



CORDIS Results Pack on **sustainable processing of mineral resources**

A thematic collection of innovative EU-funded research results

October 2023

Safety, sustainability and security for Europe's mineral processing industry

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Recovery of critical raw materials in a circular economy

Editorial

Secure access to raw materials is central to Europe's continued economic success. Growing demand and the vulnerability of supply chains to disruption have resulted in the European Commission creating a list of critical raw materials (CRMs) for the EU, which is subject to a regular review and update.

CRMs cover all raw materials where they hold high importance to the EU economy and there is high risk associated with their supply. This Results Pack therefore showcases EU-funded projects spearheading research that will improve the processing of these raw materials and enhance its sustainability.

The goal of the Critical Raw Materials Act proposed by the European Commission is to secure the EU's future supply of CRMs required for technologies such as renewable energy and battery power, by supporting the EU's self-reliance in mining, processing and recycling the 34 listed critical metals and minerals.

These technologies play a pivotal role in Europe's [green transition](#), which is aimed at making Europe the first carbon-neutral continent by 2050, and will help to deliver the [European Green Deal](#).

Focus on EU research

The 12 projects in this pack offer concrete technological solutions for mineral processing resulting from Horizon 2020 funded research and innovation projects, covering a wide range of CRMs. These include rare earth elements, which are necessary for high-tech consumer products like cellular telephones, computer hard drives, electric and hybrid vehicles, and flat screen monitors and televisions. The research also demonstrates how - by implementing technological innovation - these raw materials and side streams may be recovered and reused, instead of being discarded as waste.

Revolutionising the recovery process of valuable raw materials from industrial by-products

By combining existing methods and new technological innovations, an EU-funded project has unlocked the potential of critical metals in industrial waste.

Chromium (Cr), vanadium, molybdenum and niobium are pivotal metals for the competitiveness of the manufacturing sector and the innovation potential of high-tech sectors. However, Europe remains exceedingly dependent on their import, risking

an inflexible and insecure supply, while such metals are found in abundance in industrial waste or used in applications where their intrinsic value is not fully utilised.



Large amounts of steel and ferrochrome slag, waste after mining or processing, are produced annually. These contain significant amounts of metals, in particular Cr. Currently, the slags are mostly used in construction applications as sand or aggregates for their technical properties. However, the metals contained within do not have a purpose in this application and are therefore lost. Moreover, their presence can seriously harm the environment.

The EU-funded [CHROMIC](#) project focused on developing new, sustainable technologies for the recovery of critical and valuable metals from steel and ferrochrome slag. "We hoped to find ways to take the metals out of the slag before using them in construction applications," explains project coordinator Liesbeth Horckmans.

Juggling with hazardous substances

Removal of the large (> 2 mm) metallic particles is a common practice and state-of-the-art technology. However, the finer metallic particles and the oxidised forms of the metals are not recovered. CHROMIC was successful in developing a highly efficient hydrometallurgical method, able to recover more than 95 % of Cr present in the slag.

Nonetheless, to get the metals out of the slag, Cr must be changed from its insoluble, non-hazardous form Cr (III) into the soluble, hazardous Cr (VI). Due to the very stringent limits on Cr (VI) leaching, all residual Cr (VI) must be removed from the solid – a major challenge that the project team has not yet been able to solve.

"This proved more difficult than foreseen, and some unexpected reactions occurred. In the project, we only had limited time to investigate, so this is certainly a topic to investigate further," notes Horckmans.

"We are looking for new opportunities to continue the research – also looking at other metals. Chromium is a particularly difficult metal because of the highly hazardous nature of Cr (VI) and the resulting very rigorous legislation."


We are looking for new opportunities to continue the research – also looking at other metals.

A multi-beneficial solution

Despite the challenges, CHROMIC has reached significant and completely sustainable results. Apart from those related to the technological core of the project, there are also those addressing assessments on the impact of the technologies on the economy and society.

The solution will benefit metal-producing companies with high Cr residues, as the removal of Cr can generate value and increase the application options for the slags. The latter is especially important in the circular economy, to avoid overconcentration of metals in downstream use. Landfill owners with high Cr waste, such as governments, will also benefit from CHROMIC results, given that the removal of Cr can generate value and can make often-used materials less hazardous.

Moreover, according to an integrated economic and environmental assessment, once the Cr issue is solved, the process can be beneficial compared to landfilling. This led the CHROMIC team to perform a three-step [community involvement plan](#) gathering information from laypeople, experts and students about their views on metal recycling.

PROJECT

CHROMIC – effiCient mineral processing and Hydrometallurgical RecOvery of by-product Metals from low-grade metal containing seCondy raw materials

COORDINATED BY

Vlaamse Instelling voor Technologisch Onderzoek
in Belgium

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/730471

PROJECT WEBSITE

chromic.eu/the-project/



Digging deeper: new cobalt recycling approaches forge a path to a greener future

A first-of-its-kind compact system integrating cutting-edge recovery and sorting techniques revolutionises cobalt recovery from secondary European sources. The technology helps create a sustainable supply chain of this critical material.

From electric vehicle batteries to wind turbines, solar panels and smartphones, modern-day technology relies on the versatile and indispensable raw material cobalt to fuel progress. With the shift to a low-carbon economy, the demand for cobalt is skyrocketing, making it a critical material in creating a sustainable future.



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But where does this cobalt come from?

Although Europe possesses significant reserves of cobalt-containing ores, traditional mining methods have proven to be unsustainable. As a result, it imports about 65 % of its cobalt needs (approximately 10 000 tonnes per year) from African countries. Only 35 % is produced from secondary sources, such as the recycling of spent batteries, superalloys and hard metals.

The EU-funded [CROCODILE](#) project is leading the way towards a more sustainable and secure supply chain for cobalt. "Advanced technologies for smart cobalt recovery efficiently extract cobalt from primary and secondary sources, thereby reducing reliance on imported cobalt and promoting a circular economy through cobalt recovery from waste," notes project coordinator Dr Lourdes Yurramendi.

Sustainable cobalt recovery from primary sources

"Cobalt can be leached from primary sources using bioleaching in mining operations," notes Yurramendi. The method refers to the cobalt extraction from laterite ores using living organisms. Bacteria use the energy obtained from the oxidation of iron

oxides, clay minerals or manganese oxides (which are the host minerals for cobalt) to transform the insoluble metal into a soluble form such as cobalt sulfate.

