H2020 WORK PROGRAMME

D8.10 – REPORT ON GENERATED KNOWLEDGE IN BIORECOVER TO FEED THE RMIS - 1

LEAD BENEFICIARY: CETIM

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LIST OF ABBREVIATIONS

BR Bauxite Residue

CRM Critical Raw Materials

DG Directorate General

EC European Commission

H&S Health and Safety

HREEs Heavy Rare Earth Elements

IPR Intelectual Property Rights

JRC Joint Research Centre

LREEs Light Rare Earth Elements

MgW Magnesium low grade waste

PGM Platinum Group Metals

REEs Rare Earth Elements

RMIS Raw Materials Information System

WP Work Package

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EXECUTIVE SUMMARY

BIORECOVER project aims to apply new sustainable and safe extractive technologies to obtain a wide range of Critical Raw Materials (CRMs) from unexploited primary and secondary sources. The specific sources evaluated are the Bauxite Residue (BR), Mg low-grade waste (MgW), Platinum Group Metals (PGM) low-grade sources and PGM content by-products. The extracted materials could be used at industrial scale to produce components such as catalysts, brake pads, powder Mg, and oxygen sensors.

The European Commission's (EC) Raw Materials Information System (RMIS) is developed by the Directorate-General (DG) Joint Research Centre (JRC) in cooperation with the DG for Internal Market, Industry, Entrepreneurship and SMEs (GROWTH). The RMIS is the Commission's reference web-based knowledge platform on non-fuel, non-agricultural raw materials from primary and secondary sources. This System provides an overview of the European raw materials context, the policy mandate that underlies the development of the RMIS, its goal and scope.

BIORECOVER has assigned part of the project resources to supply new relevant acquired knowledge to RMIS. The *Task 8.2 Outreach to markets, industry and stakeholders* comprises a *Subtask 8.2.2 Information supply to EC Raw Materials Information System* is dedicated to these activities.

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1 BIORECOVER AND THE RMIS: APPLICATION PROCEDURE AND FIRST RESULTS UPLOADED

CETIM as coordinator contacted the RMIS in April the 7th of 2020. After a first evaluation based on an abstract summary of the project (ANNEX I Abstract and information submitted To be UPLOADED in the rmis), the RMIS team at JRC informed CETIM that BIORECOVER was aligned with the activities of the RMIS . The established way for the collaboration of the relevant Horizon 2020 projects with the RMIS is through the transfer of data and results into the Knowledge Gateway.

After the first contact, the formal application and the information was gathered in a document. The information submitted was published in the section "KNOWLEDGE GATEWAY & LIBRARY in the subsection "European Funded Project" on the 25th of September of 2020[1].

Image 1 Screenshot of the system where BIORECOVER project can be found

After being accepted as part of the platform, representatives from CETIM, as coordinator of the BIORECOVER project, have regularly attended the annual events organised by the RMIS team at JRC and the DG Industry, that up to this date were organised online:

- December 3rd of 2020: "Channelling knowledge from European projects into the Raw Materials Information System (RMIS)"
- December 3rd of 2021: "Channelling knowledge from European projects into the Raw Materials Information System (RMIS)"

It is possible to have access to the recordings of these events through the Newsletter of the RMIS[2].

Currently, the BIORECOVER team is defining the best mechanisms to transfer the available results and data from the project into the Knowledge Gateway. The data collected at this moment of the project includes characterisation of the primary and secondary raw materials as well as the CRM content in them. This information could be highly relevant for the European Union to align policies to enhance the impact of these technologies in the EU's strategy of self-reliance for CRMs' supply, which

[1] The link is not available due to the structure of the website that does not provide specific links
[2] https://rmis.jrc.ec.europa.eu/?page=rmis-news-c4dc3d

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is now even more relevant than before, considering the geopolitical context at European and global levels.

This is the 1st of 2 reports related to the RMIS information exchange. It comprises the first steps and application procedure. The 2nd one will include the data exchanged which still depends on the upcoming results of the project.

2 REPORT ON IMPACT OF BIORECOVER ON RAW MATERIALS POLICY

The Raw Materials Scoreboard[3] is the framework used to analyse the impact of BIORECOVER on the EU's Raw Materials Policy. This scoreboard comprises a series of indicators distributed on 6 thematic clusters (Image 2).

