#EU GREEN WEEK

6 June 2025 | online webinar

Partner Event

Circular economy innovations:

From waste to valuable materials with EU R&I

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6 June 2025 | online webinar

#EU GREEN WEEK

Partner Event

Dr. Iakovos V. Yakoumis

CEO & Founder of Monolithos Catalysts & Recycling Ltd.

MONOLITHOS
CATALYSTS - RECYCLING - INNOVATION

PEACOC Pilot: Opportunities and challenges for the recovery of critical and strategic raw materials from secondary sources

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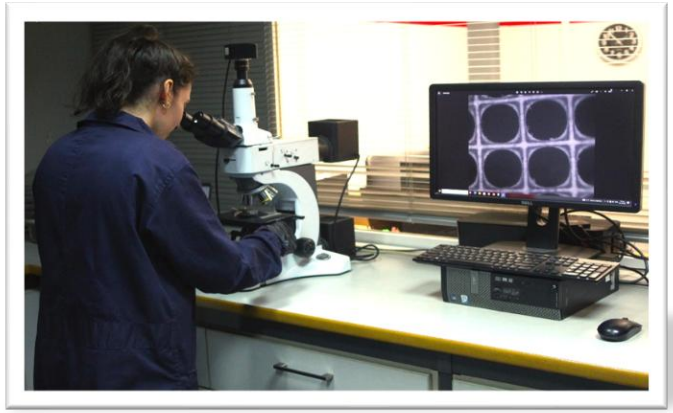
MONOLITHOS: Pioneering Sustainable Recycling via Hydrometallurgy

Commercial Achievements

- **3.9m Euros** turnover (2024)
- **34 employees** (11 Ph.D., 11M.Sc.)
- **2150sqm** industrial and lab facilities
- Locations: **Athens**, **Thessaloniki** *(Diavata, 120sqm)*, **Cyprus** *(Larnaca/Psevdas, 250sqm)*, ***UK*** *(Newcastle)*
- **Zero** Bank Loans and Open Accounts to Suppliers
- **Fully licensed** operation for the production and recycling of catalytic systems

MONOLITHOS is an SME located in Athens, Greece



Scientific Achievements

- 5 European **patents**
- 30 peer-reviewed **scientific publications**
- 4 **PhDs** partially conducted in **MONOLITHOS**
- 4 **Meng Thesis** conducted in **MONOLITHOS**
- 50 **Internships** conducted in **MONOLITHOS**

MONOLITHOS in Research & Innovation

Nano-catalysts Development

Emissions Control Catalysts

V·E·R·A

Funded by the European Union

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 101056893

CAT4HEAVY

The LIFE CAT4HEAVY project (Grant Agreement no. LIFE17 ENV/GR/000352) has received funding from the LIFE programme of the European Union

Prometheus catalyst

This project has received funding from the European Commission and the European Union's Horizon 2020 Research and Innovation program under Grant Agreement No. 778893

DIAGONAL

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 953152

Funded by the European Union

INNOCAT

Funded by the EIT RawMaterials under the Grant Agreement No. 18344

Electrocatalysts

eCO2FUEL

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 101037389

Funded by the European Union

Non emission nanocatalysts

GEORIS

Funded by the EIT RawMaterials under the Grant Agreement 21107

safevulca

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework programme for Research an Innovation under Grant Aggreement No. 18145

Critical Raw Materials Recovery

Catalysts

Platirus

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Program Under Grant Agreement No. 730224

Funded by the EIT RawMaterials under the Grant Agreement 19148

PHEIDIAS

EBRA

Funded by the EIT RawMaterials under the Grant Agreement 20220

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Funded by the European Union

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 958302

HydroCAT

NSRF 2014-2020

Fuels Cells/Electrolyzers

PROMETH2

Funded by the European Union

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 862253

This project is supported by the Clean Hydrogen Partnership and its members under Grant Agreement No. 101111784

HERACLES

Funded by the European Union

LYDIA

Funded by the EIT RawMaterials under the Grant Agreement 22019

Batteries

CROCODILE

This project has received funding from the European Union's EU Framework Programme for Research and Innovation Horizon 2020 under Grant Agreement No. 776473

Funded by the EIT RawMaterials under the Grant Agreement 22020

ReLiFe

RECYCLING LITHIUM FERROPHOSPHATE

ReLi-ion

BATTERY RECYCLING

Funded by the EIT RawMaterials under the Grant Agreement 21113

Permanent magnets

UDysCovery

Funded by the EIT RawMaterials under the Grant Agreement 21028

Electronic waste

WEEE NET9

Funded by the EIT RawMaterials under the Grant Agreement 21115

Mining Tailings

EXPOMINE

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 873149

Robotics/AI pre-processing

CRUSADE

Funded by the European Union

This Project Has Received Funding From The European Union's Horizon 2020 Research And Innovation Programme Under Grant Agreement No. 101138642