In addition to achieving higher cobalt recovery rates and reducing the need for high-temperature smelting compared to traditional primary methods, the leachate can be further processed to obtain pure cobalt metal.

Transforming secondary cobalt recovery: a synergetic approach

CROCODILE's technical concept for secondary sources relied on integrating several novel chemical engineering technologies with advanced physical pre-treatment solutions.

For example, in the case of discarded lithium-ion batteries, the first pre-treatment method is essential in breaking down the complex structures containing a mix of cobalt-based compounds and graphite (black mass) into simpler compounds.

These compounds are then separated from the waste stream using solvometallurgical treatment, which involves the use of [deep-eutectic solvent](#) (DES)-based solutions for the leaching process.

The resulting solution containing the dissolved metals is then subjected to further chemical refining processes: liquid-liquid extraction with ionic liquids (ILs) and [electrowinning](#) to isolate and purify the desired metal, cobalt in the case of CROCODILE.

"A lesson learnt in black mass treatment from lithium-ion batteries is that, along with cobalt, other metals such as nickel, manganese and lithium can be extracted and should be valorised. The recycling of all the solvents involved in the process (DES and ILs) together with the reuse of the residual black mass obtained after the leaching step are crucial for ensuring the economic viability of the process," remarks Yurramendi.

"CROCODILE produced a first of a kind viable mobile metallurgical system based on advanced hydrometallurgical and electrochemical technologies able to extract cobalt from black mass waste streams," adds Yurramendi. The mobile system can produce around 6 kg of cobalt metal per day at the pilot constructed during the project. Life cycle assessment and cost studies show that this process has potential for industrial-scale cobalt production via optimisation and upscaling.

CROCODILE's innovative integrated route offers to the market a solution to minimise reliance on imported cobalt, promoting a sustainable supply chain and waste recovery.



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*produced a first
of a kind viable
mobile metallurgical
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hydrometallurgical
and electrochemical
technologies able
to extract cobalt
from black mass
waste streams.*

PROJECT

**CROCODILE- first of a kind commercial
Compact system for the efficient Recovery
Of COBalt Designed with novel Integrated
LEading technologies**

COORDINATED BY

TECNALIA Research & Innovationin Spain

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3.

CORDIS FACTSHEET

cordis.europa.eu/project/id/776473

PROJECT WEBSITE

h2020-crocodile.eu/



Groundbreaking methods for maximising fine-particle recovery from ores

Researchers are developing new methods to more efficiently separate valuable fine materials measuring less than 20 µm from ores. The process involves attaching the particles of the desired material to air bubbles and recovering them as a froth.

Treating fine-grained materials poses a great challenge for the mining industry. Ores must first be crushed and ground down to the micrometre range, a process that increases their surface area and liberates the mineral particles from gangue.

At this early stage, froth flotation helps to separate particles based on the ability of minerals and metals, hydrophobised by flotation reagents, to adhere to the surfaces of air bubbles in an aqueous slurry. These bubble-particle aggregates are carried to the surface of the pulp (slurry), where they enter the froth which is then removed. The remaining material from the ore that does not rise to the surface forms the flotation tailings.

The challenge of recovering (ultra) fine particles

Although froth flotation can efficiently handle particles whose size ranges between 20 µm and 200 µm, it has yet to make significant headway in treating smaller particles. Fine and ultrafine particles cannot easily float as they have low collision and attachment efficiencies with air bubbles, leading to the loss of valuable minerals. Furthermore, owing to their relatively high surface area, these smaller particles require more reagents for their processing.

The EU-funded [FineFuture](#) project is working on inventive solutions for recovering fines of high grade and at high rates, so that valuable ultrafine materials are no longer discarded.



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"The ability to recover particles smaller than 20 µm in size is very important since currently no technology exists that can efficiently capture them without spending much energy and water. Our advanced energy-efficient solutions promise significant reductions in resource losses, thereby promoting the competitiveness of the EU mining industry," notes project coordinator Kerstin Eckert.

Going green and staying afloat

FineFuture aims to advance fundamental understanding of fine-particle flotation. Its groundbreaking technological solutions are expected to provide a sustainable pathway for valorising resources through reprocessing tailing deposits, while they could also help unlock new critical raw materials from natural deposits and mining waste.

Researchers are on track to offer methods that demonstrate superior performance, 20 % energy savings and 30 % water savings compared to the state of the art.

Generating electrostatic attraction and smaller bubbles



A major focus has been on effectively controlling the surface interactions between bubbles and fine particles to selectively enhance their attachment probability.

"A major focus has been on effectively controlling the surface interactions between bubbles and fine particles to selectively enhance their attachment probability," explains Eckert. So far, researchers have been testing methods to describe the interactions between collector reagents, depressants and minerals.

The FineFuture team has also reported methods to enhance the flotation selectivity of carbonate minerals. The use of non-ionic additives led to a significant decrease in the collector consumption. The project developed a new collector causing an electrostatic attraction between bubbles and silica-based particles.

An effective strategy to overcome the problems of fine-particle flotation is to decrease the bubble size and use special types of flotation cells known as reactor-separator cells that boost bubble-particle interactions. Researchers achieved progress on this front. In particular, they reported different technologies for generating microbubbles, including the use of an air-in-water microdispersion generator. Flotation tests conducted using this generator showed that microbubble addition promoted the recovery of quartz particles.

Towards a new mining paradigm

"FineFuture applies a transdisciplinary and first-of-its-kind research approach that merges colloid and interface science, fluid dynamics, physics, mineral processing, chemical engineering, electrical engineering, computational science and advanced mathematics," notes Eckert. "Our groundbreaking concepts and technologies will shift the current mining paradigm towards exploiting natural mineral deposits consisting of tiny grains in an economic and environmentally friendly way."

PROJECT

FineFuture - Innovative technologies and concepts for fine particle flotation: unlocking future fine-grained deposits and Critical Raw Materials resources for the EU

COORDINATED BY

Helmholtz-Zentrum Dresden-Rossendorf EV

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/821265

PROJECT WEBSITE

finefuture-h2020.eu/



Green, efficient approach transforms metal extraction

EU-funded researchers are pioneering a sustainable mineral processing technology to recover key by-products from primary sources efficiently and cost-effectively, while also extracting the main metal present in the ore.

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Critical raw materials such as cobalt, germanium and platinum group metals are the backbone of numerous products and technologies we use, from rechargeable batteries to solar cells and electronics. The European Commission is supporting projects centred around the recovery of these critical materials. These initiatives not only ensure economic stability but also pave the way towards a more self-reliant and sustainable future.

