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European Commission

CORDIS Results Pack on

processing and recycling of raw materials

A thematic collection of innovative EU-funded research results

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Innovative technologies strengthening the European raw materials production

Research and Innovation

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Editorial

The EU is ensuring a secure and sustainable supply of critical raw materials that underpin European industry's transition to a low-carbon, digital future.

Europe relies on the global importation of some of the building blocks that support modern life. These critical raw materials (CRMs), which combine high economic importance with high supply risk, are needed for the manufacturing of batteries, construction tools, sensors, and electronic and medical devices.

CRMs are vital to strategic sectors such as the net-zero and digital industries, as well as the aerospace and defence sectors. Demand is at an all-time high and is forecast to continue rising due to the green and digital transitions. For example, EU demand for lithium, which is used in batteries for electric vehicles and energy storage, is predicted to increase twelve-fold by 2030.

Risks to vital supply chains

However, the supply of CRMs is threatened by growing geopolitical, environmental and social challenges. Crucially, the EU faces dependency issues for several CRMs, such as lithium and rare earth elements, with often more than 90 % of EU supply coming from a single third country.

In addition, COVID-19 related disruptions to supply chains, the shortage of microchips, and the energy crisis following Russia's invasion of Ukraine all demonstrate the risks posed to the EU's economy and security by overdependence on the external supplies of strategic inputs.

Europe must ensure its own reliable supply of affordable and responsibly sourced CRMs to meet its net-zero 2050 target and achieve resource security for its strategic sectors.

Promoting access and sustainability

The goal of the European Critical Raw Materials Act is to secure the EU's supply by strengthening all stages of the European CRM value chain. The Act also addresses the need to protect the environment by improving the circularity and sustainability of CRMs.

This CORDIS Results Pack showcases 10 projects funded under the Horizon programme that developed innovative clean, sustainable solutions for processing, refining, recovering and recycling of raw materials and byproducts. These initiatives contribute to the objectives of the European Critical Raw Materials Act by reducing dependency on imported CRMs and developing more sustainable and circular supply chains.

Secure and sustainable future for silica, alumina and calcium carbonate

A pioneering co-production process yields three valuable raw materials from a single raw material source available in Europe with no bauxite residue, zero waste and net-negative CO_2 emissions.

Alumina, silica and calcium carbonate are three materials in increasing demand for application in areas including transport, energy, construction and coatings, to name just a few. Their economic importance and projected market growth are considerable.

However, the European market is at risk of a domestic supply shortage – particularly in the case of bauxite ore to produce alumina. This critical raw material is vital to aluminium production via the intermediate alumina. In addition to supply challenges, the production of these raw materials has high environmental impact. This includes tremendous global CO_2 emissions, significant solid waste and huge volumes of water to discharge waste.

The ambitious EU-funded AlSiCal project developed a pioneering approach for the green co-production of silica, alumina and calcium carbonate in a single process from a single unconventional source available in Europe, with minimum waste and net-zero CO_2 emissions.

Hydrochloric acid chemistry turns unconventional materials into 'gold'

AlSiCAl focused on rock high in silica content such as anorthosite and strategically investigated and benchmarked process alternatives. The most promising was selected and further refined.

According to AlSiCAl coordinator Asunción Aranda, formerly at the Institute for Energy Technology: "The chosen technology is based on hydrochloric acid (HCl) chemistry. The selected rock is dissolved in HCl and silica is separated and purified from the solution. This is followed by the chemical separation and calcination of alumina, and finally the precipitation of calcium carbonate." The entire process was validated at laboratory scale for anorthosite. One of the three core steps – dissolution and silica production – has also been validated at pilot scale.

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Minimum waste, net-negative CO_2 emissions

The AlSiCal technology unlocks currently unexploited mineral resources in Europe, securing a domestic supply of certain strategic raw materials. It could substantially reinforce the entire European aluminium industry value chain – from mine to market – creating jobs in the process.

It also makes a significant contribution to sustainability and environmental goals. It enables alumina and aluminium production without generating bauxite residue and achieves high resource efficiency by co-producing valuable raw materials with minimal waste generation. It also operates with net-negative CO_2 emissions by efficiently transforming



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CO_2 into the valuable raw material known as precipitated calcium carbonate. Finally, the process is designed for easy electrification and it slashes water contamination.

Culmination of years of stalled progress

Alumina production from alternative sources and secondary materials readily available in Europe has long been a goal of European metallurgy. AlSiCal is the successful culmination of efforts to reach this goal, beginning in the 1970s and 1980s in countries such as Norway and the USA. At the time, none of the technologies proposed could simultaneously satisfy technological, environmental, economic and social goals.

"Shaping the evolution of our initial concept into a tangible, feasible and robust technology during the AlSiCal project has been one of the most exciting innovation journeys of many of our partners and stakeholders," notes Aranda.

AlSiCal has created a public database of global anorthosite deposits and has developed reactors and process models for the technology. Together with its many publications, its innovative tools and the knowledge generated regarding the social dimension of mining and mineral processing technologies, AlSiCal will strengthen Europe's green minerals and metals transition. Further upscaling and optimisation of AlSiCAl's pioneering technology will accelerate industrial deployment.

PROJECT

AlSiCAl - Towards sustainable mineral and metal industry: ZERO Bauxite Residue and ZERO CO_2 from co-production of Alumina, Silica and precipitated Calcium carbonate by the Aranda-Mastin technology

COORDINATED BY

Institute for Energy Technology (IFE) in Norway

FUNDED UNDER

Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET

cordis.europa.eu/project/id/820911

PROJECT WEBSITE

alsical.eu/

Bacteria facilitate selective recovery of critical raw materials

Novel biotechnology-based processing supports a circular economy and a sustainable independent supply of critical raw materials from underexploited sources.

