Electrified (electro)catalyst production and recycling for sustainable catalyst-based chemical industries

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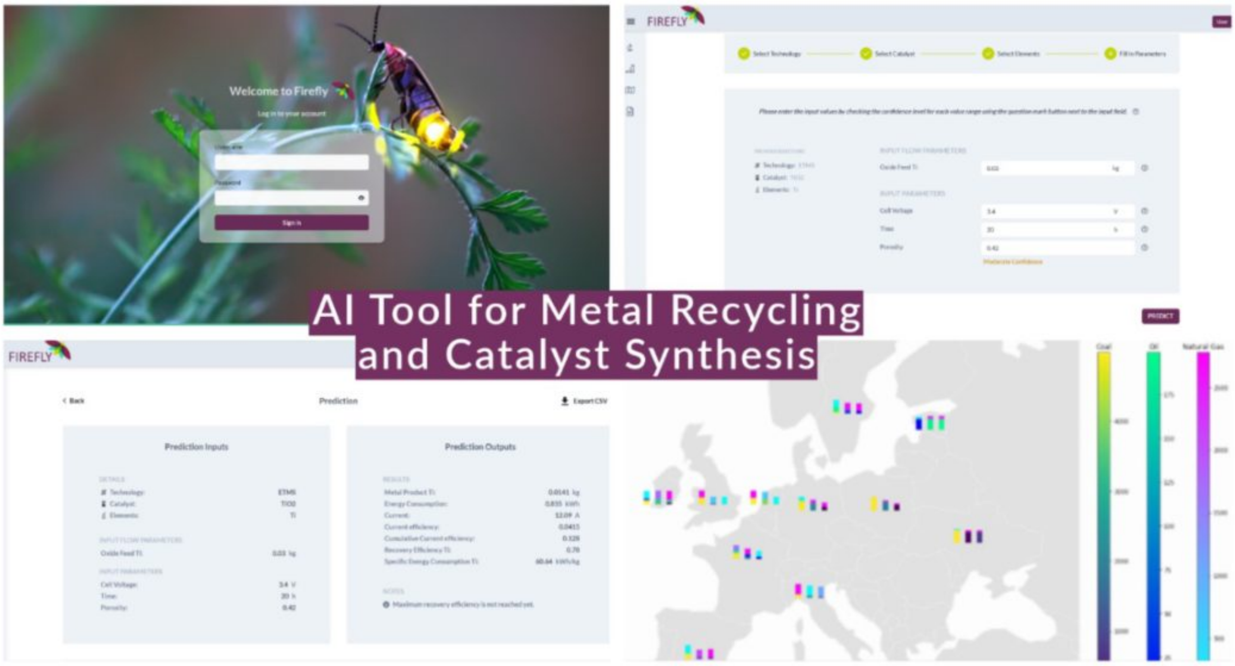


Savitha Thayumanasundaram, Research and Development Scientist at the Flemish Institute for Technological Research (VITO) & Project Coordinator of the FIREFLY consortium, explains electrified (electro)catalyst production and recycling for sustainable catalyst-based chemical industries

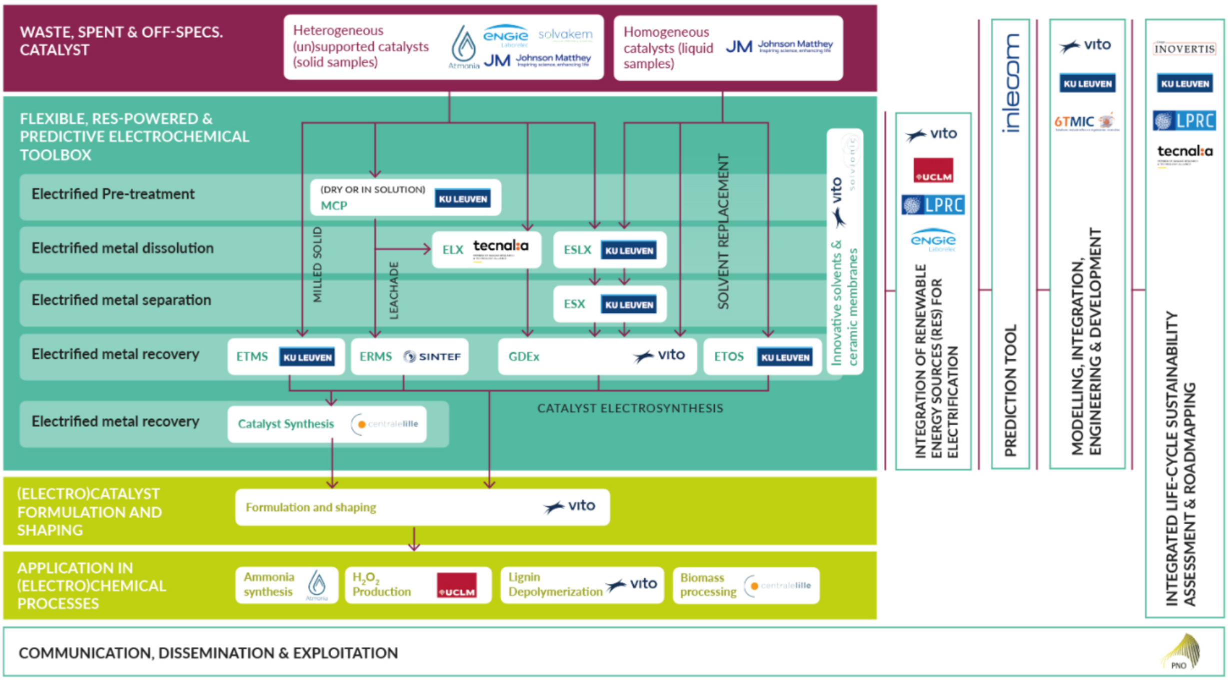
In today's rapid world trade growth, European chemical companies face challenges due to the acceleration of technological changes, decarbonisation, and high energy, labour and feedstock costs. Although the EU-27 chemical industry generated €655 billion in 2023, the world market share of EU27 has dropped to 13% in the last 20 years.