The EU-funded [ION4RAW](#) project is working to develop a more efficient and eco-friendly way of extracting metals from primary resources. This marks a significant shift from many existing

hydrometallurgical processes, which often resort to using toxic substances detrimental to the environment.

An alternative, groundbreaking ionometallurgical technology

"At its core, ION4RAW utilises leaching with deep eutectic solvent (DES) ionic liquids and electrorecovery. DES are green, chemically stable solvents that can be customised to recover

different metals," explains project coordinator Maria Tripiana. They provide an eco-friendly alternative to conventional ionometallurgical processes, making ION4RAW's approach more resource- and cost-efficient. "They are composed of two components, Lewis and Brønsted acids, which melt at a different temperature than the mixture as a whole. Depending on the metals of interest, different DES formulations have been tested," adds Tripiana.

Following upstream conditioning, ore minerals are dissolved in DES. The resulting solution contains a mix of different metals, which are then electrodeposited in solid form using the DES as the electrolyte solution. This process involves a cathode and an anode, and with the application of current, the metals are deposited on the cathode in solid form.

However, the technology faces challenges, particularly in scaling up the process and proving its effectiveness outside a laboratory environment. Yet, significant progress has been made, with researchers aiming to reach TRL 5 by the project's end. The prototype of the technology will be developed at TECNALIA's facilities. The final months will be devoted to fine-tuning the process performance and testing the quality of the recovered by-products.


In terms of sustainability, the ION4RAW process outperforms conventional recovery routes. It offers reduced energy consumption and uses non-flammable solvents, ensuring a healthier and safer process.

To maximise by-product upstream recovery from primary sources and minimise downstream environmental impact, project members mapped the behaviour of by-product-bearing minerals present in polymetallic reference ores. The team also demonstrated effective filtration, washing and recovery processes, confirming their effectiveness without jeopardising material properties or DES quality.

Ultimately, project members employed ionometallurgical methods to cost-efficiently recover by-products from primary sources. A mineral liberation analysis was conducted to characterise sulfide concentrates from all primary ores studied. Two leaching approaches were evaluated, namely chemical and electrochemical, with the former using choline chloride/ethylene glycol with copper/lead concentrates emerging as the most promising. The team further investigated the influence of solvent composition on the speciation and behaviour of the target elements.

"In terms of sustainability, the ION4RAW process outperforms conventional recovery routes. It offers reduced energy consumption and uses non-flammable solvents, ensuring a healthier and safer process," states Tripiana. The reduction in both capital and operating expenditures makes this process a viable option for mining and mineral processing companies.

Activities benefiting sustainable resource management

Project members have undertaken several activities to achieve their objectives. They initially focused on supporting by-product recovery through a comprehensive assessment of by-product potential. By compiling geological and historical analytical data, querying European data sets and collecting samples from selected locations, a reliable inventory of targeted by-product distribution across Europe was established. Multi-scale characterisation techniques were employed to analyse the ores and identify by-product mineral carriers.

PROJECT

ION4RAW - Ionometallurgy of primary sources for an enhanced raw materials recovery

COORDINATED BY

Idener Technologies SL in Spain

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/815748

PROJECT WEBSITE

ion4raw.eu/



Mine tailings to treasure: providing society with sustainable resources

Critical metals are vital to emerging technologies, but their extraction leaves behind a potentially dangerous environmental legacy. An EU-funded project is working towards novel solutions for the treatment of mining waste.

Sulfidic mining waste, residues from mining and processing sulfidic ores to produce copper (Cu), zinc (Zn), lead (Pb), nickel (Ni) and other critical metals, represents the largest extractive waste in Europe. Approximately 600 Mtonnes is produced a year and there is a historic stockpile of 28 000 Mtonnes deposited in either tailings storage facilities, dry stacked or back-filled in mines.

When poorly managed, this waste can become an environmental hazard, causing problems such as acid-mine drainage, the outflow of acidic water from mine waste. At the same time, this waste represents a new stock of critical metals and minerals needed to move to a green circular society.

Recently, the [European Innovation Partnership on Raw Materials](#) launched a 'call to arms' to transform the 'extractive waste problem' into a 'resource recovery opportunity'. Responding to this call is the EU-funded [NEMO](#) project.

"Using a 'four pilots – three case studies' concept, NEMO takes up the challenge to develop, demonstrate and exploit new ways to valorise sulfidic tailings," outlines Mika Paajanen, project coordinator. The aim is to recycle up to [95 % of waste](#). Key to achieving this is increasing the technology readiness level of various innovative technologies within the near-zero waste treatment of sulfidic ores and sulfidic mining waste.

The NEMO concept

The project focuses on three cases: the Sotkamo Ni-Cu-Zn-REE/Sc (rare earth element scandium) mine in Finland, the Luikonlahti processing facility in Finland and the Tara Zn-Pb mine in Ireland. Through four pilots, using NEMO technologies, the project aims

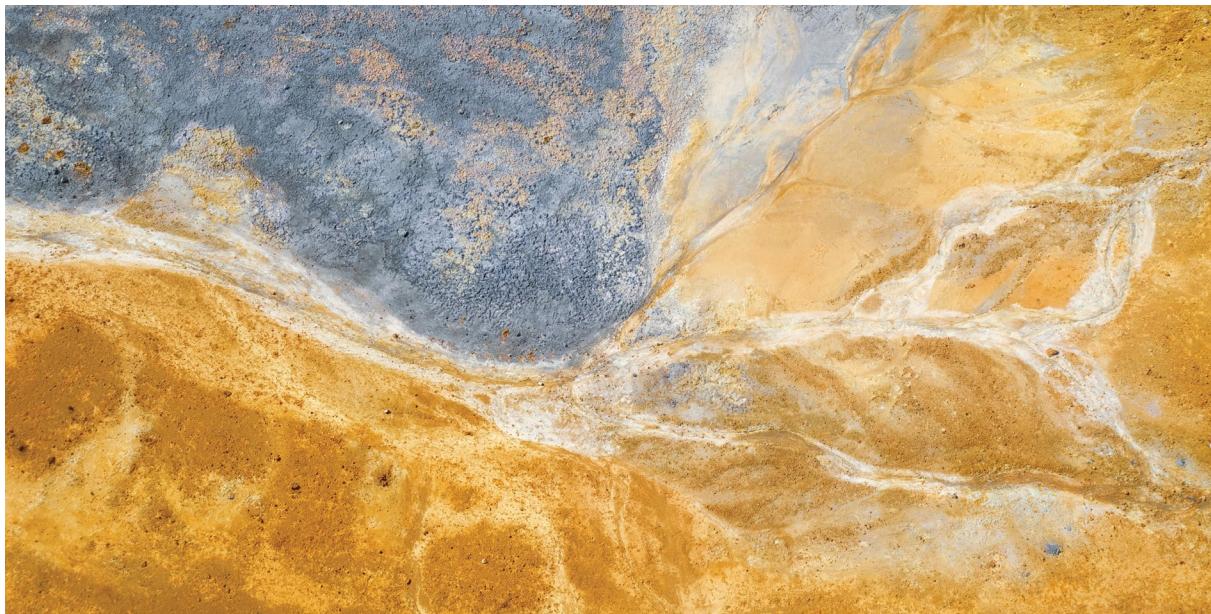
to demonstrate cutting-edge [bioleaching](#) processes to recover additional metals from sulfidic ores/residues and to boost the conversion of sulfides to sulfates – helping to eliminate the risk of acid-mine drainage. It also seeks to 'clean' the residual matrix allowing its use in cement and construction applications.