Training

ChemPGM

Funded by the European Union

The project leading to this application has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007669

EXP SKILLS:REM

Funded by the EIT RawMaterials under the Grant Agreement 21104

3RW LU DRZ

ΕΣΠΑ 2014-2020

3D Briefcase of mineral applications

Funded by the EIT RawMaterials under the Grant Agreement 19010

HydroMetEC

Funded by the EIT RawMaterials under the Grant Agreement 19033

CO2MPRISE

Funded by the European Union

This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie Grant Agreement No. 734873

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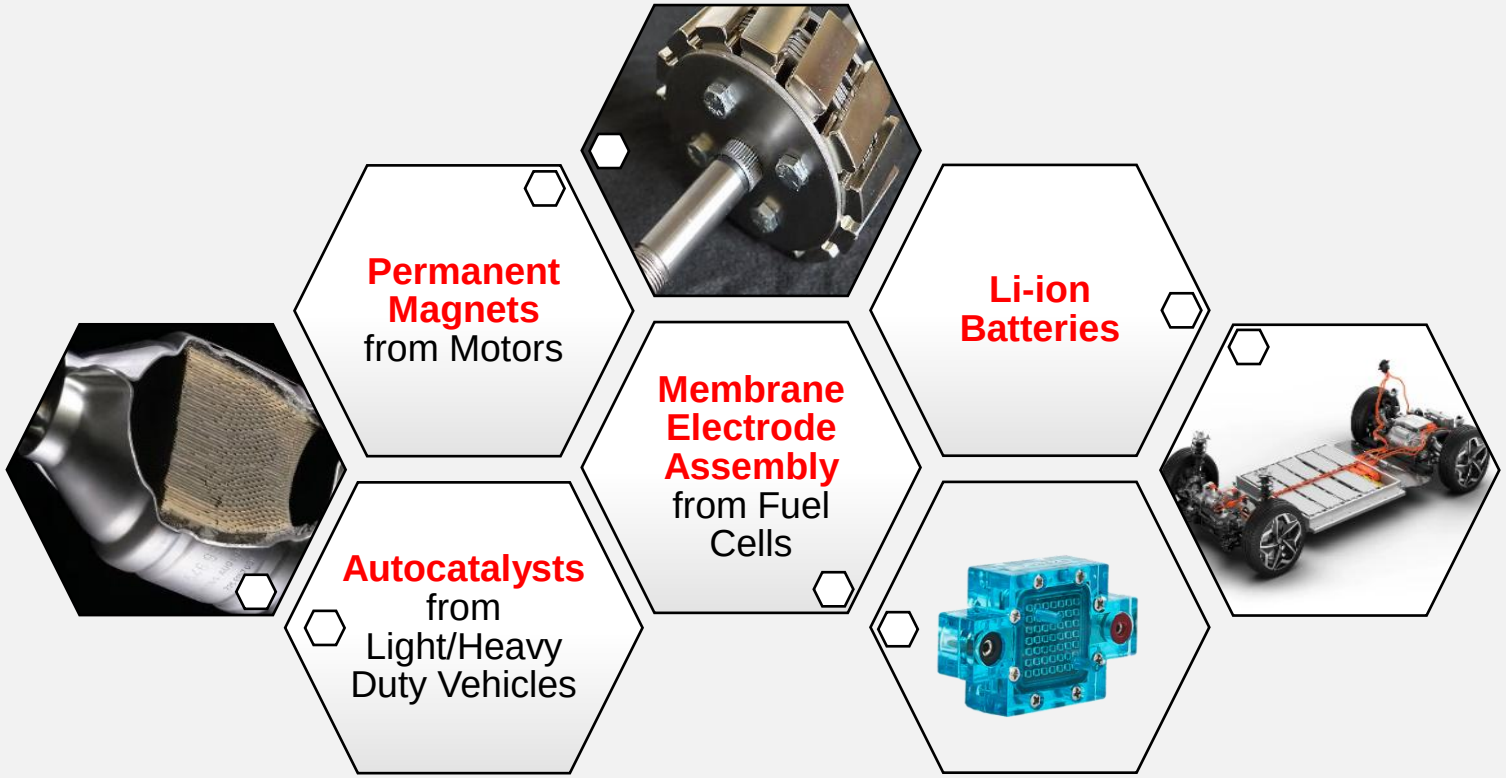
MONOLITHOS: Pioneering Sustainable Recycling via Chlorine Hydrometallurgy Pilot before Peacoc