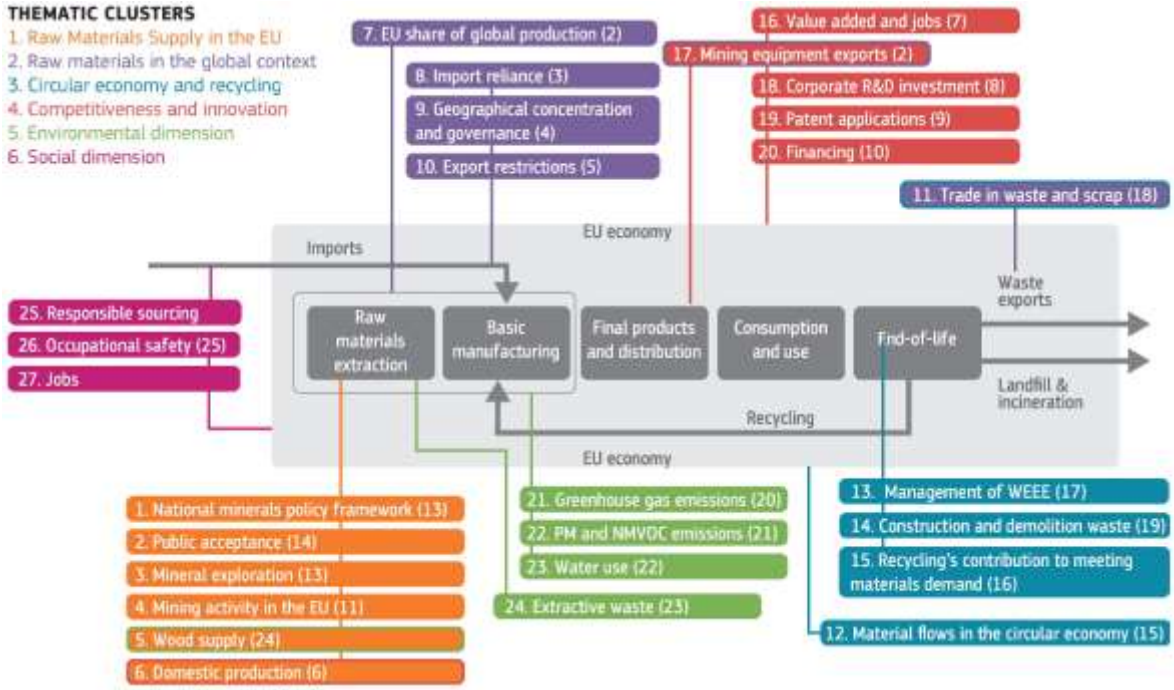

Image 2 The Raw Materials Scoreboard, structure of clusters and indicators along the supply chain

[3] It must be considered that some of the assumptions at BIORECOVER's proposal stage were made with the 2018 version of the Raw Materials Scoreboard:
European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *Raw materials scoreboard 2018: European innovation partnership on raw materials*, Publications Office, 2018, https://data.europa.eu/doi/10.2873/08258
Currently the 3rd Raw Materials Scoreboard has been published:
European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, *3rd Raw Materials Scoreboard: European innovation partnership on raw materials*, Publications Office, 2021, https://data.europa.eu/doi/10.2873/567799

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The developments in BIORECOVER are targeted to the recovery of CRMs. In particular Rare Earth Elements (REE), Magnesium (MgW) and Platinum Group Metals (PGM). The selected raw materials are EU CRMs with high supply-risk (5.0, 4.9, 4.0 and 2.5) and high economic importance (3.6, 3.7, 7.1, and 5.0) from LREEs, HREEs, Mg and PGM, respectively. The import reliance rate is 100% for REE and Mg, and 99.6% for PGM. The project is developing activities to ensure that these indicators will be improved as an output from the project results. In relation with Materials Policies, the project will contribute to the next indicators:

- **Thematic Cluster 1 Raw Materials Supply in the EU: Indicator 2: Public acceptance of mining activities:** Within the raw materials extraction step of the supply chain, BIORECOVER is implementing a public awareness campaign to raise awareness about the impact of CRMs in different sectors, devices and applications that can affect the daily life of citizens. A public perception study is also being carried out; results will be published in the project's website and social media accounts by the end of 2022.
- **Thematic Cluster 1 Raw Materials Supply in the EU: Indicator 6: Domestic Production and Thematic Cluster 2 Raw Materials in the Global Context: Indicator 7: EU share of global production:** Again within the extraction step of the supply chain, BIORECOVER project will enable new sources. At this point methodologies have been developed for the recovery of 6 CRM including PGM (Pt, Pd and Ir), Mg and REE (Y and Sc).

The impact of the BIORECOVER project in the criticality of supply (CRM score assessment) is being currently analysed as part of the broader impact studies developed in the projects outreach activities. This information will feed the RMIS once the studies conclude and will part of the next report *"Impact on the CRM criticality"* which will be available in September 2022.

3 MARKET ASSESSMENT RELATED TO BIORECOVER

BIORECOVER project is collecting data about REEs, MgW and PGM which includes the balance of import/exports as well as current trade restrictions and barriers for these materials. These studies are currently being developed as part of the project's Exploitation, Dissemination and Communication strategy. The studies related to market assessment are still under development and will be presented later on as part of the report on *"Exploitation plan, business models and IPR "* that will be launched on the autumn of 2022. Once these studies have been completed , the information will be submitted to the RMIS.