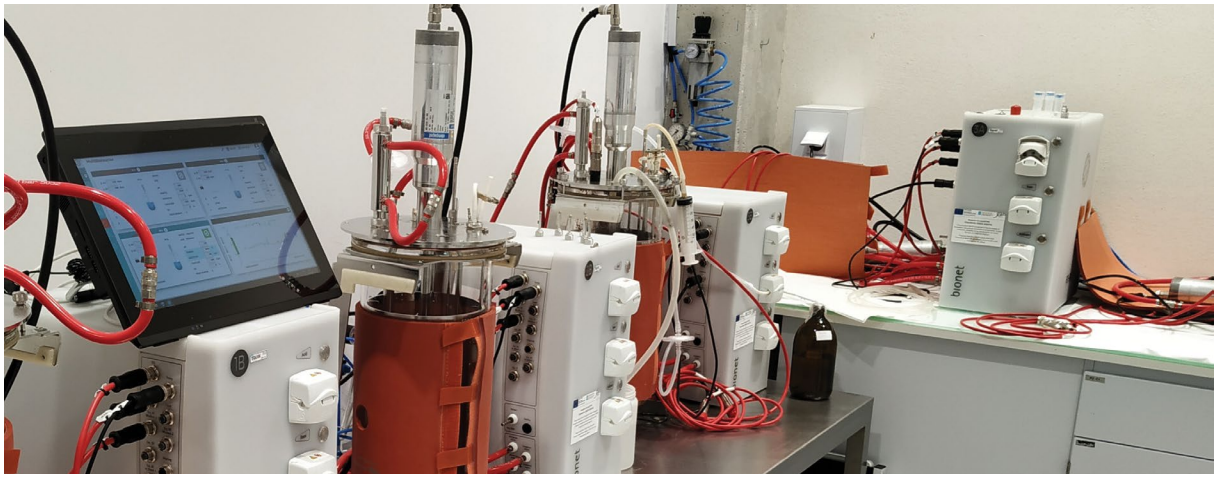
Europe is almost entirely dependent on a foreign supply of rare earth elements (REEs), magnesium and platinum group metals (PGMs). The EU is accelerating efforts to increase independence while improving mining sustainability and supporting a circular economy.

To support these goals, the EU-funded BIORECOVER project developed biotechnology-based solutions to recover critical raw materials (CRMs) from unexploited primary and secondary sources.

Target minerals and recovery process methodology

According to Cristina Martínez of CETIM, project scientific leader: "BIORECOVER focused on the recovery of three CRMs: REEs from bauxite residue (a waste product of aluminium processing), magnesium (Mg) from low-grade minerals, and PGMs from process residues and low-grade PGM ores." The team's multi-step process at semi-pilot scale was tailored to the CRM target metals and sources.

BIORECOVER isolated and screened a plethora of bacteria from the natural population inhabiting mine residues and investigated their detailed mechanisms of action, including studies of their DNA. The bacteria were then used to remove impurities in the sources. The pre-processing was followed by CRM mobilisation via bioleaching –extraction and solubilisation of CRMs using biologically produced mineral and organic acids – and immobilisation via microorganisms to produce a bioleachate enriched in target CRMs. Innovative methodologies supported selective recovery of CRMs from the multi-metal



© CETIM

bioleachate. A combination of modelling and testing in synthetic and natural solutions containing CRMs enabled optimisation.

Laying the foundation for selective CRM recovery

A milestone in the purification of bioleachates has been achieved using electroprecipitation technologies for the highly successful specific recovery of Mg from Mg bioleachates, resulting in a maximum recovery rate of 100 % and selectivity of 92 % in the post-treatment process. The final purity of magnesium hydroxide (brucite) was almost 90%.

Following the bioleaching process, a series of advanced technologies were implemented, each addressing critical steps specific to the three distinct groups of CRMs studied in the project. These tailored approaches ensured optimal recovery and processing for each CRM group, highlighting the importance of precise technological application at key stages of the process.

Novel microcapsules to selectively recover yttrium and scandium from REE-enriched bioleachate achieved a maximum recovery rate of approximately 80 % for yttrium and scandium. The maximum recovery rate for neodymium was approximately 40 % and for lanthanum and caesium about 20 %. Using commercial polymeric microcapsules and synthetic solutions, BIORECOVER achieved a selectivity of 95 % for yttrium.

A milestone in the purification of bioleachates has been achieved using electroprecipitation technologies for the highly successful specific recovery of Mg from Mg bioleachates, resulting in a maximum recovery rate of 100 % and selectivity of 92 % in the post-treatment process. The final purity of magnesium hydroxide (brucite) was almost 90 %.

Finally, a biopolymer modified with bacterial siderophores facilitated selective recovery of PGMs. The biopolymer enabled a maximum recovery of about 78 % and 58 % of platinum (Pt) and palladium, respectively, from PGM by-products and approximately 98 % and 92 % selectivity for Pt and iridium from PGM synthetic leachate. "Mobilisation of PGMs from low-grade PGM ore was challenging due to the refractory nature of the PGM hosting minerals. However, BIORECOVER achieved more than 90 % mobilisation of gold," adds Martínez.

Sustainable future in focus

The life-cycle assessment (LCA), based on laboratory-scale processes and equipment, provided important insight for scale-up. "In all recovery pathways studied, reduced energy consumption is key for large-scale viability – autoclave electricity and energy for reactor heating should be reduced," explains Martínez. The latter could be done by optimising bioleaching time to balance bioreactor energy consumption relative to increased CRM mobilisation.