Automotive parts containing C(S)RMs



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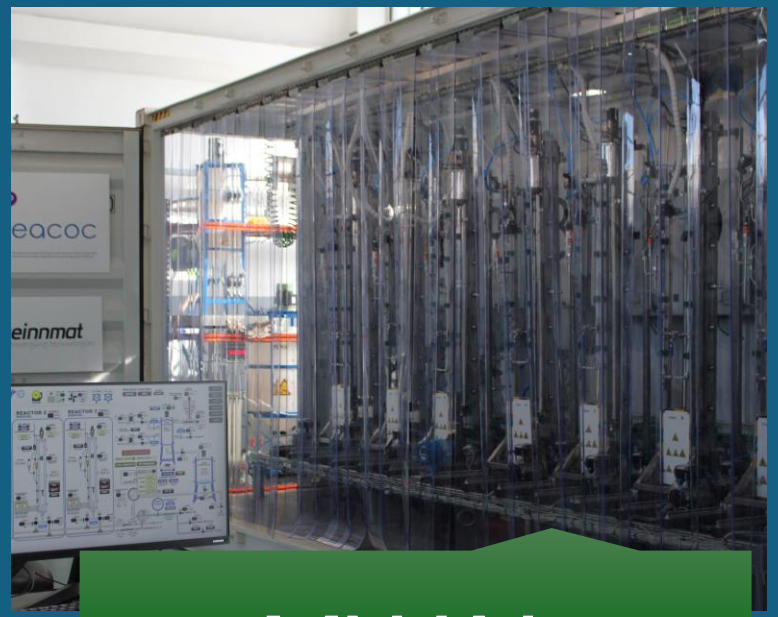
The PEACOC pilot unit



MWAL

- ✓ 7 reactors with microwave heating
- ✓ Automated feeding of reagents/EoL materials
- ✓ Complete control of the unit from the software

Filtration

- ✓ Settling function before filtration
- ✓ 2 filter units with possibility to add more
- ✓ Automated process via platform control

GDEx

- ✓ 6-cell stack
- ✓ Continuous mode GDEx reactor
- ✓ Selective recovery of PGMs

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The PEACOC pilot unit - MWAL

In the first step of the PEACOC pilot, the MWAL unit carries out the leaching of end-of-life (EoL) materials using acidic solutions under microwave-assisted heating and pressurized conditions. This method significantly reduces the leaching time required to achieve high metal recovery yields.

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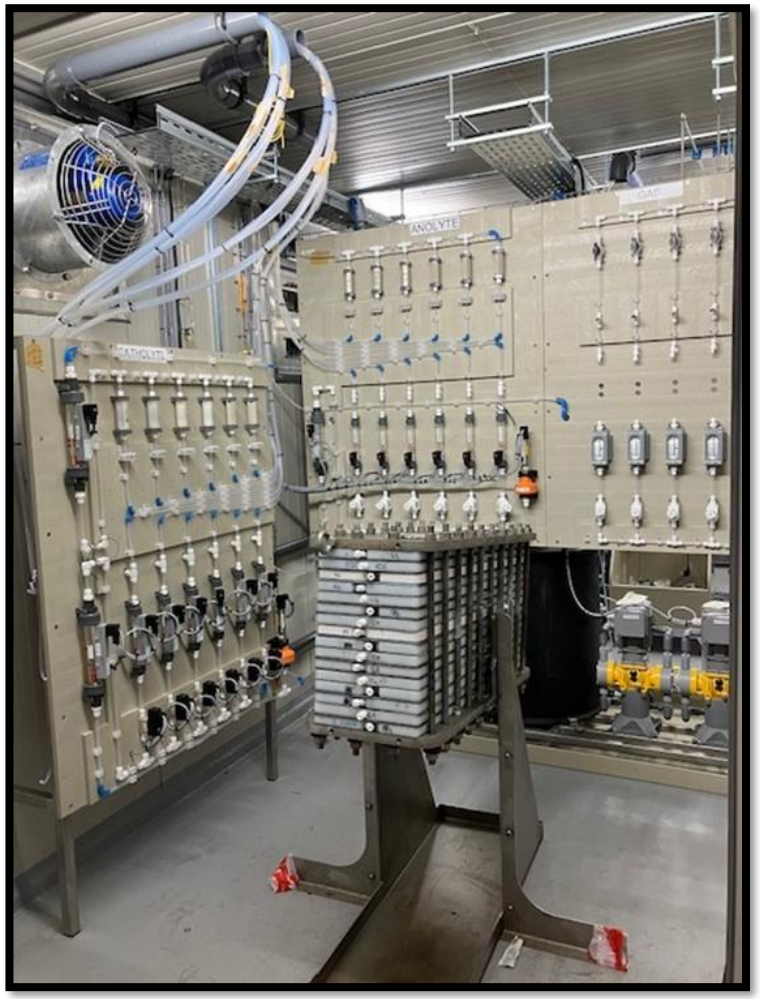
The PEACOC pilot unit - Filtration

In the second step of the PEACOC pilot, the filtration unit employs a settler as the initial stage of separation. After a designated settling period, the overflow leachate solution is transferred to the filters to ensure the successful recovery of the leachate without any solid particulates.