To rise to these challenges, it is crucial to focus on developing breakthrough recycling technologies towards the shift to a circular economy, significant reduction of CO_2 emissions, integration of renewable energy sources (RES), and digital revolution (adoption of artificial intelligence (AI)).

Catalysts are indispensable for most chemical industries, boosting energy efficiency and enabling efficient production processes. They usually contain metals, including critical raw materials (CRM). The demand for these materials is increasing exponentially, and their supply chains are global, complex and hindered by socio-political issues.

These challenges could be tackled by increasing the secondary raw materials supply through efficient recovery/ recycling technologies. Unfortunately, the current industrial recycling processes consume high energy, produce toxic and corrosive gases and are expensive.

Electrification via electrochemistry for both catalyst synthesis and recycling could be the best solution to these challenges, as it offers significant decarbonisation and cost-competitiveness through reduction in energy consumption, processing steps, capital expenditure (CAPEX) and operating expenses (OPEX).



Cradle-to-Cradle approach by FIREFLY

Comprised of 16 partners, The EU-funded FIREFLY project prioritises implementing sustainable practices in the catalyst-based chemical industry. The cradle-to-cradle approach which focuses on sustainable production of strategic (electro)catalysts from secondary resources and manifesting these catalysts in selected chemical processes such as synthesis of ammonia and hydrogen peroxide. This approach has the potential to reduce significantly the dependency on virgin raw materials and fossil energy, thereby minimising the environmental footprint of the chemical industry.

The action plan also includes development of a flexible, AI-based, predictive and RES-powered electrochemical toolbox. This toolbox will incorporate various innovative (electro)chemical technologies to demonstrate the TRL6 FIREFLY process for recycling metal-based catalysts and simultaneous production of (electro) catalysts. The relevant material flows, and stocks treated in the electrochemical toolbox will also be mapped using a material flow analysis (MFA) and a geographic information system-based inventory (GIS inventory).

Intermediate results: Flexible (electro)chemical technologies

Within two years, FIREFLY is already reporting remarkable milestones:

- Researchers at KU Leuven recovered over 95% tungsten (W) and more than 80% vanadium (V) from spent DeNOx catalysts as well as 100% palladium (Pd) from the waste stream of the lignin depolymerisation process, using their mechanochemical process (MCP).
- Another team of KU Leuven implemented electro-driven solvoleaching (ESLX) and electro-driven solvent extraction (ESX) technologies to achieve 85% Pd recovery from spent catalysts and nearly 100% stripping of Pd in non-aqueous solvent extraction.
- TECNALIA's research group optimised the operation conditions of their electro-leaching (ELX) process, reporting extraction rates of 80% for V and molybdenum (Mo) from spent DeNOx catalysts.
- The gas-diffusion electrocrystallisation (GDEx) process 'coined' by VITO's researchers achieved over 99% Pd recovery from a waste stream. Scientists are now addressing the technical aspects to improve the operational conditions.

Moreover, researchers at VITO and Centrale Lille have synthesised, formulated, and shaped more than three (electro)catalysts to be tested in innovative (electro)chemical processes. As these individual technologies reach the final stages of optimisation, the most promising processes will further be integrated in the electrochemical toolbox.

As these individual technologies reach the final optimisation stages, the consortium will benchmark them against state-of-the-art (SoA) technologies. The most promising processes will further be integrated into the (electro)chemical toolbox.

Mapping of available resources

Researchers at LPRC performed a preliminary MFA and GIS inventory analysis for the DeNOx catalysts by enforcing the MaTrace methodology. For the DeNOx technosphere, the stock and outflows of coal, oil and gas-fired power plants are being considered.

Among these resources, coal and natural gas-fired power plants constitute most of the spent catalyst outflow, with oil-fired power plants only being used in niche situations. Germany, Poland, France, Italy and Spain are the countries that have the significant spent catalysts stock. This study will support a transition towards resource circularity, prevention of waste and material security and consequently suggest policy interventions to promote sustainable management of spent catalysts.

AI-based predictive tool for the RES-powered electrochemical toolbox

Inlecom is developing an AI-based tool to predict the output of each electrochemical process and propose optimal recycling flowsheets. Researchers have designed a user-centric prototype application and are currently training the machine learning (ML) algorithms to forecast output and energy consumption.

The ML models are already finalised for the ETMS and GDEx technologies and are waiting to be extended to the remaining technologies. In the future, the predictive tool will be equipped with an interactive map based on the GIS inventory developed by LPRC, and the app's first version is expected soon.

The FIREFLY project is set to transform the chemical industry with cutting-edge (electro)chemical technologies for sustainable metal recovery. By integrating renewable energy and AI-driven optimisation, FIREFLY addresses market demands for greener solutions and aligns with key EU policies, driving significant CO_2 reductions and cost savings.

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What does this mean?

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