4 MATERIAL EFFICIENCY AND VALUE CHAIN OF BIORECOVER RAW MATERIALS

BIORECOVER multidisciplinary consortium covers the whole raw materials value chain from suppliers (MYTILINEOS, MAGNA, UWITS & JM) to end users (FAE, MAGNA & JM) involving also industries, RTOs & universities (CETIM, UCPH, UC, UWITS, LNU, CeBER, TR, ALGAENERGY). Moreover, 2 specialised SMEs (ENSO, LGI) will address the H&S and risk; socio-economic assessment & public perception; dissemination & communication included awareness campaign; outreach to markets,

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industry & stakeholders; networking with projects; exploitation, business models & IPR; impact and replicability through Circular Economy models.

BIORECOVER is directly framed in the secondary raw materials and circular economy framework. In this sense. The project extracts value materials from BR, MgW and PGM mining wastes and by-products for their reuse, involving the whole value chain from raw materials suppliers to end users.

The project has identified different residues from partners with a significant content of CRM:

- REE (Rare Earths) coming from Bauxite Residue (BR) from Greece (MYTILINEOS);

- Mg (Magnesium) contained in Mg wastes of low-grade minerals with silicon or limestone impurities & calcination by-products- (MgW) from Spain (MAGNA);

- PGM (Platinum Group Metals) included in PGM low-grade ores consisting in flotation tailings (PLGO) from South Africa (UWITS) & PGM by-products from United Kingdom (JM).

The updated results as well as the potential impact of the outputs of the project will be feed into the RMIS. These analyses will be part of the report "*Impact on the CRM value chain"* and a summary of the information submitted to the RMIS will be part of the next version of this "*Report on generated knowledge in BIORECOVER to feed the RMIS*".

5 SOCIAL & ENVIRONMENTAL ASSESSMENT OF BIORECOVER

BIORECOVER is developing a detailed Sustainability, Social, Health, Safety and Economic aspects assessment to identify social consequences together with bottlenecks and barriers related to social acceptance. Specific Social Acceptance Actions such as the awareness campaign mentioned before are addressed to relevant actors and the general public to increase awareness and trust regarding raw materials importance, the challenges related to their EU supply and the proposed solutions. An environmental, economic, health and safety analysis is being also carried out and the results will support the social actions. In addition, the Scientific and Stakeholder Advisory Panel (SSAP) created in the project will support these analyses.

The results are being gathered in the reports Environmental validation including a LCA, Technological and non-technological risks; Health and Safety Study Socio-Economic repercussions & public perception study and Economic feasibility LCC. Once this information is consolidated, a report will be sent to the RMIS. A summary of this report will be part of the next "*Report on generated knowledge in BIORECOVER to feed the RMIS*".

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ANNEX I ABSTRACT AND INFORMATION SUBMITTED TO BE UPLOADED IN THE RMIS

BIORECOVER OBJECTIVES

The **overall objective of BIORECOVER** is the research and development of a **new sustainable and safe process, essentially based on biotechnology,** for **selective extraction** of a wide range of **Critical Raw Materials** (CRMs), involving a multidisciplinary consortium that encompass the whole value chain and key international cooperation (ZA: UWITS, CeBER), from relevant unexploited **secondary and primary sources:**

- **REE (Rare Earths) coming from Bauxite Residue (BR)** from Greece (MYTILINEOS);
- **Mg (Magnesium) contained in Mg wastes of** low-grade minerals with silicon or limestone impurities & calcination by-products- **(MgW)** from Spain (MAGNA);
- **PGM (Platinum Group Metals) included in PGM low-grade ores** consisting in **flotation tailings** (**PLGO**) from South Africa (UWITS) & **PGM slags, dusts and press cake (PCBP)** from United Kingdom (JM).

BIORECOVER will be a versatile and flexible solution applicable in several conditions (pH, mineral complex, raw materials, etc.), **obtaining high recovery yields (≥ 90%), selectivity (>95), purity (≥ 99.9%) and both environmental and cost-efficiency in safe conditions.** The **BIORECOVER strategy will be based on research, integration and optimisation of the following stages at laboratory scale** (from TRL 2-3 to TRL 5):

i) Pre-Treatment: To increase the concentration and the accessibility to the target CRMs present in complex matrices, the Interfering Components (IC i.e. Fe, Al, Ca and Ti for BR; Silicon, Fe and $CaCO_3$ for MgW; Cu, Ni and Co for PLGO; Cu, Ni, Zn and Fe for PCBP) in the raw materials will be removed by specific microbial action (indigenous bacteria, thermophiles, consortia and fungi).

ii) Treatment: Selective CRMs mobilisation to obtain a bioleachate, by the action of pure strains and consortia of microorganisms (cyanogenic and acidophiles bacteria, fungi etc.), siderophores (high-affinity metal-chelating compounds secreted by microorganisms), and/or metabolites (organic acids or cyanide) from microorganism.

iii) Post-Treatment: to recover the CRMs from the bioleachate with high selectivity and purity, five sustainable technologies will be studied and applied separately and/or in combination (eco-friendly reusable polymeric microcapsules, immobilised microalgae, bacteria and siderophores & active cell uptake, fungal-based biorecovery and engineered proteins).