The PEACOC pilot unit - GDEx



In the third and final step of the PEACOC pilot, the leachate solution is directed to the GDEx unit, where high-purity metals are recovered with excellent yields. The GDEx unit employs the Gas-Diffusion Electrocrystallization process, which facilitates metal recovery from aqueous solutions by inducing their precipitation through the in-situ generation of reactive species at gas-diffusion electrodes.

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The PEACOC pilot unit

3 different EoL **streams** will be processed and demonstrated within PEACOC

Automotive catalysts

Photovoltaic scrap

PCBAs

Microwave-Assisted Leaching

Filtration

Electrocrystallization (GDEx)

High purity metals with commercial value

The pilot consists of 3 inter-connected containers.

Each container integrates a different cutting-edge technology.

Designed for flexible operation in batch or continuous mode.

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The PEACOC pilot unit – Autocatalysts stream

Pilot scale autocatalysts preprocessing unit

Process capability of **100 full scale catalysts per hour** (equivalent to 75kg of spent cordierites per hour, ie 3tns per week).

Efficient comminution as it can **crush and grind the spent autocatalysts** (<2mm) into powder to increase of the surface are for subsequent processing steps

High-specification **dust extraction unit** that prevents escape of dust to the elements ensuring the maximum possible recovery of PGMs

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The PEACOC pilot unit – Autocatalysts stream

EoL TWC autocatalyst → MWAL unit → Filtration unit → Leachate solution containing PGMs

EoL TWC catalyst	1.5M HCl	1.5M NaCl	10% S/L	180 ºC, 8.5 bar

Testing conditions

First test using real stream (EoL TWC) was successfully completed

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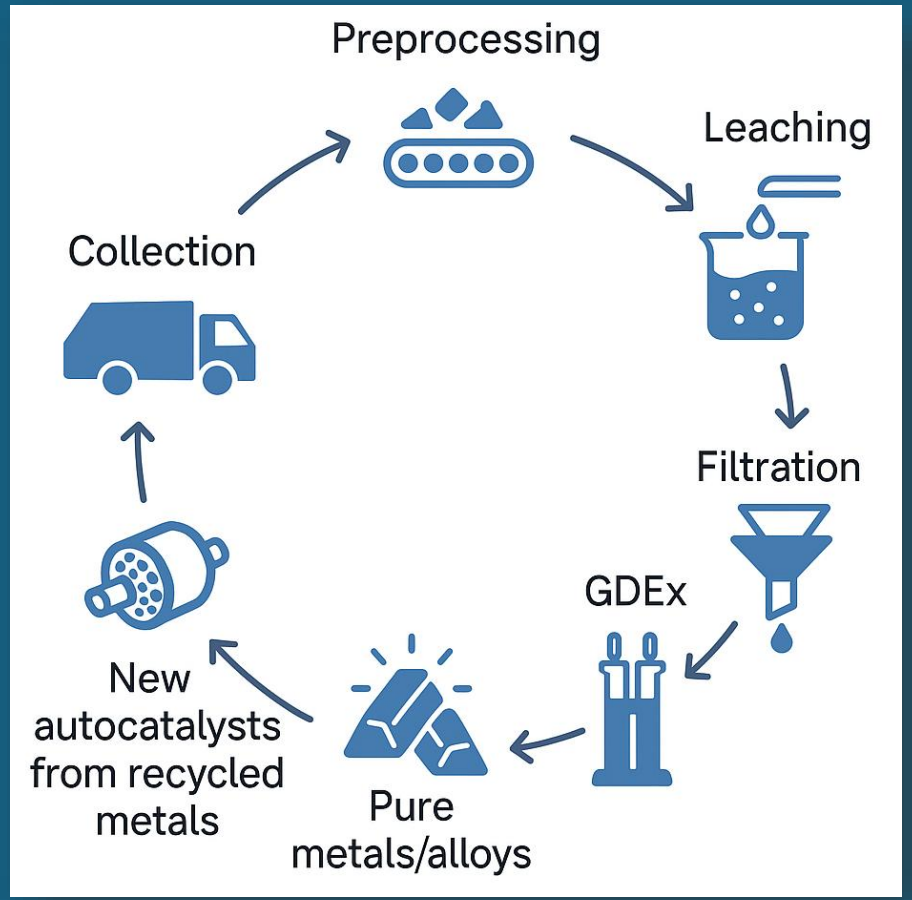
The PEACOC pilot unit – Autocatalysts stream