"Results from the pilots to date include the development and evaluation of novel and innovative unit processes and flowsheets for the hydrometallurgical valorisation of low-grade base metals from processing residues. These include a low-duty bioreactor for cost-efficient hydrometallurgical processing and novel hydrometallurgical flowsheets for production of battery-grade metal concentrates," confirms Paajanen.

Additionally, two bioleaching options have been benchmarked: one in Sotkamo and one in BRGM France. In Sotkamo a bioleaching heap with enhanced operating conditions and in France a bioleaching pond. Metal extraction above 90 % was achieved in the first step of the pond bioleaching pilot.

"NEMO has also developed processes and mixtures that can incorporate a high percentage of mine tailings and has demonstrated the potential use of mine tailings in concrete products. These developments were achieved by project partners Boliden, Thyssenkrupp, VITO and Resourcefull, specifically targeting the tailings from the Tara mine of Boliden," emphasises Paajanen.

A new understanding of the specific nature of the secondary raw materials at each studied mining site has also provided useful information on their suitability for various processing and valorisation methods and on their exploitation potential.



Looking onwards



It is expected that NEMO's technology will provide the EU with a range of benefits from new resources for the metal and agricultural sectors to a reduction in CO₂ levels in the metal recovery process.

"It is expected that NEMO's technology will provide the EU with a range of benefits from new resources for the metal and agricultural sectors to a reduction in CO₂ levels in the metal recovery process and the replacement of ordinary Portland cement," concludes Paajanen. It will also be instrumental in eliminating acid-mine drainage and other environmental problems.

The project will continue monitoring the delivery of samples and the performance of the different pilots. It aims to replicate its technologies and concepts in other mines within the EU and beyond.

PROJECT

NEMO - Near-zero-waste recycling of low-grade sulphidic mining waste for critical-metal, mineral and construction raw-material production in a circular economy

COORDINATED BY

Teknologian tutkimuskeskus VTT Oy

FUNDED UNDER

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CORDIS FACTSHEET

cordis.europa.eu/project/id/776846

PROJECT WEBSITE

h2020-nemo.eu/



A sustainable bridge for the gap between supply and demand of valuable metals

Closely linked to green technologies and crucial for a broad spectrum of technological applications, platinum group metals are in demand more than ever. An EU-funded project addresses the challenge of establishing their stable supply in Europe.



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Among the rarest of Earth's elements, the platinum group metals, so-called PGMs, are classified by the European Commission as [critical raw materials](#). The group includes six elements: ruthenium (Ru), rhodium (Rh), palladium (Pd), iridium (Ir), osmium (Os) and platinum (Pt), the last being the most commercially significant as it is extensively used from the automotive and electronics to high-tech industries.

(Ir), osmium (Os) and platinum (Pt), the last being the most commercially significant as it is extensively used from the automotive and electronics to high-tech industries.

While global demand is disproportionately growing in comparison to the supply potential, even more dramatically within the context of the global geopolitical turmoil, there is an urgent need for effective circular solutions. Apart from traditional mining, PGMs can also be acquired through conventional recycling methods that are, however, highly energy intensive and harmful for the environment.

Through the joint work of a consortium comprised of 11 recognised and experienced key actors across the value chain representing industry, research and academic organisations, the EU-funded [PLATIRUS](#) project developed innovative, cost-efficient and sustainable technologies to recover PGMs from spent autocatalysts, mining and electronic waste.

Moving forward through trial and selection

PLATIRUS was split into three key phases. Phase 2016–2018 focused on researching innovative technologies in all stages of leaching, separation and recovery.

The period 2018-2019 included the selection of the best technologies for validation supported by economic and environmental assessments. Microwave-assisted leaching (VITO, Belgium), non-conventional liquid extraction (KU Leuven, Belgium) and gas-diffusion electro-crystallisation (VITO, Belgium) technologies have been evaluated with the highest recovery, environmental impact, flexibility, low-cost and compact-size technologies.

Finally, the main objective of phase 2019-2021 was the upscaling of the selected technologies and operation in cascade in an industrially relevant environment. These methods successfully recovered PGMs from secondary resources and demonstrated that it is possible to use these recycled PGMs to manufacture new autocatalysts.

A green and competitive goal that benefits us all

Deployment of PLATIRUS's solutions will enable optimisation of PGM recycling, increase resource efficiency and production of new sustainable products. PLATIRUS will reduce the EU's current dependence on PGMs by filling the supply gap up to 30 %, diversify the supply chain and make Europe competitive while preserving the environment.

The project has been highly successful: four PLATIRUS technologies have been categorised as market-ready innovations in the [Innovation Radar](#), the European Commission initiative to identify high-potential innovations and innovators in EU-funded research and innovation projects.

Moreover, essential information about the developed technologies, as well as the potential exploitation routes for the recovery of PGMs, has been shared with interested stakeholders through a series of [seminars, workshops and conferences](#).

PROJECT

**PLATIRUS - PLATInum group metals Recovery
Using Secondary raw materials**

COORDINATED BY

TECNALIA Research & Innovation in Spain

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/730224

PROJECT WEBSITE

platirus.eu/



Aluminium processing takes on new lustre

Researchers are demonstrating technologies to valorise bauxite residue – the by-product of aluminium production – so that it no longer needs to be disposed of as waste.