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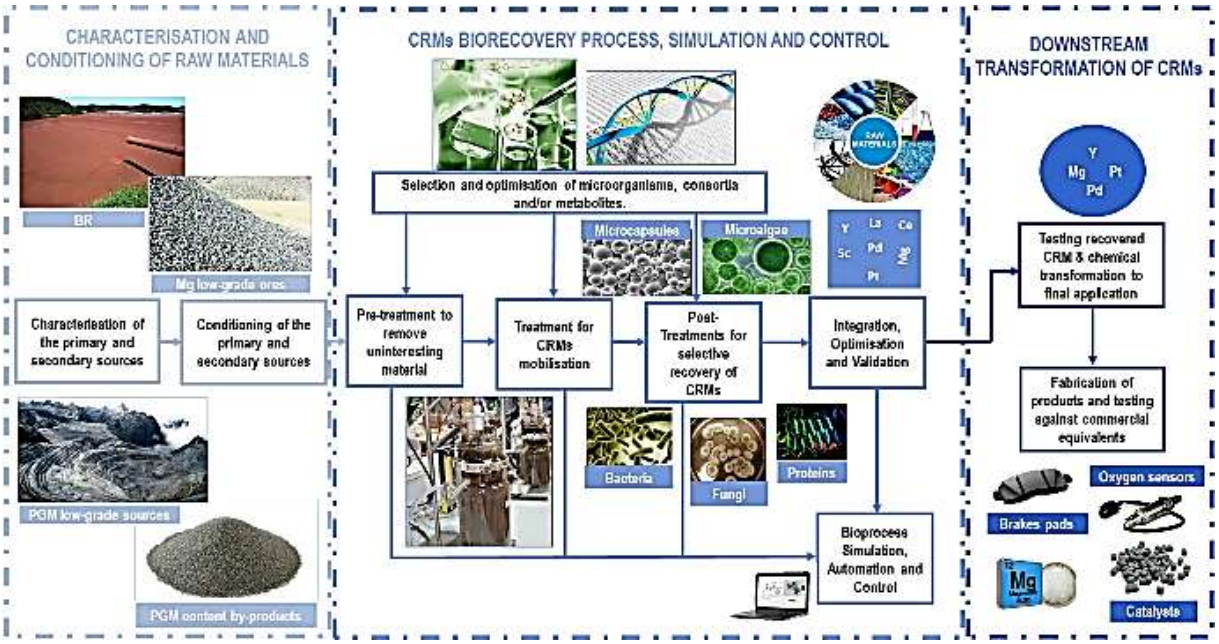

Image 3 Basic flow-scheme of BIORECOVER

The **BIORECOVER R&D methodology will comprise two phases**. In the first one, the study of the different technologies will be carried out separately. **Indigenous microorganisms** from the used raw materials (BR, MgW & PLGO) will be tested in order to improve the technical (resistance to raw material conditions, pH, oxidant, reducing, ...) and economic viability of the process and its performance. Afterwards, in the second phase, the selection and **integration of the best technologies** will be carried out (one route for each type of raw material) which will be optimised and validated. Finally, **downstream processing** of the extracted CRMs will be studied to achieve the meet quality requirements for their reuse in different applications (brake pads, oxygen sensors, powder Mg and catalysts). Moreover, to increase the material efficiency and the sustainability of BIORECOVER process, the **valorisation of the by-products** and wastes generated in each step (especially as **construction raw materials**) will be also studied towards a **Zero Liquid Discharge (ZLD) process.** These BIORECOVER aims will be supported by applying and taking advantage of tools such as **interactive LCA & LCC**. Additionally, **Modelling of the overall process** will also be carried out to develop a Decision-Making Framework (DMF) to maximise the performance.

The **awareness, trust and acceptance of the society** about the importance of raw materials and their supply, production and use will be improved by the implementation of an **awareness campaign**. Besides, the project results will contribute to building the EU bio-mining knowledge (**RMIS**). The whole value chain will be involved implementing the EU **Circular Economy models** and supporting the goals of the **EIP on Raw Materials**. Furthermore, a **Stakeholder and Scientific Panel (SSAP)** will be involved to guaranty the quality of the research and to improve the dissemination and communication activities as well as the further market penetration.