Circular economy concept



Monolith Preparation

Placement in metallic cannister

Catalyst Validation

TWC autocatalysts

STELLANTIS | CRF

DOC autocatalysts

FORD OTOSAN

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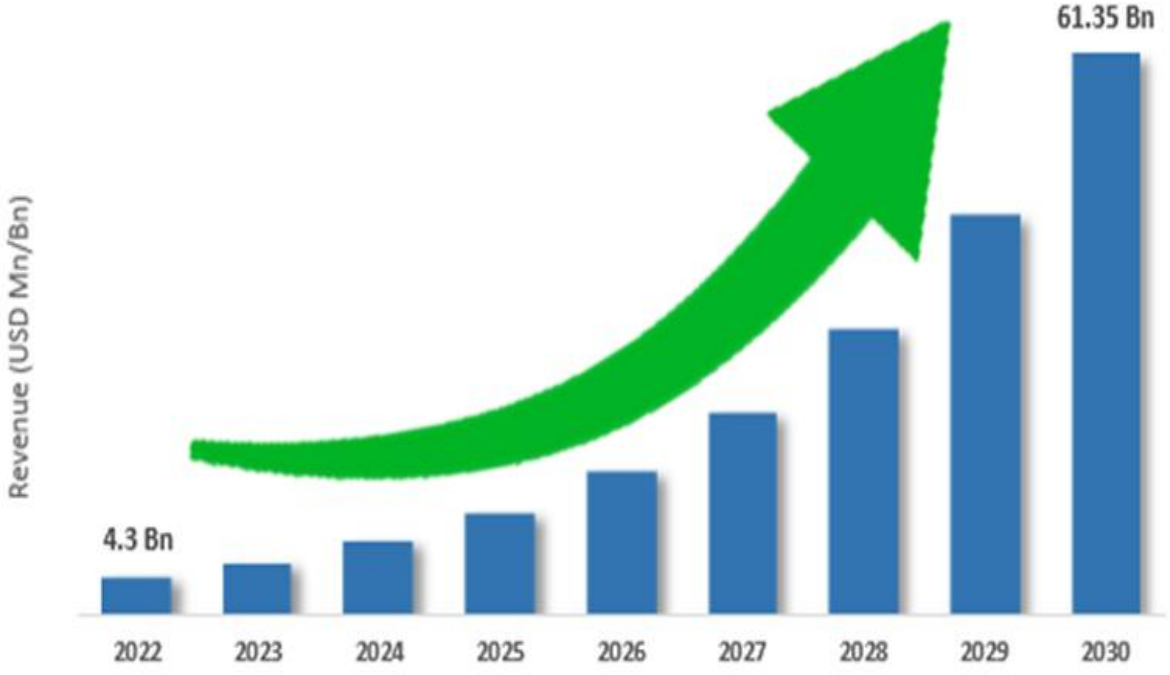
1st Future Challenge for Peacoc Pilot
Hydrogen devices recycling: A sustainable challenge and opportunity