The LCA identified the culture medium and chemicals to produce it as the main environmental bottleneck in REE recovery from bauxite residue. Using by-products such as sugarcane bagasse, vinasse or molasses could reduce this impact. The need to sterilise bauxite residue prior to processing leads to the main environmental impact regarding Mg waste.

BIORECOVER's biotechnology-based pathways to CRM recovery from unexploited sources with less energy, water and waste pave the way to a more sustainable and secure supply of CRMs and a brighter future for the environment.

PROJECT
BIORECOVER - Development of an innovative sustainable strategy for selective biorecover of critical raw materials from Primary and Secondary sources

COORDINATED BY
CETIM in Spain

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/821096

PROJECT WEBSITE
biorecover.eu/

End-of-life tyres: from waste to a valuable resource

An EU-funded project has established a circular economy model that breathes new life into used tyres. Through groundbreaking technologies, it transforms old tyres into high quality feedstock to produce new lines of passenger car and truck tyres, available for purchase across Europe and worldwide.

High-quality recycled materials from end-of-life tyres (ELTs) for new tyres and accessible ELT feedstock have to date been insufficient. Since 2020, approximately 1.6 billion ELTs, totalling 26 million tonnes, have become waste globally each year, with Europe contributing 3.5 million tonnes. Furthermore, 50 % of collected tyres in Europe are exported for valorisation elsewhere.

Although 90 % of ELTs are collected in Europe, most are used for energy recovery or non-tyre applications like playgrounds and rubber goods. Only a small portion is reused in new tyre production owing to inadequate quality.

Four key challenges

As highly technical products, tyres must balance safety, lifespan and energy efficiency. To maintain these standards without compromising performance, especially when replacing fossil materials, innovative technologies for processing ELTs into high-quality raw materials are essential.

Scaling up laboratory technologies for tyre applications is also crucial for supplying large quantities of new raw materials. This requires investment and expertise to develop processes that ensure consistent quality. However, competing with established fossil raw materials poses challenges, as they have optimised productivity and amortised investments. “The new value chain requires further investment and optimisation, and it is uncertain whether consumers will pay more for tyres with recycled content. Therefore, it is crucial to enhance the new tyre value chain, ensuring full valorisation of its outputs,” notes Jean-Michel Douarre, coordinator of the EU-funded BlackCycle project.



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Ultimately, the new value chain’s life cycle assessment must surpass that of fossil materials and current recycling methods like energy recovery, without causing new environmental problems.

The main technological breakthroughs

BlackCycle sought to establish a tyre circular economy by transforming ELTs into high-technology second raw materials. It developed new technologies and optimised the entire value chain to eliminate resource waste and minimise environmental impact.

In the upstream part of the value chain, project partners introduced an innovative deconstruction process. Before tyres are fully taken apart, MICHELIN developed two machines to separate valuable rubber components. An inside rubber grinding machine extracts inner liner rubber to create micronised rubber powder (MRP), which can be reused in new tyres. An outside rubber cutting machine cuts tread rubber, which is then processed to produce oils and higher quality recovered carbon black. It could as well be used to produce pure MRP made of tread rubber. This careful separation enhances material value and promotes recycling. The remaining tyre parts are processed to separate metal, textile and rubber pellets for further use.

Rubber pellets undergo pyrolysis, a high-heat process without oxygen, breaking them into gas, oil and solid parts. The gas powers the process, while the solid yields recover carbon black and minerals. The oil, known as tyre pyrolysis oil, also called crude tyre tar (CTT), is rich in carbon and hydrogen. The Auger and moving bed processes were refined to enhance oil quality for producing high-grade materials.

By developing 5 new processes and 4 new SRMs, BlackCycle significantly reduces greenhouse gas emissions compared to traditional energy recovery and chemical recycling methods. The new sustainable and recovered carbon blacks emit less CO_2 than virgin carbon black throughout their life cycle.

The production of high-quality secondary raw materials (SRMs) requires refining crude tyre tar (CTT) involving a distillation step. This process separates the CTT into heavy tyre tar (HTT) and light tyre tar (LTT). HTT replaces fossil fuels in ORION's furnace process to create sustainable carbon black, a high-quality product comparable to commercial carbon blacks. LTT is further distilled into resin tyre tar, rich in limonene and used to make s-resin, a technical plasticiser developed by MICHELIN.

A viable value chain

"By developing five new processes and four new SRMs, BlackCycle significantly reduces greenhouse gas emissions compared to traditional energy recovery and chemical recycling methods. The new sustainable and recovered carbon blacks emit less CO_2 than virgin carbon black throughout their life cycle," concludes Jean-Michel Douarre. "Furthermore, recovering the inner liner MRP results in three times lower CO_2 emissions than producing new inner liner rubber."

PROJECT
BlackCycle - FOR THE CIRCULAR ECONOMY OF TYRE DOMAIN: RECYCLING END OF LIFE TYRES INTO SECONDARY RAW MATERIALS FOR TYRES AND OTHER PRODUCT APPLICATIONS

COORDINATED BY
Michelin in France

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/869625

PROJECT WEBSITE
blackcycle-project.eu/

Efficient methods to reclaim valuable materials from old buildings

EU-funded researchers demonstrated recycling practices in the building sector by improving how materials from old structures are recovered. New building products contained up to 100 % recycled content, promoting more sustainable construction practices.

Construction, renovation and demolition waste is a major and bulky waste stream in the EU 27, generating 374 million tonnes annually, excluding excavation waste. Although recovery rates are relatively high, they mainly depend on backfilling and low-quality recycling.