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Technical objectives
O1- Determine the detailed characteristics (concentration in CRMs, physical properties, particle size, impurities content and mineralogical properties) and establish a conditioning procedure **for each raw material to maximise the subsequent biorecovery** process (selection of the optimal raw matter density and pH from BR, grain size, etc.). **O2- Remove the main IC such as Fe, Al, Ti and Ca (≥60%) present in BR** by means of indigenous bacteria and consortia with genetic metal resistance isolated from BR in order to concentrate the REE and increasing their accessibility as well as minimising their loss (<2%). **O3- Eliminate impurities (≥65%), mainly $CaCO_3$** via decalcifying microorganism and other minor interferences such as **silicon, Fe, etc.** with indigenous bacteria isolated from MgW **to concentrate and facilitate the mobilisation of Mg, while minimising its loss by dissolution (<2%).** **O4- Remove ≥60% of the uninteresting metals (**Cu, Ni, Co, Zn and Fe) that can encapsulate **PGM** by bacteria, thermophiles, consortia and fungi concentrating it, facilitating their recovery and **minimising its losses (<2%).** **O5- Determine the effectivity of the pre-treatment for each source, in order to decide whether to include it in the BIORECOVER integrated strategy or not,** by comparing the mobilisation obtained from concentrated pre-treated solids and untreated matrices. **O6- High and selective mobilisation of the target CRMs in the bioleachate (REE from BR by ≥90%, Mg from MgW by ≥95%, and PGM from both PLGO & PCBP by ≥90%)** by **optimising and improving** (by means of HTS, RSM, neural network optimisation and other techniques) **specific bacteria** (e.g. cyanogenic o acidophilic) and consortia, **fungi, siderophores and metabolites** (biologically produced organic acids). **O7-** Develop eco-friendly **reusable polymeric microcapsules** with **high REE** (mainly Y but also others REE) **and Pt recovery rates (>95%)** and **selectivity (>95%)** with **high material efficiency** (reusable, "almost zero" extractant consumption). **Maximise** its **reutilisation and functional lifespan.** **O8-** Obtain specific **biosorbents** based on **immobilised microalgae biomass (***Chlorella vulgaris*, *Desmodesmus* sp, *Anabaena* sp, *Arthrospira sp.…***)** with **high selectivity (≥ 95%)** to REE (mainly Y but also other REE), Mg and PGM (mainly Pt & Pd but also other PGM), **recovery rates up to 95% and high material- and cost- efficiency as well as easy operation.** **O9-** Get **selective immobilised biosorbents based on siderophore-producing bacteria and purified siderophores** for extracting selectively REE (mainly Y but also other REE) and PGM (mainly Pt & Pd but also other PGM) (**at least 95% for both recovery and selectivity**) that are **easy to use, and material- and cost-efficient**. **O10-** Develop **fungal-based biosorbents** (fungal cell-free filtrates) **for Mg recovery (>95%) as nanoparticles.**

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O11- Development of improved **proteins** (genetic engineering, computational structural modelling…) **for selective biosorption of Mg and Pt (95%)** with **high recovery rate** (**>90%).**

O12- Develop downstream processes to achieve at least a purity of 99.9% and the proper physico-chemical state of the BIORECOVER elements (Y, Mg, Pt and Pd) for their subsequent **reuse.**

O13. Develop a flexible modelling and forecasting tool (DMF) with universal code and easy to implement and which included **technical, environmental & economic issues for optimising the BIORECOVER process** (predict metal recovery, time and effort) as well as its adaptability to other sources of raw materials and its future scaling up.

O14- Obtain a flexible (ability to operate in varied conditions) **and modular** (different steps which can be changed, added, excluded, according to the needs) **biorecovery process** able to treat primary and secondary sources with application in a wide range of raw materials with easy and safe operation and low environmental impact and cost.

O15- Define the optimal combination of processes of the BIORECOVER solution to obtain the target **recovery rates (≥ 90%), selectivity (at least 95%)** and **purity (≥ 99.9%)**.

O16- Ensure the highest health, safety and risk performance (≥90% of improvement of current process) and **reliability** through Risk and H&S (health & safety) assessment, implementing mitigation and correction measures.

O17- Define the quality requirements of the metals recovered and **if necessary, develop the downstream processes for its purification and/or modification** (e.g. calcination, reduction, dissolution, precipitation, recrystallization) to achieve the optimal characteristics established.

O18- Develop brakes pads using the recovered Pt, oxygen sensors with Y, and catalysts using Pt and Pd, as well as powder magnesium, which meet the commercial requirements.

Economic objectives

O19- **Patent of the BIORECOVER process, and individual research** and developments for each stage (pre-treatment, treatment, and post-treatment) and further exploitation. It is expected to reach **11 patents**.