Growing use of hydrogen technologies → Increased EoL/spent materials

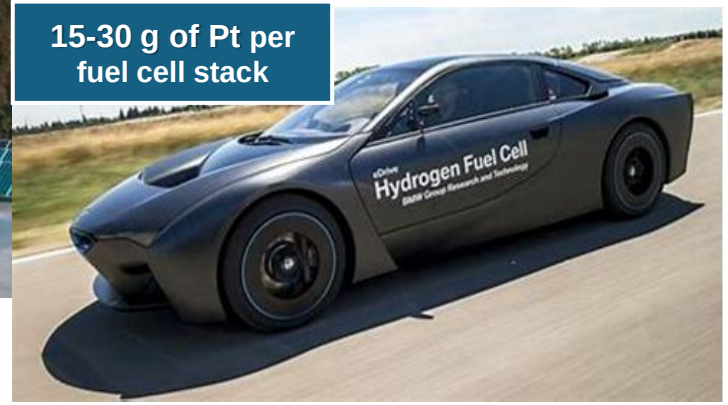


https://www.zionmarketresearch.com/report/green-hydrogen-market

Global Green Hydrogen Market 2030

1-3 g of Pt and 2-4 g of Ir/Ru per kW of electrolyzer

15-30 g of Pt per fuel cell stack



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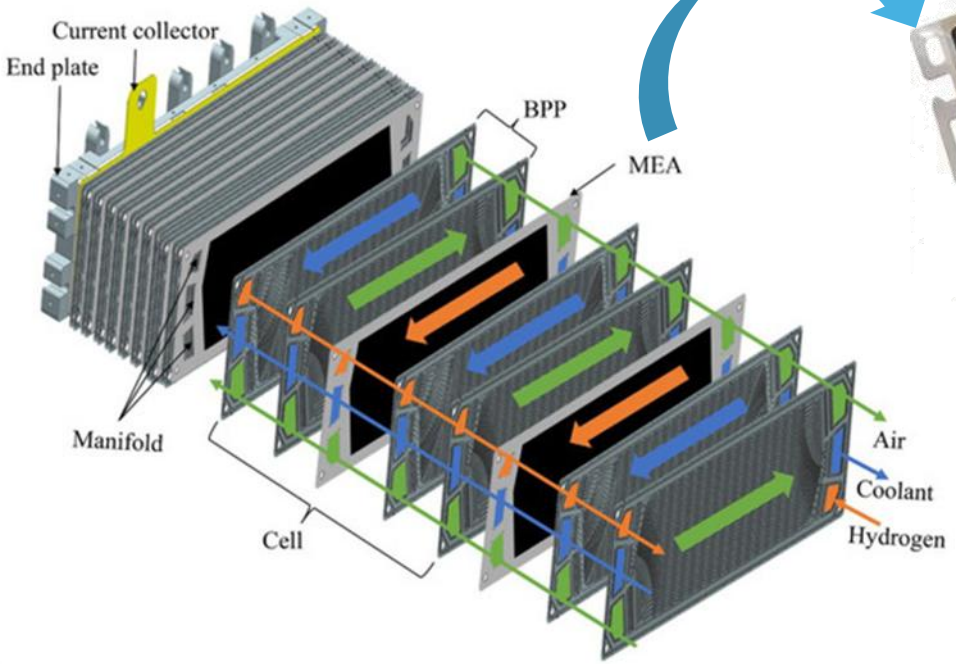
Hydrogen devices recycling: MON's chlorine hydrometallurgy



EoL MEAs

Key component of hydrogen devices:

Membrane electrode assembly (MEA) consists of CRMs such as Platinum, Iridium, Nickel, Cobalt, etc.

Mild conditions

HCl (2-4M)
Cl^- (2-5M)
H_2O_2 (1-3%)

<80°C, <4h

Leaching yields

>99% Pt, Ni, Co

>60% Ir

MONOLITHOS chlorine hydrometallurgical leaching method

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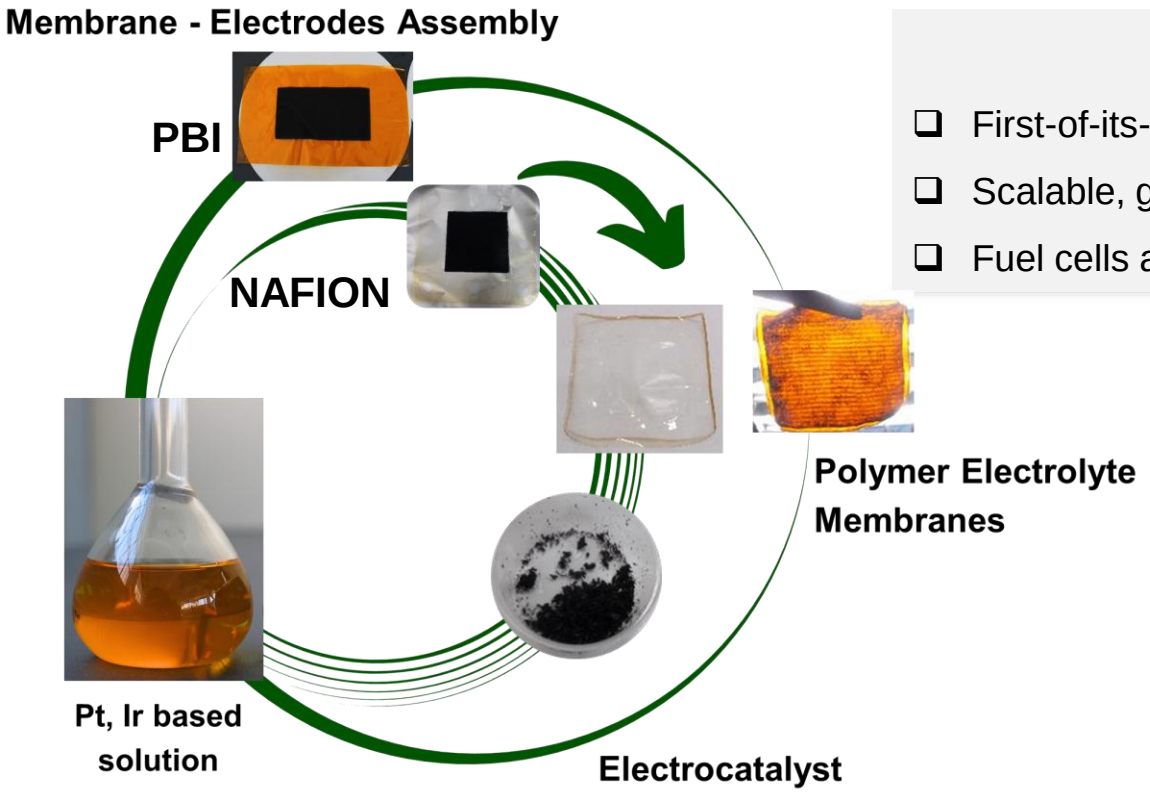
Hydrogen devices recycling: Microwave pilot plant for leaching