A lack of competitive pricing and trust in the quality of secondary materials further hampers effective recycling efforts. The traditional design of buildings, which often overlooks ease of disassembly, reusability and recycling of materials, is a key barrier to adopting circular economy principles in construction. Overcoming these challenges requires a comprehensive approach, including shifts in design philosophy, technological advancements, updated regulatory frameworks and economic incentives to steer the building industry towards a more circular model.



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The EU-funded ICEBERG project has been established to revolutionise how end-of-life building materials are used, by overcoming the main barriers hindering the circular economy in the building sector. “Our primary goal has been to develop and demonstrate innovative, cost-effective solutions for enhancing the recovery of secondary building materials throughout the entire value chain,” notes project coordinator David Garcia Estevez. “This spans from end-of-life building materials to the production of new building products designed for circularity and resource efficiency, featuring 30 % to 100 % high-purity recycled content.”

Smart tools and recovery technologies for sustainable building practices

ICEBERG has pioneered a suite of integrated smart solutions designed to transform circular reverse logistics. First, an enhanced

building information modelling (BIM)-aided smart demolition tool was developed for planning, quantifying waste streams and assessing the environmental and economic impacts of renovation and demolition projects. Second, a blockchain-based platform was implemented to ensure traceability of end-of-life building materials. Finally, researchers employed a radio-frequency identification and QR code system for precise identification and authentication.

In terms of material recovery technologies, ICEBERG developed advanced methods such as hyperspectral imaging combined with machine-learning software to boost the efficiency of automatic sorting in mixed waste fractions. Other innovations included an optimised system for crushing, sorting and cleaning materials, alongside fast pyrolysis and purification for wood waste. Furthermore, it generated a process combining purification and solvolysis for polymeric insulating foams, and advanced hydrothermal and supercritical processing techniques for glass and silica-containing waste.

ICEBERG advanced building refurbishment and demolition with smart tools like BIM and cloud traceability. It showcased technologies for automatic waste sorting and high-quality recycling, alongside new circular building products with eco-design features.

Transforming building materials with high recycled content

ICEBERG introduced circular design solutions to improve the circularity of end-of-life building materials and develop innovative building products with high recycled content. These included eco-hybrid cement, which comprised recycled glass, brick, concrete and gypsum. The project also created precast concrete elements that feature reversible connections, alongside ultra-lightweight foam and woodchip concrete panels.

Another innovation was the demountable hollow-core blocks that used Carbstone technology. Circular ceramic tiles were developed with 70 % recycled content, while a resin derived from bio-oil was also produced. Furthermore, flexible woodchip panels and plasterboards containing 35 % recycled gypsum were produced.

ICEBERG showcased its developments in real-world settings through six case studies conducted across Europe and Turkey. Real-time data from these demonstrations was used to evaluate the economic and environmental impacts of the newly developed solutions.

"ICEBERG supported building refurbishment and demolition with smart tools like BIM and cloud traceability. It showcased technologies for automatic waste sorting and high-quality recycling, alongside new circular building products with eco-design features," highlights Garcia Estevez. "Improved purification and recycling methods delivered superior secondary raw materials. However, some ICEBERG products, even with a higher degree of circularity and lower virgin material content, may be even more expensive compared to currently available market solutions owing to economic conditions."

PROJECT
ICEBERG - Innovative Circular Economy Based solutions demonstrating the Efficient recovery of valuable material Resources from the Generation of representative End-of-Life building materials

COORDINATED BY
Tecnalia Research and Innovation in Spain

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/869336

PROJECT WEBSITE
iceberg-project.eu/

Efficient, low-cost technologies for recovering precious metals from autocatalysts, electronic waste and PV scrap

EU-funded researchers are working to develop low-cost, eco-friendly technologies for recovering precious metals from complex waste mixtures. Their pre-commercial successes pave the way for a more sustainable approach to metal recovery.

The technology we use daily relies on materials that are facing potential supply challenges. Precious metals like platinum group metals, gold and silver are essential components in many devices and are indispensable in various industries owing to their unique properties. Currently, Europe depends on other countries for these metals. However, these valuable resources can also be found in end-of-life products that could be recycled. Unfortunately, Europe's current recycling capacity is insufficient to meet even a fraction of the demand for these metals.

The EU-funded PEACOC project is helping Europe to boost the recycling of precious metals in the near future. Launched in 2021, "PEACOC is working to show that it can effectively recover precious metals like platinum group metals, gold, and silver from three waste sources: autocatalysts, printed circuit board assemblies (PCBAs) and photovoltaic panels. The project operates at a pre-commercial scale, specifically at technology readiness level (TRL) 7," notes project coordinator Elisabet Andres Garcia.

"The streamlined process involves collecting waste, pre-treating and concentrating the waste, and refining the metals. Furthermore,



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PEACOC aims to transform the recovered metals into marketable products, adding value to the entire process," adds Andres Garcia.

Two novel refining technologies in the spotlight

Recycling of waste streams like low- and mid-grade PCBAs, photovoltaic scrap, and spent autocatalysts has been limited so far. Traditional methods, such as smelting and hydrometallurgy, are energy-intensive and leave a significant carbon footprint.

PEACOC introduces new industrial alternatives aimed at making European resources more sustainable. Building on earlier successful activities, the focus has shifted to refining technologies. Partners VITO from Belgium, CEINNMAT from Spain, and 6TMIC from France are spearheading this effort. This phase aims to refine and upscale two crucial technologies: microwave-assisted leaching and gas-diffusion electrocrystallisation. The goal is to advance these technologies from a laboratory setting (TRL 4) to a fully operational pre-commercial scale (TRL 7), paving the way for a more efficient refining process.