O20- **Unlock unexploited ore reserves**: 863 t/yr of REEs from BR (MYTILINEOS), 69,000 t/yr of Mg from MgW (MAGNA) and 3.3 t/yr of PGM from PCBP (JM) which will allow **to reduce the dependency of EU from CRMs** importations by promoting sustainable self-production through application of BIORECOVER solution.

O21- **Reach a treatment with lower cost (35%)** with respect to the current processes using a solution with **higher recovery rates, using indigenous bacteria from raw materials, minimising the use of materials** (reagents, water, sorbents, immobilisation of biosorbents…) and **energy consumption** & **lower maintenance cost**, ensured by LCC.

O22- **Development of business and circular economy models** and aiming to, in the longer term, put on the market a sustainable technology, improving the competitiveness and creating added

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value and growth in EU, boosting the innovation and competitiveness. An **exploitation strategy**, identifying potential barriers and drivers, will be drafted.

Environmental objectives

O23- Valorise the generated **residual streams (at least 90%)** as **construction raw materials** and other **processing scenarios** (further recovering of other metals such as Fe), **minimise the water consumption and wastewater generation** to achieve a **ZLD** in order to obtain an **environmentally sustainable process** ensured by **interactive LCA** of the whole process from raw materials to end users.

O24- Fight climate change through the acquisition of **processes with lower energy consumption (20-30%)** and implementation of **circular economy models** and, thus **reduce (60%) the emission of GHG,** at the same time as **reach an efficient use of resources reducing the storage of wastes from industrial and mining.**

Social objectives

O25- Contribute to building the EU CRM processing knowledge through **patents (11), scientific (public/private) publications (30), PhD & MSc (22), specialised congresses (2-3 per partner), workshops (2 technical) & seminars (3) and one summer School.** Plus, specific reports will be elaborate to **feed the RMIS (at least once/year).**

O26- Improve the awareness, acceptance and trust of society regarding the importance of raw materials and its challenges for their supply and the need to recover resources present in wastes through developed of **public perception study and awareness campaign and socio-economic assessment,** as well as promote **gender equality**.

O27- Establish a continuous communication with other projects in order **to find synergies and inputs**.

O28- Guarantee the security of the EU supply of essential raw materials, in particular CRM, creating growth and employment (20 jobs during the project) and improve the **competitiveness in all value chain of raw materials.**

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BIORECOVER concept

BIORECOVER concept (Image 4 Overall BIORECOVER conceptImage 4) aims to reduce the gap between the European supply and the demand for CRM (REE & Sc, Mg, PGM) providing a breakthrough **flexible, versatile and modular** alternative, **based on three mainly bio-based** steps. The scientific advances in the field of biotechnology (bacterial, microalgae, fungi, proteins and acid or cyanide metabolites from microorganism, siderophores, etc.) will allow to **exploit primary (MgW and PLGO) and secondary raw materials (BR & PCBP)**, inaccessible by conventional extraction methods. For this purpose, **BIORECOVER** relies on an **interdisciplinary approach** involving partners of the **whole value chain** from suppliers, experts from the scientific fields to end users as well as two SME specialised in dissemination, communication, exploitation & social issues. Moreover, within the overall BIORECOVER concept, **the sustainability, health, safety and cost-efficiency will be key points in the project development strategy**, as well as, **the improvement of the awareness, acceptance and trust of society about raw materials**.

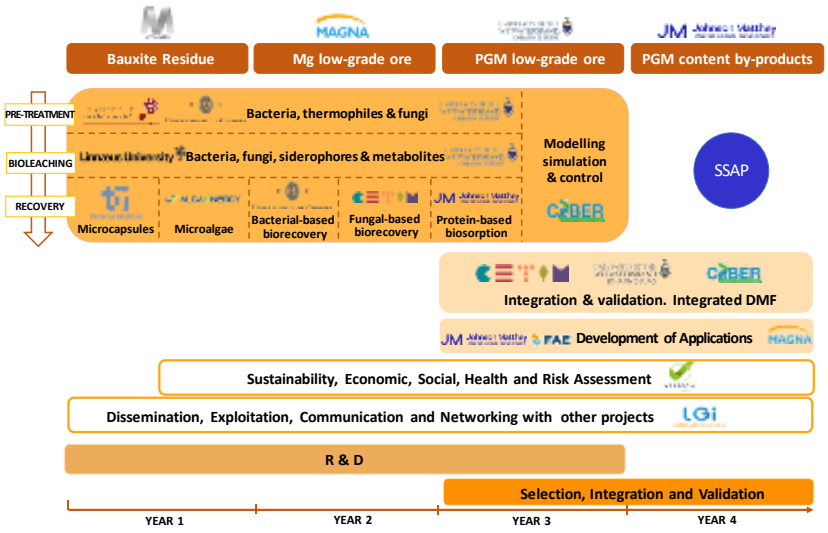

Image 4 Overall BIORECOVER concept

In addition, a SSAP will be constituted to involve other relevant stakeholders to exchange knowledge and experiences, at least once per year, in order to meet the goals of the project, to promote the dissemination of the results and to facilitate the future market penetration. Besides, the project will also address the international cooperation, involving two South Africa partners and an international SSAP.