MONOLITHOS VISION

- ❑ First-of-its-kind pilot plant for hydrogen device recycling
- ❑ Scalable, green and cost-effective recycling process
- ❑ Fuel cells and electrolyzers recycling sustainable at scale

Selective valuable metals recovery

Strong metal-metal and metal-support interactions contribute to slow leaching kinetics

Modular setup for treating different hydrogen device components (e.g. spent catalytic layers)

Closing the loop on critical and strategic raw materials

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2nd Future Challenge for Peacoc Pilot
Rare Earth Elements (REEs) recycling from Permanent Magnets

Separation
Rare earth oxides

Mining and extraction
Rare earth ores
e.g. bastnaesite

Processing and Refining
REEs metals & alloys

Permanent magnets
on electric vehicles
1.7kg NdPr

Wind turbines
150kg NdPr/MW

EoL permanent magnets

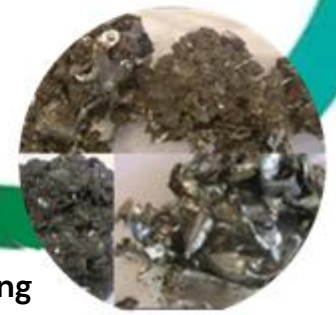
REEs and Co oxides

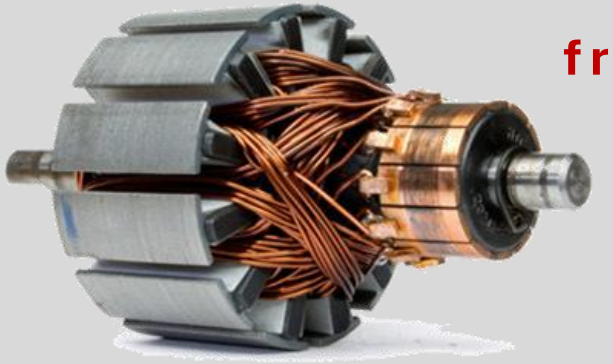
Leaching/ Extraction

Circular Economy Approach

Collection

Preprocessing





CRMs recovered from permanent magnets

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MONOLITHOS hydrometallurgical recycling of REEs

Spent material


Defected magnets


Heavily oxidized magnets


Magnet sludges

Step 1 Preprocessing

Step 2 Leaching

Step 3 Refining

Step 4 Metals recovery

Final product

- Safe pre-processing via dry and wet milling
- >99% Fe removal from leachates
- >90% recovery of REEs
- High-purity recycled materials

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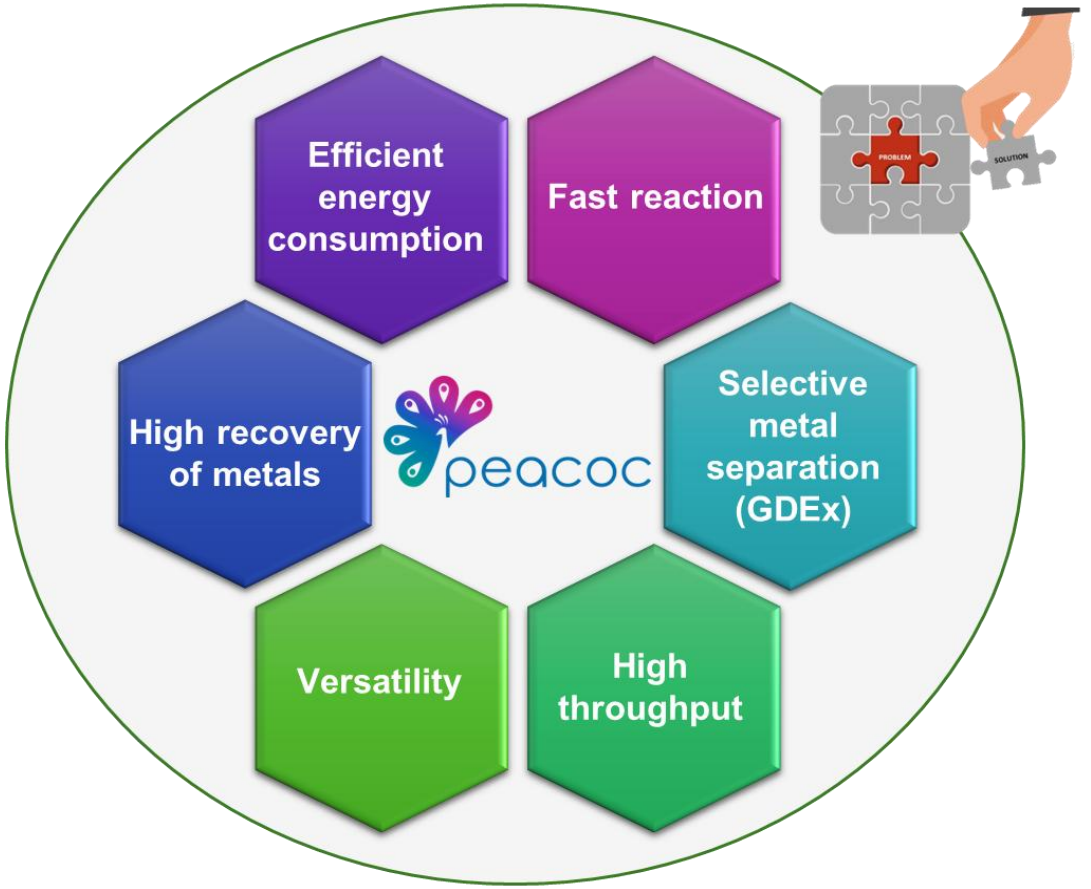
Challenges and opportunities in magnet recycling