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Practical and highly sought after, aluminium is a common material used in power lines, household appliances, consumer electronics, aircraft components, electric cars and modern buildings. The list of uses for which the material is proving itself keeps growing. Despite its tremendous value, this lightweight yet strong and corrosion-resistant silvery metal presents a major constraint during its production: red mud, formally known as bauxite residue.

How the red mud stockpile increases

Bauxite residue is a caustic blend of different oxide compounds just like silicon, iron, aluminium, calcium, titanium and sodium oxides. Often with rare-earth element fragments, it is the industrial waste generated during processing into alumina using the Bayer process. And it is piling up.

"As its name suggests, bauxite residue is what's left after treating the bauxite ore for alumina extraction. The extracted alumina is then used in primary aluminium production," notes Efthymios Balomenos, senior consultant at Greece-based energy & aluminium company [MYTILINEOS](#). The amount of the waste generated is dazzling. "We need about 2 tonnes of alumina to make 1 tonne of metallic aluminium. A tonne of alumina production generates on average 0.8 tonnes of bauxite residue in Europe."

To estimate the accumulated waste, we need to consider that around 4 million tonnes of aluminium are produced each year in Europe, which account for just 8 % of the global production. "It is now evident how bauxite residue piles up since only 3 % of it is reused as a raw material," adds Balomenos.

Technologies to remove the waste streams

Balomenos is coordinating the EU-funded RemovAL project that his company has been running since 2018. RemovAL is designed to pool together certain technologies that help transform bauxite residue into valuable products and raw materials and scale them up at industrial pilots. The next step is to combine them in sustainable flowsheets that can achieve complete bauxite residue valorisation in specific alumina plants with waste generation close to zero."

"What sets us apart from state-of-the-art initiatives is that we do not only help advance the technological readiness of aluminium processing solutions but also take first steps towards designing new industrial ecosystems and value chains around bauxite residue reuse," explains Balomenos.

Researchers' attempts to demonstrate bauxite residue treatment technologies have so far been rewarding. At a MYTILINEOS pilot plant unit and then in another refinery in Ireland, researchers demonstrated a new residue treatment method to decrease the alkaline concentration in bauxite residue, keeping the sodium oxide content below 0.5 % wt.

This opens up a plethora of new applications, with the ability to use processed bauxite residue. Together with other industrial by-products, bauxite residue was used to produce a stable and safe substrate for road construction, as demonstrated in a pilot application in Ireland.

Lightweight aggregates and high-performance binders for buildings are other exciting application uses of bauxite residue. A pilot plant in Germany demonstrated the production of lightweight aggregates from bauxite residue, while at the KU Leuven University, a new high-strength binder has been created. In Norway, researchers aim to scale the production of a ferro-silicon alloy by heating bauxite residue and other industrial by-products from aluminium primary production, such as spent potlining, in an electric arc furnace. The slag from this process is used in hydrometallurgical pilots in the project in Greece and Germany to recover aluminium and titanium oxides as well as critical raw materials like scandium and gallium.

RemovAL provides a sustainable pathway for valorising bauxite residue along with other industrial by-products from its pilot plants, considering waste characteristics, logistics and the potential for symbiosis with other nearby plants. "In the long term, we plan to achieve 100 % reuse of bauxite residue, providing significant gains in environmental and resource preservation. Europe-based production of critical raw materials like scandium and gallium is an additional bonus," Balomenos concludes.



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and resource
preservation.*

PROJECT

RemovAL – Removing the waste streams from the primary Aluminium production and other metal sectors in Europe

COORDINATED BY

MYTILINAIOS ANONIMI ETAIREIA in Greece

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/776469

PROJECT WEBSITE

removal-project.com/



Elusive scandium awaits in industrial by-products

Researchers are developing technologies for extracting scandium from metallurgical waste that could provide the EU with a reliable supply of this valuable rare earth material.

Owing to its scarcity and limited production, scandium is currently one of the costliest elements on the market. This soft, silvery transition metal has been used for decades to create high-intensity lighting solid oxide fuel cells, as well as Al-Sc alloys used in high-end sporting equipment and 3D printing applications. However, scandium supply has been limited to imports from Asia and Russia.

Turning industrial waste into treasure

The EU-funded [SCALE](#) project is taking the first steps to establishing a closed supply chain for scandium in Europe. The use of industrial by-products, which now are mostly disposed and stockpiled, contributes to the circular economy approach adopted by the EU.

"Bauxite residues from alumina production and acid waste from titanium dioxide pigment production contain trace amounts of scandium that could be exploited with a viable extraction technology," notes Eftymios Balomenos, senior consultant at Greece-based energy & aluminium company [MYTILINEOS](#) and project coordinator. These mineral concentrates are then processed with advanced refining technologies to produce pure scandium compounds. The pure scandium compounds are used, in turn, as feedstock for producing aluminium-scandium master alloys.

SCALE has been developing breakthrough technologies to overcome both metal extraction and production barriers. It has also been optimising refining technologies to decrease the processing costs and eliminate the use of harmful reagents. So far, significant progress has been achieved in the pilot-scale

extraction of scandium from bauxite residue and acid waste from TiO₂ production. Using 10 tonnes of bauxite residue and 2 m³ of acid waste, researchers obtained scandium concentrates with scandium content up to 25 wt %.