The **three major stages that make up the overall concept of the project are:** 1) make the target CRMs accessible for recovery by removal of IC and concentration of them from the raw materials (pre-treatment), 2) mobilisation of the CRMs in a leachate (treatment) and, 3) the selective recovery of the CRM mobilised by developed specific technologies or combination of them. The first two stages will be mediated in **pre-treatment** by mainly bacteria, thermophiles, consortia and fungi and in the **treatment** by bacteria (e.g. cyanogenic, acidophilic etc.) or consortia, fungi, siderophores and metabolites (organic acids and cyanide) from microorganism. While in the latter stage, reusable microcapsules, microalgae and proteins will be also used as free cells or in immobilised systems. The different stages will be **integrated**, following the most optimal configuration, and will be optimised. **Flexible modelling and forecasting tool** (**DMF**), which will include technical, environmental and economic issues, will help to predict metal recovery, time and effort needed and to improve the performance and to facilitate the further **replicability** and scaling up of the BIORECOVER

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technology. The **quality** of the recovered CRM will be **validated by the end users** through the development of high added value applications (brakes pads, oxygen sensors, powder Mg and catalysts). Furthermore, to obtain a competitive, secure, sustainable and public acceptability process, the project will be supported by **interactive LCA & LCC, socio-economic and H&S analyses**, which will continuously feed to the project researches and developments. Finally, this approach also addresses the **valorisation of the residual streams** generated during the project, mainly in construction materials (geopolymers), to achieve **ZLD process**, contributing to the **EU Circular Economy** and the overall sustainability of the process.

Moreover, **the transmission of the generated knowledge** will constitute other of the fundamental aspects of the BIORECOVER concept through effective diffusion actions such as conferences, seminars, workshops, publication of the relevant results in high impact journals, development of reports to feed the RMIS database, among others. Finally, the improvement of the **awareness, trust and acceptance** by relevant actors and general public about the importance of raw materials and its EU supply, will be crucial for project success, and will be addressed through an **awareness campaign** as part of dissemination and public perception studies towards novel BIORECOVER process.

Positioning of the project

BIORECOVER is focused on R &D of an innovative multi-step process to exploit unexploited primary and secondary raw materials for the recovery of CRM (REE, Mg and PGM) based mainly in biological technologies. The forecasted TRL evolution of individual technologies during the project compared to the current ones is explained in Image 5.

