1.35E-11
VII Elution	NH ₃ 6%	15.13	kg	4.57E+01	8.35E+02	2.80E-01	8.62E-03	6.54E-09
	Demineralized water	432.28	kg	1.09E-02	1.36E+02	3.65E-05	4.08E-06	1.09E-12
VIII Washing after elution	HCl solution	144.09	kg	8.78E+01	1.86E+03	3.26E-01	3.13E-02	3.54E-08
IX Neutralization	H ₂ SO ₄	5.40	kg	5.94E-01	9.35E+00	3.61E-02	6.16E-04	4.06E-11
TOTAL				2.25E+02	9.38E+03	2.10E+00	7.83E-02	5.11E-08

5.2 RE RECYCLING ENVIRONMENTAL RESULTS

Figures 5 to 9 shows the comparison of the virgin primary process of Re primary extraction versus the info that has been collected for Re recovery process. It is important to keep in mind that only the material input flow has been considered, so, in the gap between the virgin and the recovery process, energy flows and effluent treatment must be also considered.

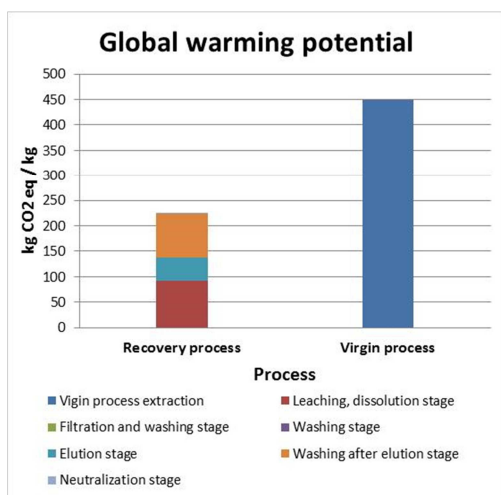


Figure 5. Global warming potential results for Re

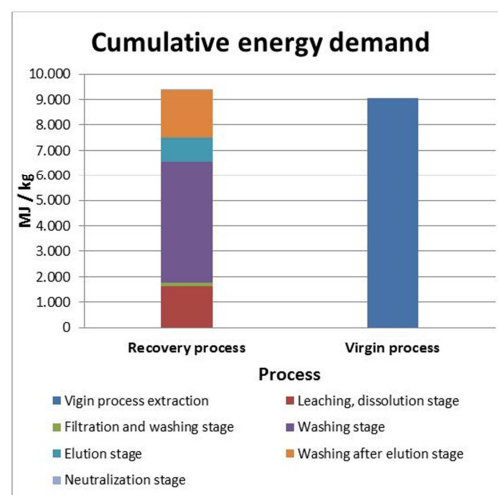


Figure 6. Cumulative energy demand results for Re

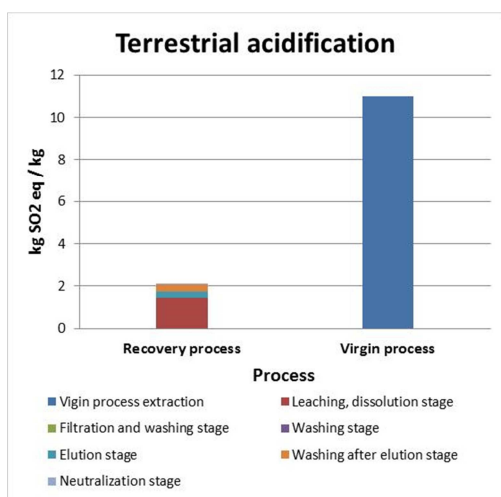


Figure 7. Terrestrial acidification results for Re

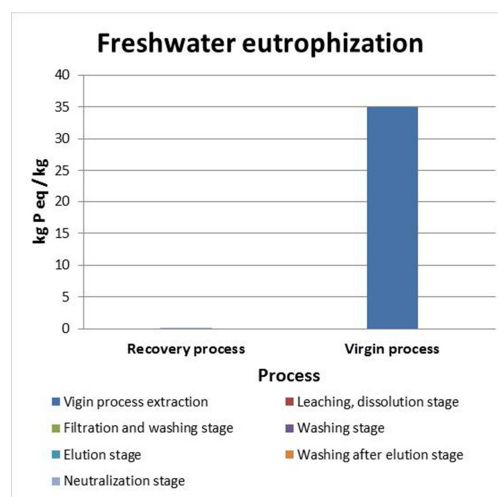


Figure 8. Freshwater eutrophication results for Re

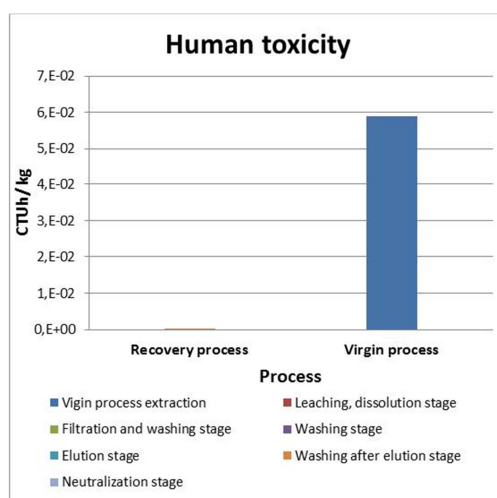


Figure 9. Human toxicity results for Re

In the figure 10, a global comparison has been represented, considering a percentage comparison approach.