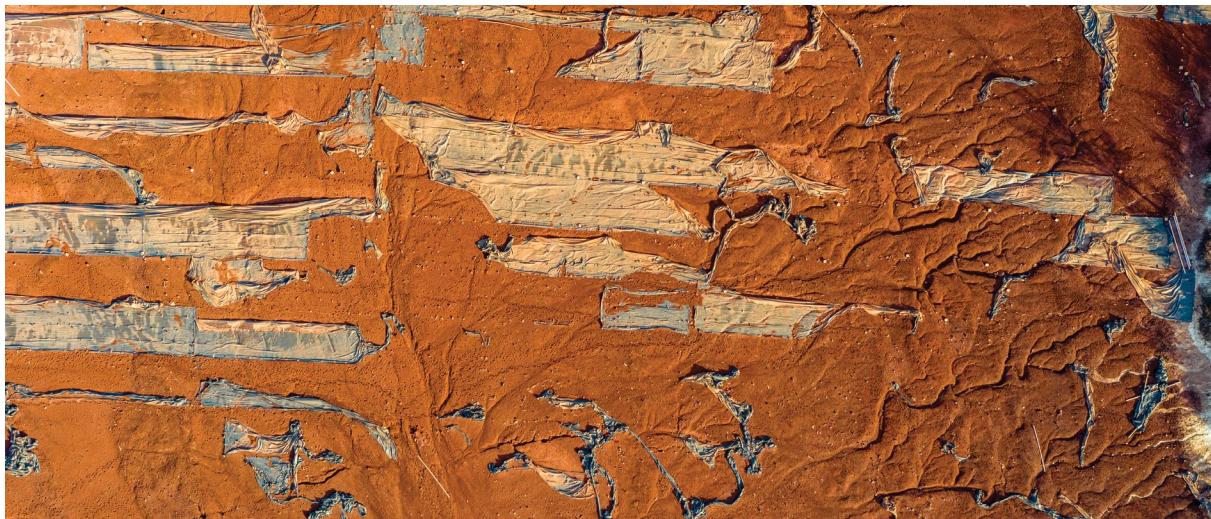
A novel scandium refining flowsheet has also been developed, allowing efficient and flexible scandium(III) oxide (Sc₂O₃) and scandium(III) fluoride (ScF₃) production, circumventing the use

of commonly used hazardous chemicals like hydrogen fluoride gas. Furthermore, researchers trialled the production of high-performance aluminium-scandium master alloys in a pilot plant. Through the aluminothermic reduction of ScF₃ or the molten salt co-electrolysis of aluminium and Sc₂O₃, they eliminated the need for metallic calcium, a highly expensive and difficult to produce reagent.

The work conducted in SCALE will continue in two follow-up projects under EIT RawMaterials, that are likely to bring about the creation of a supply chain for scandium in Europe. The first one aims to create a scandium refinery process obtaining acid waste as primary feedstock and Sc₂O₃ as a product. The second one will focus on further optimising and scaling up scandium extraction from bauxite residue.

Tapping into the potential of aluminium-scandium alloys

Aluminium-scandium alloys represent a new generation of high-performance alloys with superior properties compared to all other aluminium alloys. Small amounts of scandium enhance the metal strength, corrosion resistance, grain size and



recrystallisation resistance. Importantly, the element provides the highest increment of tensile strength per atomic percentage than any other alloying element when added to aluminium.

"Aircraft manufacturers, for instance, could use it to build planes that have lighter aluminium framing and burn less fuel," notes Balomenos. "Scandium use in bicycle frames has demonstrated a 12 % reduction in weight, a 50 % increase in yield strength and a 25 % improvement in fatigue life compared to the best-selling aluminium bicycle frames."

PROJECT

SCALE - Production of Scandium compounds and Scandium Aluminum alloys from European metallurgical by- products

COORDINATED BY

MYTILINAIOS ANONIMI ETAIREIA in Greece

FUNDED UNDER

H2020-EU.3.5, H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/730105

PROJECT WEBSITE

scaleup.tesmet.gr/



Building a European value chain for rare earth elements

Critical raw materials are of high economic and strategic importance to the European economy, but they are associated with high supply risks. One forward-looking team of researchers has set to work to secure Europe's access to these materials.

[Rare earth elements](#) (REEs) are crucial for producing the goods and applications we use every day, including vital green technologies such as computers, TVs, electric vehicles and wind turbines. There is, however, growing concern over reliable and unrestricted access to certain raw materials, particularly in Europe. This is because Europe does not have primary REE

sources, and as a result is dependent on imports from mining countries such as Australia, China, Myanmar/Burma and the United States.

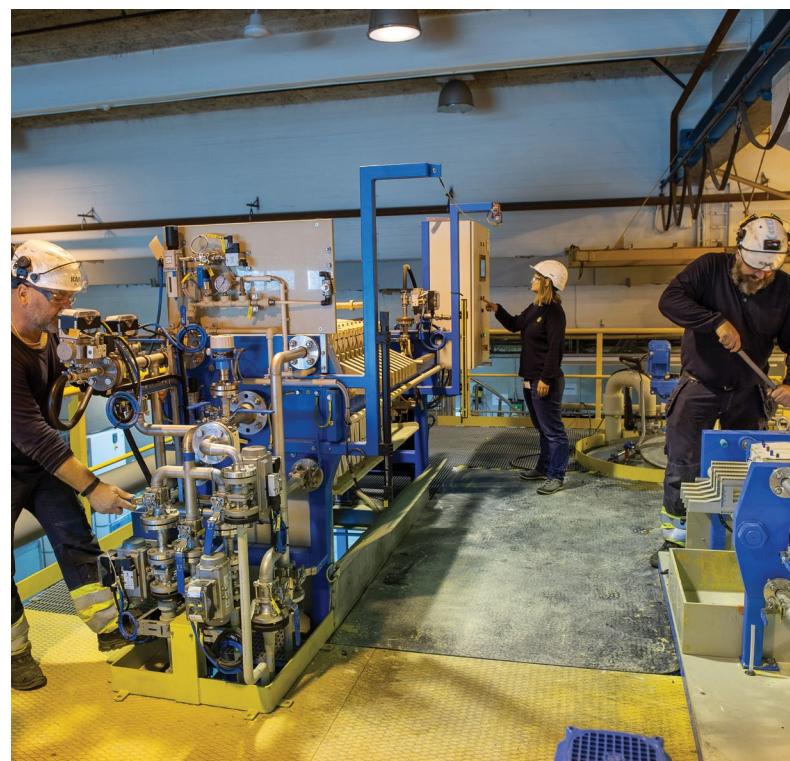
 *We aim to establish a stable and secure supply of critical REEs based on a sustainable extraction from phosphate rocks used in European production of fertilisers.*

The EU-funded [SecREETs](#) project seeks to transform the way Europe acquires these elements. "We aim to establish a stable and secure supply of critical REEs based on a sustainable extraction from phosphate rocks used in European production of fertilisers," outlines Arne Petter Ratvik, project coordinator and senior research scientist with SINTEF, one of Europe's largest independent research organisations.

Game-changing value chain

To achieve this, the project is working towards the creation of an integrated value chain to produce REEs in Europe, based on process demonstrations in three pilots. "Focus will be on the metals praseodymium (Pr), neodymium (Nd) and dysprosium (Dy) used in permanent magnets, as these are extremely critical for the European economy," notes Ratvik.