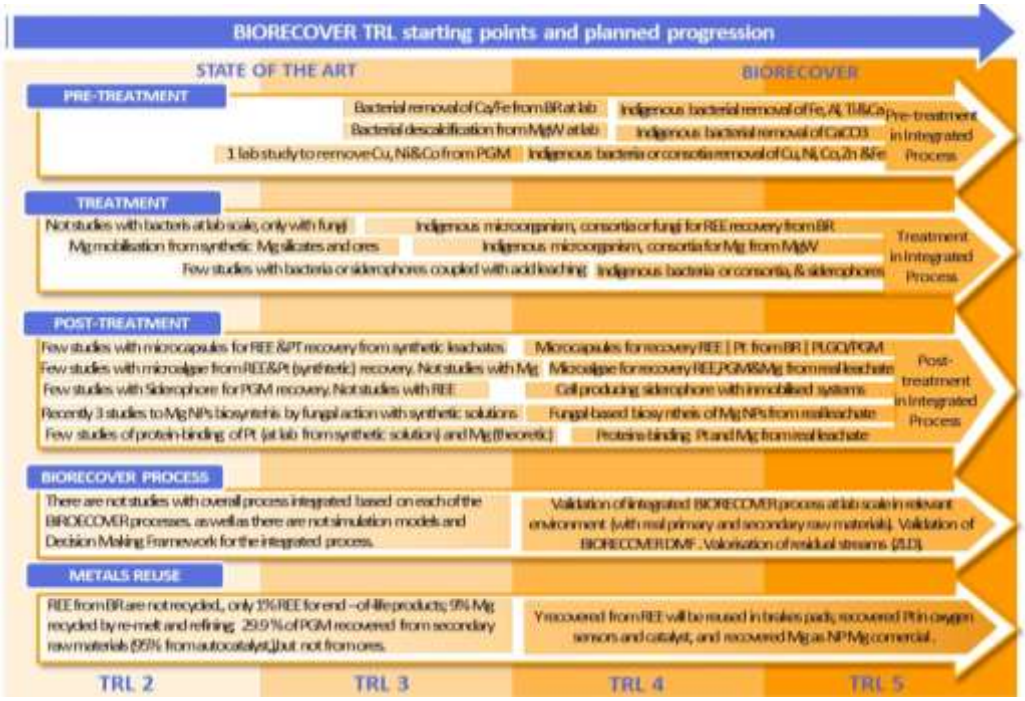

Image 5 TRL of the BIOREOVER technologies

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BIORECOVER INNOVATION

BIORECOVER will research and develop a new sustainable process for CRM (REE, Mg, PGM) extraction (from BR, MgW & PGM sources), using innovative approaches such as indigenous microorganism, OMICS approaches and immobilisation systems. Moreover, BIORECOVER solution will be based on the combination of, mainly, three biotechnological steps that will give it modularity to the process and thus, versatility to apply it to broad range of source of raw materials, enabling to unlock reserves of currently unexploited CRM sources. BIORECOVER main innovations are:

Pre-treatment: Different strategies such as bioreduction to mobilise metal oxides[4], dissolution of carbonates by microorganisms[iError! Marcador no definido.] or biooxidation of metal sulphides will be evaluated, in which an IC elimination up to 60% is expected. To achieve this target, **metagenomics** using **high-throughput sequencing as well as metatranscriptomics** to identify **indigenous microorganisms** with high activity to remove IC will be applied. Their usage will be useful as those strains are already adapted to high metal concentrations, improving the cost-efficiency of the process. **Microbial consortia** will be also assessed to look for new collaborative features that will increase the efficiency of this step.

Treatment (Bioleching): Microorganisms (bacteria and fungi), consortia, siderophores and metabolites (organic acids and cyanide from microorganisms) will be evaluated and optimised to mobilise the selected metals from pre-treated sources (solids enriched in target CRMs), obtaining mobilisation yields up to 90%. In the same way as the pre-treatment, **high-throughput sequencing and metatranscriptomics** will be applied to identify **indigenous microorganisms** (bacteria or fungi) and **consortia** with high activity to mobilise the target CRM. Moreover, **cyanide-producing bacteria** will be used for PGM mobilisation **avoiding ion chloride**, which has an occupational exposure limit that is about to decrease significantly.

Post-treatment: BIORECOVER post-treatment will focus on **five novel and eco-friendly different approaches** that will be researched and developed to recover the CRMs with high selectivity (95%) and efficiency. Adsorption of REE & PGM by **reusable polymeric microcapsules** specifically designed for each target leachate, involving the optimisation of both extractant and precursor components as well as its right combination while preserving the integrity and allowing their reutilisation as well as increasing their functional lifespan. **Biosorption** of REEs, PGM and Mg **by microalgae** and; **biosorption** of REE & PGM **by bacterial cells** using chemical "arm" spacers, in order to induce the covalent immobilisation without loss of the ability to metal coordination, due to the influence of surface characteristics. In several cases (microalgae and bacterial cells & siderophores) **immobilisation systems** will be used to obtain better mechanical resistance and biological stability that will allow **to reuse the biosorbents in several cycles**. Eco-friendly **biosynthesis of Mg NP by fungi** applied to real leachate. Finally, **biosorption of Mg and Pt by proteins** will be obtained by **protein engineering to produce metal-binding protein domains** with high metal affinity & specificity, stability and beneficial properties to facilitate the recovery of CRM (precipitation or hydrogel-forming capability with metals). **Computational structural modelling** will be applied for its design.

[4] Papassiopi et al. (2010). Minerals Engineering, 23(1), 25-31.

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Simulation of sustainable (bio) metallurgy processes: specific **flexible modelling & forecasting BIORECOVER Decision Making Framework will be developed** that will include **technical performance, economic** and **environmental efficiency**. BIORECOVER DMF will allow process **optimisation** together with **prediction of metal recovery efficiencies** and **efforts needed**. This model will integrate the different stages in a unique tool (universal code) for easy operation.

Downstream of recovered CRMs: BIORECOVER will **R& D specific downstream processes** to purify and/or modify the recovered CRMs such as thermal & chemical treatments, precipitations, recrystallization, etc. to meet the quality requirements of CRMs for their reuse in high value products (brakes pads, oxygen sensor, powder Mg and catalysts). In addition, these high value products will be produced in an industrial environment; now, most of these recovered metals have not been reused in these applications.

Residual streams valorisation: BIORECOVER will valorise the generated residual streams from the specific process defined for each raw material to obtain mainly geopolymers with remediation environment applications. It should be noted that, few studies have been carried out on residual streams waste from MgW and PGM by-products).

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