VITO researchers have successfully improved the microwave-assisted leaching process by cutting down on chemical use, boosting equipment longevity and reducing corrosiveness. This enhanced process now efficiently extracts gold and silver from waste PCBAs and photovoltaic panels, as well as platinum group metals from used autocatalysts. CEINNMAT has developed innovative hydrothermal microwave leaching reactors and constructed a first-of-a-kind pilot-scale microwave plant. Seven interconnected units, able to handle at least 50 litres per hour, are integrated in a modular microwave system housed in a portable container.

Using industrial-grade materials, VITO researchers have also successfully scaled and tested the gas-diffusion electrocrystallisation process. This system, featuring a two-cell stack configuration, achieved 95 % selectivity for palladium while effectively separating copper from precious metals. The team plans to expand to a six-cell configuration to improve performance and reduce energy consumption.

Prototype reactor for metal extraction and concentration

Researchers at the University of Liege and TU Delft have developed preliminary processes for metal extraction in order to concentrate the content of the targeted elements and thus improve the refining phase.

The University of Liege (ULI) optimised and scaled-up the NOVA technology to process mid- and low-grade PCBAs. They experimented with PCBAs from cathode-ray tube and LCD TVs, using electrochemistry and mechanical activation to separate valuable metals. The 'rotary screen reactor' has been identified as the most effective design for scaling. The upscaled NOVA prototype was received in August 2024 at ULI´s facilities. ULI team is working on the final logistics to make the equipment ready for operation.

PEACOC marks the first-time innovative concentration and refining technologies which have been scaled to a pre-commercial level, showcasing an industrial sustainable alternative for supplying Europe with critical and precious metals from waste.

Additionally, TU Delft researchers have optimised and upscaled the magnetic density separation prototype able to selectively recover the components containing gold from PCBAs with relatively high recoveries. This technology uses a combination of roller sorting, a superconducting magnet and a magnetic fluid that have been scaled up and tailored within the project.

"PEACOC marks the first-time innovative concentration and refining technologies which have been scaled to a pre-commercial level, showcasing an industrial sustainable alternative for supplying Europe with critical and precious metals from waste. The PEACOC pilot plant will facilitate a genuine technology transfer from R&D to market-ready products," concludes Andres Garcia.

PROJECT
PEACOC - Pre-commercial pilot for the efficient recovery of Precious Metals from European end of life resources with novel low cost technologies

COORDINATED BY
Tecnalia Research and Innovation in Spain

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/958302

PROJECT WEBSITE
peacoc-h2020.eu/

Photovoltaics: paving the path to a sustainable future

The decreasing cost of solar power has spurred widespread installation of photovoltaic panels. But what will happen to these panels, especially electronic components, when they reach the end of their lifespan in the coming decades? An EU-funded project is unveiling reliable solutions to mitigate growing concerns.

One of the most pressing global priorities today is reducing carbon emissions to keep global warming below 2 °C, as outlined by the Paris Agreement. Solar energy is leading the charge as it offers an accessible and affordable solution to decrease reliance on fossil fuels and move towards carbon neutrality.

The photovoltaic (PV) industry plays a crucial role in this effort. It must set a high standard by being resilient and sustainable and should demonstrate the effectiveness and feasibility of collaborative approaches and innovative business strategies. However, the increase in waste electrical and electronic equipment such as PV devices, presents a challenge. These devices are complexly layered, making it difficult to extract valuable raw materials like silicon, silver or indium, gallium embedded within them.

The EU-funded PHOTORAMA project seeks to create a sustainable and profitable circular value chain. By developing innovative recycling solutions, PHOTORAMA intends to recover and reuse all material components from end-of-life PV panels, thereby promoting a carbon-neutral PV industry.

End-of-life panels: the weak link in the PV value chain

"PHOTORAMA is tackling the global challenge of recycling solar panels by focusing on technological innovation where it is most needed – end-of-life management. Recycling these panels is tough and current methods often waste valuable materials –recycling requires carefully separating materials to maintain their purity," notes project coordinator Claire Agraffeil.

PHOTORAMA shows that smart innovation can lead to high-value recycling. The project involves a step-by-step process: first, disassembling external components (aluminium frame, junction box), then separating layers from the sandwich structure (frontsheet, cells, backsheet) and finally recovering critical raw materials (silicon, copper, aluminium, silver from crystalline-silicon panels and indium, gallium from CI(G)S panels).

PHOTORAMA is tackling the global challenge of recycling solar panels by focusing on technological innovation where it is most needed – end-of-life management. Recycling these panels is tough and current methods often waste valuable materials.

Most of the recycling practices are based on shredding or crushing processes that are identified as down-cycling approaches. The external components can be easily isolated for recycling, while the glass fraction is usually targeted for low-value applications. The polymers from the sealing layers and the backsheet are at best recovered as energy fuel, but most is landfilled, and the metals are usually not recovered. This leads to irreversible loss of valuable materials embedded in PV panels.



© PHOTORAMA

PHOTORAMA addressed the main challenges of separating the sandwich layers without mixing materials and recovering critical raw materials. Project partners are working together to scale up the technologies. From the early stage of innovation at technology readiness level (TRL) 4–5, the maturity of technologies will reach TRL 6–7 by the end of the project.

"Recycling PV devices is a complex task owing to the existence of over 150 000 models that may be different by the design specifications. This diversity makes a universal disassembly method challenging, requiring not just technological advancements but also the creation of a flexible system capable of managing all types of PV waste," outlines Agraffeil. "High-throughput and volume treatment are crucial in recycling, setting our work apart by efficiently addressing these challenges."