The project primarily involves Yara International ASA, a company that aims at extracting a concentrate of REEs from its fertiliser production. Yara's production uses approximately [650 000 tonnes of phosphate annually](#). This contains approximately 0.3 % to 1 % rare earths, which are not currently being extracted.



© Torbjørn Tandberg

"A company working on REE separation technology, [REEtec](#), separates out rare earths that are input to magnet metal maker Less Common Metals (LCM), while returning the non-rare earth products to Yara's fertiliser production line," adds Ratvik. Magnet alloys produced at LCM are validated by magnet producer Vacuumschmelze.

The produced magnets will be supplied to application areas such as automotive (electric vehicles), industrial motors (advanced manufacturing), and potentially, clean energies (wind turbines).

Great potential

"Good progress has been made in all pilot stages," reports Ratvik. Further verification and optimisation activities will continue. It is expected that a successful industrial implementation of the pilots can lead to a supply of at least 600 tonnes annually of neodymium-praseodymium (NdPr) REEs to European industries, with EUR 85 million in estimated value based on current prices.

Ratvik concludes: "Establishing a new value chain in Europe based on already mined ore for fertiliser production represents

by far the lowest environmental footprint of rare earth extraction globally." This is due to the fact that new mining waste is not being created. The value chain is also expected to further strengthen Europe as a resource-efficient and environmentally conscious area, and help create and secure existing jobs, reduce import risks and support the growing green technology industry.

PROJECT

SecREEtS - Secure European Critical Rare Earth Elements

COORDINATED BY

SINTEF AS in Norway

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/776559

PROJECT WEBSITE

sintef.no/projectweb/secreets/



Silicon via aluminothermic reduction of quartz in slag

An unprecedented alternative to the submerged arc furnace for silicon production slashes emissions and energy use and relies on secondary aluminium and silicon sources.

© Veronika Djupvik



Silicon is essential to human applications. It is widely used in electronics and solar cells and is a major constituent in ceramics, bricks and Portland cement. Its supply is at high risk and silicon has been designated one of 34 [critical raw materials](#).

State-of-the-art silicon production is highly energy- and carbon-intensive and generates tremendous CO₂ emissions. Given that global silicon production was close to [9 million tonnes](#) in 2022, more sustainable and carbon-neutral production methods will have tremendous impact. The pioneering EU-funded [SisAl Pilot](#) project has delivered the step-change process that the mining

industry – and the planet – needs, replacing today's carbon-intensive process with one using secondary aluminium and quartz (silicon dioxide) sources in large-scale silicon production.

Aluminothermic reduction of quartz in slag

Since the beginning of the 1900s, silicon has primarily been produced from quartz (the most abundant mineral in Earth's

crust) by reacting it with carbon-containing materials at very high temperature in a submerged arc furnace. Each tonne of silicon produced requires an electrical input greater than 10 MWh and generates about 5 tonnes of CO₂. The SisAl Pilot project has enabled the first (and to date only) alternative silicon production process to be demonstrated beyond the 100 kg scale.

According to project coordinator Gabriella Tranell of the [Norwegian University of Science and Technology](#), "the SisAl process replaces carbon-rich reducing agents with secondary aluminium sources such as end-of-life scrap and production side streams. Producing silicon from quartz via aluminothermic reduction generates no direct CO₂ emissions. Further, the aluminium recovery process is very efficient and the SisAl process can flexibly use multiple secondary quartz streams such as slag (a metal oxides and silicon dioxide by-product) and quartz fine tailings (finely ground residues)." In addition to its flexible resource use and emissions reductions, the reaction between aluminium and the quartz found in slag releases energy rather than requiring it.

Circular economy and industrial symbiosis

Replacing the carbothermic submerged arc furnace approach with SisAl Pilot's aluminothermic reduction of the quartz in slag does more than reduce energy and materials' use and emissions. Silicon is the most widely used alloying element, particularly valuable in improving the properties of aluminium. The SisAl Pilot's process closes the loop between the aluminium and silicon industries in an outstanding example of industrial symbiosis that contributes to a circular economy.

"Metallurgy is a very old discipline. Metals have been produced via carbothermic reduction since the Bronze Age. New processes and fundamental knowledge are needed. We are now at the threshold of the biggest transformation in the industry's history

– decarbonisation. Industrial symbiosis is extremely important to reaching this goal and the SisAl process has demonstrated that this is possible," Tranell adds.


The SisAl process replaces carbon-rich reducing agents with secondary aluminium sources such as end-of-life scrap and production side streams.

A large-scale pilot attracts international attention

"Typically, industry wants proof that a process works beyond the lab to believe in its commercial potential. The [SisAl Pilot project](#) has demonstrated the aluminothermic reduction of quartz at large scale with different reactors and raw material mixes, attracting commercial actors from around the globe for customised business case discussions and calculations including detailed environmental impact studies," notes Tranell.

In a tremendous evolutionary leap, an alternative to carbothermic reduction is on its way to market, promising unprecedented impact on sustainability and climate change mitigation.

PROJECT

SisAl Pilot – Innovative pilot for Silicon production with low environmental impact using secondary Aluminium and silicon raw materials

COORDINATED BY

Norges teknisk-naturvitenskapelige universitet NTNU in Norway

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/869268

PROJECT WEBSITE

sisal-pilot.eu/



A more sustainable value chain for the sought-after metal neodymium-iron-boron

An EU-funded project is pioneering industrial-scale technologies to extract rare-earth neodymium-iron-boron (NdFeB) from discarded items containing permanent magnets. Striving for a local supply, these new methods will optimise recycling of otherwise wasted resources.

The demand for rare-earth magnets, especially neodymium-iron-boron, is increasing. Neodymium-containing magnets are key components in various products driving the green transition, including wind turbines, electric vehicles and water pumps. However, the current supply chain cannot cope with the anticipated demand.

The ambitious goal of the EU-funded [SUSMAGPRO](#) project is to boost the availability of these magnets in Europe by creating a circular economy through recycling and reuse.



SUSMAGPRO is introducing new ways to recycle magnets directly from waste, creating a shorter recycling loop with a higher recovery rate and increased yield (25 %) compared to traditional methods.

A green cycle for neodymium-containing magnets

SUSMAGPRO is introducing new ways to recycle and reuse magnets directly from waste, creating a shorter recycling loop with a higher recovery rate and increased yield (25 %) compared to traditional methods. "Recycled materials are reshaped into various products, including cast alloys and different types of magnets, using innovative production methods that minimise waste," notes project coordinator Carlo Burkhardt.