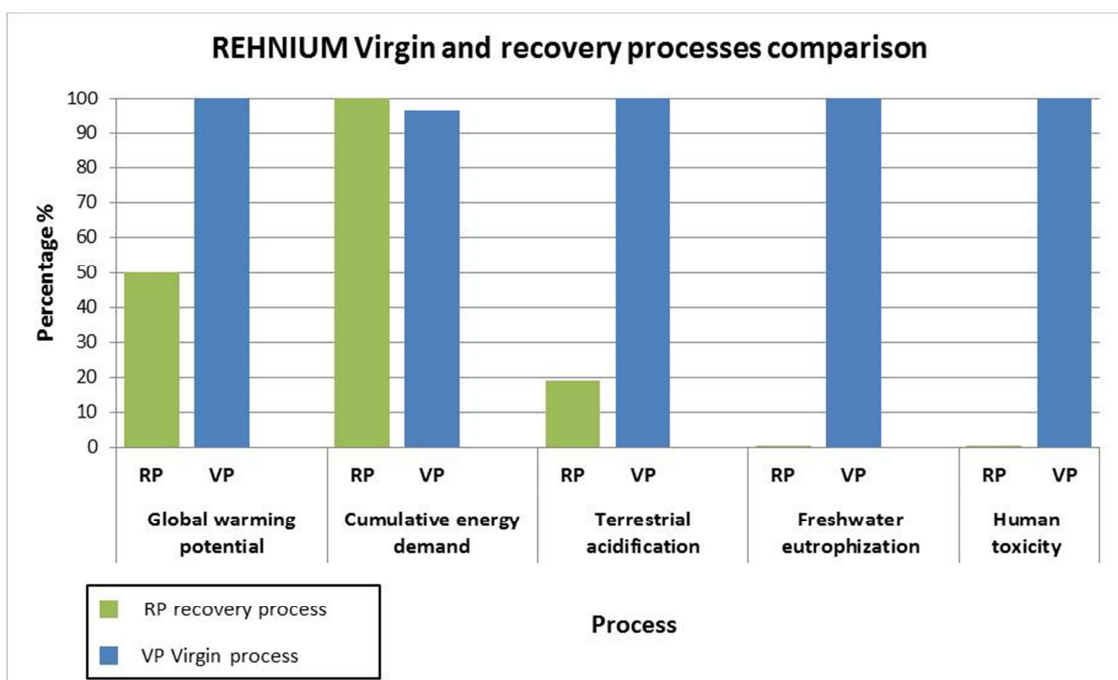


Figure 10. Processes comparison between virgin primary extraction and recovery process according to the process selected in urban mining.

6 CONCLUSIONS

6.1 RE RECOVERY. ENVIRONMENTAL CONCLUSIONS

Although the environmental data for Re primary extraction is reported in a cradle to gate approach in a complete and representative way, the life cycle inventory of the recovery process for Re is not fully complete, considering that only materials have been reported.

This implies that the environmental impact of the recovery process is not fully completed, considering that there is no data available for the energy and waste environmental impacts.

Considering the two previous conditionings, it is not possible to establish a full comparison between the virgin primary extraction and the recovery process, although it is possible to determine the hot spots and the most impacting materials used in the process

Leaching and solution stage is the most impacting stage (in terms of materials use) in the categories of global warming potential and terrestrial acidification.

In the cumulative energy demand category, the washing stage is the most impacting stage.

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