Photovoltaics in the circular economy

"PHOTORAMA is a precursor in the PV field, aiming to transform the industry by reimagining the entire value chain with a circular model. The project emphasises the necessity of field experience to transform theoretical principles and guidelines into practical reality," highlights Agraffeil.

"By covering the entire PV value chain, PHOTORAMA bridges the gap between manufacturing and recycling industries, typically addressed only conceptually. We focus on sharing progress and best practices to build a solid economic framework that involves diverse business stakeholders," concludes Agraffeil. The project also seeks to inspire other sectors to rethink and adopt sustainable models.

PHOTORAMA won the Innovation Awards 2024 at EU Sustainable Energy Week 2024 that "recognise outstanding individuals and projects for their innovation and efforts in the field of energy efficiency and renewables". It developed technologies to recover PV panel components with high purity. Its approach went beyond recycling, focusing on repurposing the recovered materials through a comprehensive value chain strategy.

PROJECT
PHOTORAMA - PHOtovoltaic waste management – advanced Technologies for recOvery and recycling of secondary RAw MAterials from end-of-life modules

COORDINATED BY
French Alternative Energies and Atomic Energy Commission in France

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/958223

PROJECT WEBSITE
photorama-project.eu/

The future of mining: valorising mine waste and re-using water

Novel technologies and processes have shown the potential of a new source of critical raw materials – waste from active and abandoned mines – in a circular economy model.



© RAWMINA consortium

Critical raw materials (CRMs) are not necessarily scarce. They are of high economic importance for key sectors, have a high supply risk due to import dependence, and do not have viable substitutes. The transition to digital and green technologies is putting CRMs increasingly in the spotlight and the official list of them is growing.

Although Europe has negligible mining of CRMs, it has many active and abandoned mines for other minerals whose 'extractive waste' – materials discarded because they are not considered valuable – may contain valuable CRMs. To support a circular economy model for mining, the EU-funded RAWMINA project developed an industrially scalable mine waste valorisation pilot that also slashes water consumption.

Supporting valorisation of Europe's untapped potential

Mine waste is often stored in large volumes without any treatment, leaving valuable metals unrecovered and posing environmental hazards due to contamination of the local environment. RAWMINA strategically focused on antimony (Sb), cobalt (Co), germanium (Ge), and tungsten (W). These CRMs are essential for many high-tech applications and the growth of Europe's technology, business and manufacturing sectors.

"Currently exploited Sb, Co, Ge and W reserves within the EU represent a small percentage of the total reserves available. Additional reserves at existing deposits are continuously being identified, and the EU's progressive discovery of new deposits has opened additional exploration potential," notes Diego Morillo of LEITAT, and RAWMINA's technical coordinator.

Innovative processing for a circular economy in CRM mining

RAWMINA embraced circular economy principles by transforming mine waste into valuable products and reusing process water. "Innovations include continuous bioleaching using microorganisms for efficient metal extraction, and selective metal recovery technologies leveraging nanofibrous composite materials, thermo-desorption, electrowinning, and electrocoagulation," Morillo explains. In addition, magnetic separation enables iron removal to convert iron waste into high-value products. A closed-loop water recirculation system reuses water and reduces waste.

According to Morillo, "After industrial implementation, the RAWMINA system will enable reducing mine waste generation by 95 % and reusing 90 % of the processing water. This reduces environmental harm, conserves resources and promotes sustainable industrial practices."

Scalable technologies and societal support

The RAWMINA pilot system is ready and can treat 100-150 kilograms of mine waste per day, achieving high recovery rates and selectivity for CRMs and high-value products. Furthermore, RAWMINA's adaptable process technologies are suitable for various global locations.

"RAWMINA has successfully demonstrated the feasibility of a continuous and industrially scalable pilot system that combines multiple innovative technologies for efficient and sustainable metal recovery from mine waste. This sets a new standard for the mining industry and underscores the potential for circular economy practices," Morillo says.

The project not only advanced technical innovations but also emphasised the importance of societal acceptance and public awareness. "By fostering dialogue with stakeholders and the public, we aim to build trust and support for sustainable mining practices and encourage international cooperation and market development. Additionally, the project's commitment to ethical, transparent and inclusive research sets a positive example for future initiatives in the sector," notes Morillo.



RAWMINA has successfully demonstrated the feasibility of a continuous and industrially scalable pilot system that combines multiple innovative technologies for efficient and sustainable metal recovery from mine waste. This sets a new standard for the mining industry and underscores the potential for circular economy practices.

RAWMINA is contributing to the security of Europe's CRM supply and the sustainability of its mining sector. Furthermore, it has taken a step towards a future in which mining becomes redundant, with demand met by the resources already in circulation.

PROJECT
RAWMINA – Integrated innovative pilot system for Critical Raw Materials recovery from mines wastes in a circular economy context

COORDINATED BY
LEITAT in Spain

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/958252

PROJECT WEBSITE
rawmina.eu/

Multi-mineral, modular brine 'mining' process

Groundbreaking processes for the recovery of raw materials from brine, a large sample database and upcoming modelling platform pave the way to a secure and sustainable minerals supply.

Desalination of seawater is accelerating, largely driven by increasing water demand and the effects of climate change on freshwater resources. In the EU alone, desalination facilities can now supply up to 3.4 billion cubic metres of desalted water annually.