The process begins with evaluating scrap products and thoroughly analysing all materials. This data informs component segregation and guides recommendations for efficient recycling designs. The scrap products are then robotically disassembled, separating magnet-containing items from the waste streams using a sensor array. The resulting magnet scrap is exposed to a hydrogen atmosphere to produce powders for further processing, with or without prior thermal demagnetisation.

The powders are subsequently transformed into new alloys or magnets through various processes. These include an innovative technique based on metal injection moulding that involves shaping, debinding and sintering and allows creating complexly shaped magnets with minimal production waste. The newly produced magnets can then be distributed to end users for use in various applications, such as car speakers, water pumps and automotive rotors.

Obstacles hindering rare-earth magnet recycling

Recycling rare-earth magnets presents many technical challenges. One key issue is the size of the magnets used in smaller technological devices, such as smartphones. The rare-earth amount in these devices is too small to make the extraction process time- and cost-efficient.

Product design is another factor impeding recycling of rare-earth metals. "For example, our innovative hydrogen-processing magnet scrap technology requires space for magnets to expand during the hydrogen reaction, which is impossible if magnets are tightly embedded in components," explains Burkhardt. This can be addressed by disassembly technologies, but products designed for recycling would make circular economy much more competitive.

Magnetic material conditions may also create issues for recycling, causing inconsistent properties in the end materials. The project consortium aims to tackle technology readiness level (TRL) 7-8 upscaling challenges, like impurities, high oxygen content and varied magnet compositions by project end. "End users will soon start realising recycled magnets can match or surpass originals," notes Burkhardt.

Small but decisive steps to transitioning to a circular economy

Laura Grau, research associate, states: "Many current car motors are not easily recyclable but are likely to be our largest scrap source soon. Given the global shift towards electric vehicles, it is not a matter of if we need efficient recycling designs, but when. There is no set deadline, but with governments pushing for electrification, we must act swiftly. Manufacturers need to reassess traditional designs urgently. Our aim is to identify what is recyclable and what is not, and help manufacturers make these crucial changes."

In addition to the alloy and magnet production pilots project partners unveiled, which can produce over 100 t/year, two recycling spin-offs have been established, each with an initial capacity of 50 t/year. Plans are underway to double the production capacity. "While this quantity is small compared to China's output of 230 000 t in the previous year, it is a scalable beginning," concludes Burkhardt.



© Carlo Burkhardt

PROJECT

SUSMAGPRO - Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SUSMAGPRO)

COORDINATED BY

Hochschule Pforzheim in Germany

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/821114

PROJECT WEBSITE

susmagpro.eu/



Recovery of critical raw materials in a circular economy

Europe will soon increase its supply of the critical raw materials tungsten, niobium and tantalum via processing technologies that recover them from European waste.

The list of [critical raw materials](#) for the EU now numbers 34. These materials are of high importance to the EU economy, but their supply is at risk.

Tungsten, niobium and tantalum are among them. Recovering these metals from pre-consumer scrap and processing waste will not only increase Europe's strength and independence but also make an important contribution towards a zero-waste economy. The goal of the EU-funded [TARANTULA](#) project was to support this effort by developing a toolkit of novel, efficient and flexible metallurgical technologies with high selectivity and recovery rates for tungsten, niobium and tantalum.

Small quantities of essential metals without substitute

Tungsten, niobium and tantalum are refractory metals characterised by their extraordinary resistance to heat and wear. They are essential to many [critical applications](#) including wind power, robotics, 3D printing and digital technologies. There are no viable substitutes and, without them, the supply of products including, cutting tools and dies, turbine engines, traction motors, drones and microelectronics would be threatened.



According to project coordinator Lourdes Yurramendi of [TECNALIA Research and Innovation](#), "Despite having the largest tungsten resources and reserves, China has become a [net importer](#) of tungsten ores and concentrates. The EU's primary production of [tungsten ore](#) – mainly in mines located in Austria, Portugal and Spain – covers only a limited part of EU domestic demand. Similarly, although it has some niobium deposits, the EU does not produce any niobium ore and is [entirely reliant on imports](#). Indeed, deposits in Brazil cover over 90 % of EU – and global niobium demand. The EU also imports 100 % of its tantalum, mainly from Africa. Finding alternative, secondary sources of tungsten, tantalum and niobium is paramount."

Anthropogenic sources in a zero-waste economy

Conventional mining secures raw materials from natural resources. Secondary raw materials – ores – are mined and processed to produce primary products. TARANTULA 'mines' tungsten, niobium and tantalum from tungsten-containing scrap and industrial waste from the processing of mined ore (tailings and slag).

Deep eutectic solvents facilitated the separation and recovery of more than 90 % of the tungsten in industrial process residues and tailings at lab scale. Subsequent solvent extraction with ionic liquids enabled recovery of over 99 % of the extracted tungsten (in the form of tungsten oxide). "TARANTULA's findings support the process' potential to deliver a sustainable annual supply of tungsten equivalent to 50 % of the EU's current primary production," Yurramendi notes.


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Niobium and tantalum are often present in the same sample. The project's multi-step technology can recover both as separated marketable products. The team believes optimisations will enable achieving high-quality tantalum and niobium equivalent to at least 120 % and 5 % of the EU's annual demand, respectively.

Ramping up technological readiness

"We developed and tested several eco-friendly and scalable technologies. A combination of ionometallurgy and electrometallurgy was the best from technical, economic and environmental perspectives. The most promising technologies were further upscaled and optimised in our prototype. It was designed to produce metal oxides at a kilogram-per-day capacity, with products meeting the commercial specifications of their broadest market segments thanks to rigorous testing," adds Yurramendi.

The team is already showcasing their recycled materials in oxide-based coatings from each of the three and a tungsten carbide-based coating, currently at lab scale. TARANTULA's outcomes will boost EU strategic autonomy and strength in competitive markets while reducing waste.

PROJECT

TARANTULA - Recovery of Tungsten, Niobium and Tantalum occurring as by-products in mining and processing waste streams

COORDINATED BY

TECNALIA Research and Innovation in Spain

FUNDED UNDER

H2020-EU.3.5., H2020-EU.3.5.3

CORDIS FACTSHEET

cordis.europa.eu/project/id/821159

PROJECT WEBSITE

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