About the same volume of concentrated brine remains, containing precious critical raw materials (CRMs) and other raw materials that are currently discharged back to sea as waste. The EU-funded SEA4VALUE project set out to develop a multi-mineral modular process that can be adapted to the brine composition, making the advanced technologies economically and technically feasible.

Expanding circularity to meet critical needs

SEA4VALUE originally targeted nine elements of industrial relevance – the CRMs magnesium, scandium, vanadium, gallium, boron and lithium, as well as the elements indium, molybdenum and rubidium. However, the team identified another need as well.

Conventional desalination can produce water that is almost 'too pure' – lacking the minerals necessary for human health. Restoring these elements to drinking water requires buying them, often from distant suppliers. SEA4VALUE added calcium to its list of target minerals, further supporting a circular economy in which the calcium removed from seawater can be reintroduced to the drinking water.

...some technologies are recovering more than 95 % of the target element. These include modified nanofiltration, calcium recovery, non-dispersive solvent extraction, adsorption and electrodialysis with bipolar membranes. Other technologies such as ionic-liquid extraction or polymer inclusion membranes require further research to increase their selectivity and efficiency.

Real samples collected worldwide undergo pilot testing

SEA4VALUE's separation, concentration and crystallisation technologies were developed and tested by partners in their laboratories throughout Europe using synthetic and real brines. The laboratory tests were quite successful at meeting target recovery of 90 % with 90 % purity.

"SEA4VALUE's technologies have been brought together in our 'moving lab' installed at the Aqualia-managed desalination plant in La Caleta de Adeje, Tenerife. Here, nearly 150 seawater and brine samples from locations around the world are being tested, validating the recovery of key elements under different concentrations and possible interferences," explains Alexandra Scherer of the European Science Communication Institute.

The 'moving lab' is generating great insight. In the meantime, the conventional laboratory experiments demonstrated that "some technologies are recovering more than 95 % of the target element. These include modified nanofiltration, calcium recovery, non-dispersive solvent extraction, adsorption and electrodialysis with bipolar membranes. Other technologies such as ionic-liquid extraction or polymer inclusion membranes require further research to increase their selectivity and efficiency," says SEA4VALUE's technical coordinator Sandra Casas of EURECAT. Technologies developed in the project are based on green reagents to reduce the impact of the

treatment and aim to increase the water recovered from the desalination process by 20 %.

A legacy extending beyond SEA4VALUE's project duration

SEA4VALUE also developed an evaporator resistant to corrosion by salt water and with lower energy consumption, with many potential applications beyond SEA4VALUE. Furthermore, the project has been raising awareness of desalination for mineral recovery. As one of the first such projects, SEA4VALUE initiated a CEN workshop on brine 'mining', providing public recommendations on minerals and treatments.

The mineral content of the samples can be found in a database accessible on the project's website with free registration. A platform to model the process is being developed for use in defining the most suitable treatment scheme based on the initial brine composition.

SEA4VALUE has made a great contribution to two key global challenges – access to a sustainable, local supply of minerals and metals and to healthy drinking water – through a circular economy leveraging desalination plants.

PROJECT
SEA4VALUE - Development of radical innovations to recover minerals and metals from seawater desalination brines

COORDINATED BY
Eurecat in Spain

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/869703

PROJECT WEBSITE
sea4value.eu/



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Saltworks could be sustainable 'mines' for Europe's CRMs

Innovative electromembrane processes have enabled recovery of critical raw materials from seawater brine in a completely circular and sustainable approach.

The Mediterranean Sea is full of valuable minerals, generally in very low concentrations. Ancient civilisations found a way to extract some of this bounty, relying on the natural evaporation of seawater and crystallisation in shallow basins to produce salt. This process is still widely used by saltworks today.

In addition to the sodium chloride and calcium salts that seawater yields, the bittern that remains is a highly concentrated solution rich in magnesium, lithium and other critical raw materials (CRMs). This natural concentrating process transforms CRMs into low-hanging fruit accessible with sustainable processes.

The EU-funded SEArcularMINE project demonstrated this potential in a fully operational pilot plant. Based on analysis of bittern contents, their market value and technologies research, SEArcularMINE focused on the recovery of magnesium, lithium, boron, rubidium, bromine and sodium sulphate/chloride salts.

Circular economy and renewable-energy driven processes

The pioneering SEArcularMINE approach is based on fully circular, low-carbon and cost-effective processes. As project coordinator Andrea Cipollina of the University of Palermo explains: "The bittern, which saltworks are currently discharging, is our only material input other than water. This is revolutionary – the minerals we are recovering commonly come from resources mined in conditions detrimental to the environment and/or processes requiring chemical reactants."



© Michael Papapetrou

Electricity is the third and final input, necessary to drive separation processes. SEArcularMINE leveraged electromembrane processes – promising green alternatives to conventional separation methods. These use an electric potential gradient as the driving force of ion transport, and ion-exchange membranes for separation and removal of charged components from solutions.

Electromembrane processes are energy intensive. Ours can be run using sustainable sources to produce electricity on-site thanks to flexible intermittent and variable load operation, adapting to the available energy. Our vision is grid independence using electricity produced from the salinity gradient and solar and wind energy.

"Electromembrane processes are energy intensive. Ours can be run using sustainable sources to produce electricity on-site thanks to flexible intermittent and variable load operation, adapting to the available energy. Our vision is grid independence using electricity produced from the salinity gradient, and solar and wind energy," notes Cipollina.

Preserving ancient methods while building Europe's digital future

Thanks to the synergistic action of dedicated researchers with diverse expertise, SEArcularMINE rapidly scaled up technologies. Within four years, the consortium went from an original idea to a fully operational pilot plant. Located on the premises of partner ResourSEAs, a University of Palermo spin-off, it is near the famous Trapani saltworks from where SEArcularMINE gets its bittern. The ancient salt pans there date back some 2 700 years. They are now part of a nature reserve managed by the World Wildlife Fund, a fitting site for SEArcularMINE's green and sustainable CRM 'mining' venture.

"Delocalised production of CRMs in the Mediterranean basin through a fully circular and energy-self-sustained technology will benefit the Mediterranean's population, economy and sustainable growth tremendously. This is particularly important considering that most interested parties (where saltworks are located – in southern Europe and North Africa) are often in need of economic growth drivers," notes Cipollina.

"The knowledge generated as we successfully addressed multiple engineering challenges and gained operational experience has been huge," Cipollina continues. The pilot plant successfully demonstrated the technologies' technical feasibility, producing up to 100 kilograms of target materials daily. The work also spawned ideas for lithium recovery from used batteries as well as several patents, including one for a circular desalination process. Furthermore, the upskilling and exchange of over 80 early career researchers has created a synergic network of professionals to continue this work.

ResourSEAs is now actively building partnerships with saltworks around the Mediterranean to plan the first full-scale plants producing minerals from Europe for Europe. Seawater is set to become Europe's sustainable CRM 'mining' solution.

PROJECT
SEArcularMINE – Circular Processing of Seawater Brines from Saltworks for Recovery of Valuable Raw Materials

COORDINATED BY
University of Palermo in Italy

FUNDED UNDER
Horizon 2020 - ENVIRONMENT

CORDIS FACTSHEET
cordis.europa.eu/project/id/869467

PROJECT WEBSITE
searcularmine.eu/

Recycled polymer works its way into laminated glass

Once limited to coatings and textiles, recycled PVB – a popular plastic – is finding its way in new applications. EU-funded researchers unveiled technology that not only recovers glass but also cleans, sorts and processes PVB for reuse in making new laminated glass.

Polyvinyl butyral (PVB) is a widely used plastic material – commonly seen in car windshields and building windows – that makes laminated glass safe and shatterproof. However, PVB recycling poses significant challenges, leading to its frequent classification as waste.

A major issue is the presence of leftover glass pieces in recycled PVB, resulting in a hazy, less clear product. Furthermore, exposure to weather over time allows laminated glass to separate more easily from PVB, but this process can degrade the PVB and complicate its reuse. Variations in PVB compositions from different sources can also exacerbate the haze problem when mixed. Owing to these difficulties, only a small fraction of PVB is recycled, with most recyclers focusing on retrieving the glass and leaving PVB as a limited-use by-product.

The EU-funded SUNRISE project sought to tackle this problem by developing an advanced sorting system designed to separate and purify PVB, potentially recycling over 125 000 tonnes of it. This innovative system promises significant economic, environmental and social benefits by reducing waste and creating new applications for high-quality recycled PVB.

Innovative technology for glass recovery and PVB reuse

"We have developed a cutting-edge multi-sensor tool that can sort laminated glass waste based on the composition and condition of the PVB inside," notes project coordinator Angélica Pérez Manso. "This tool uses advanced optical sensors and smart algorithms to quickly and accurately assess PVB composition. With this technology, we can sort through 100 pieces of laminated glass per hour, ensuring that each piece is categorised correctly."

A pilot demonstration of the prototype tool is underway in Spain. Once the glass is sorted, it is treated in a specialised facility that can recycle up to 360 kilogrammes of PVB per hour. The recycling process involves a mix of mechanical and chemical methods. Depending on the type of waste (automotive or construction), they help separate the glass from the PVB efficiently.

The mechanical step involves breaking down laminated glass into smaller pieces to separate the glass from the PVB layer. After that, a special chemical wash is applied to help weaken the bonds between the glass fragments and PVB. This makes it easier to remove the glass, ensuring the PVB is clean and ready for recycling. The team has also explored adding antioxidants to inhibit thermal degradation of PVB during reprocessing, ensuring it remains stable.

This tool uses advanced optical sensors and smart algorithms to quickly and accurately assess PVB composition. With this technology, we can sort through 100 pieces of laminated glass per hour, ensuring that each piece is categorised correctly.



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Creating new laminated glass, reduce waste and setting recycling standards

"The most promising application we target is creating new interlayer films for laminated glass. However, we are not stopping at glass but are also exploring other applications for recycled PVB, such as creating coatings, textiles and even components for energy storage devices like batteries," states Pérez Manso.

SUNRISE activities are transforming PVB recycling, turning this costly material into new laminated glass, which supports a circular economy. By reusing PVB, the project significantly reduces plastic waste in the EU and boosts recycling rates for glass manufacturers. This innovative technology not only adds value to existing recycling processes but also paves the way for new products and markets. Moreover, SUNRISE is fostering industry standards through a CEN workshop agreement to ensure the quality of recycled PVB.

PROJECT

SUNRISE - MultiSensor sorting tools in a circular economy approach for the efficient recycling of PVB interlayer material in high-quality prodUcts from laminated glass coNstRuction and demolItion waStEs

COORDINATED BY

Lurederra in Spain

FUNDED UNDER

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CORDIS FACTSHEET

cordis.europa.eu/project/id/958243

PROJECT WEBSITE

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RESULTS PACK ON SUSTAINABLE MINERAL EXTRACTION – SECOND EDITION

The challenge confronting the extractive industry is to scale up promising innovative technologies and to demonstrate that raw materials can be extracted sustainably at minimum environmental and social costs. This Results Pack showcases seven Horizon 2020 funded research and innovation projects offering concrete technological solutions for sustainable mineral extraction.



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