Key challenges in the hydrometallurgical upscale recycling of permanent magnets for REEs recovery

- *Impurity Management and Selectivity*
- *Impurity Management and Selectivity*
- *Process Efficiency and Yield*
- *Economic Viability and Material Handling*



PEACOC process can elevate REEs hydrometallurgical recycling

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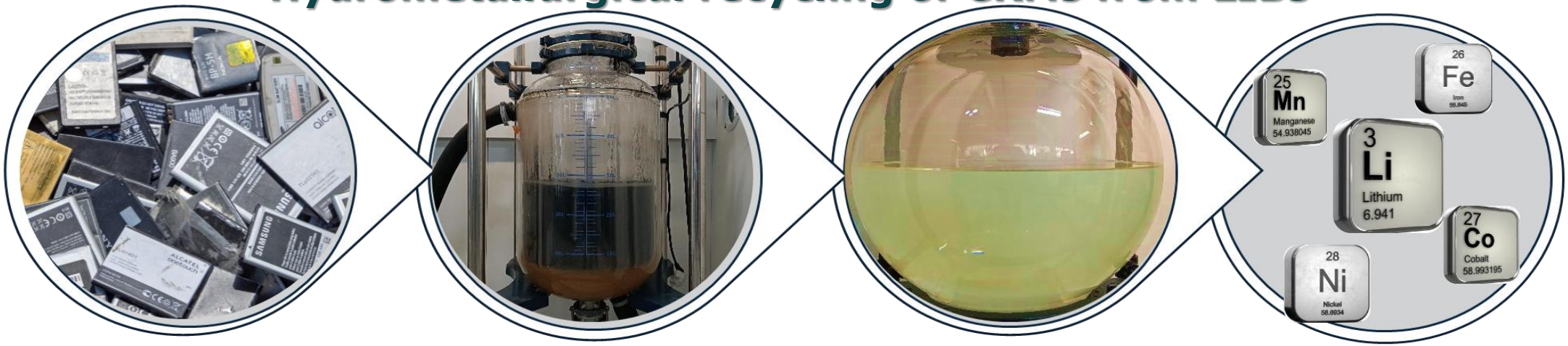
3rd Future Challenge for Peacoc Pilot: Hydrometallurgical recycling of CRMs from LIBs

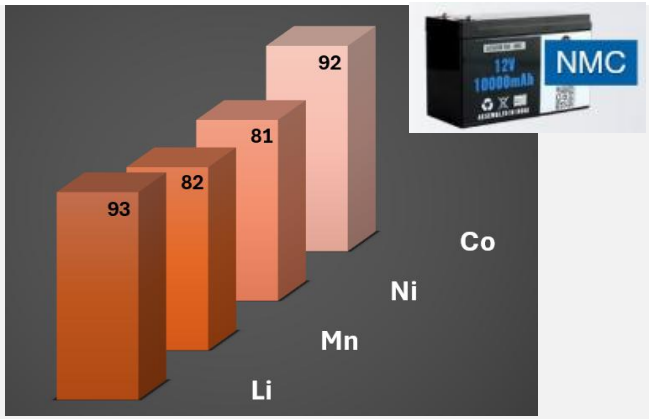


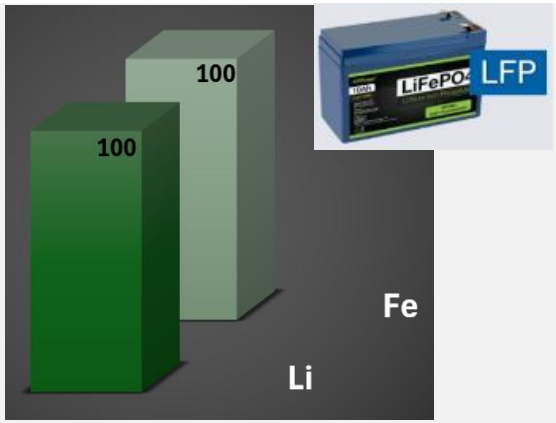
Black mass from EoL Li-ion batteries

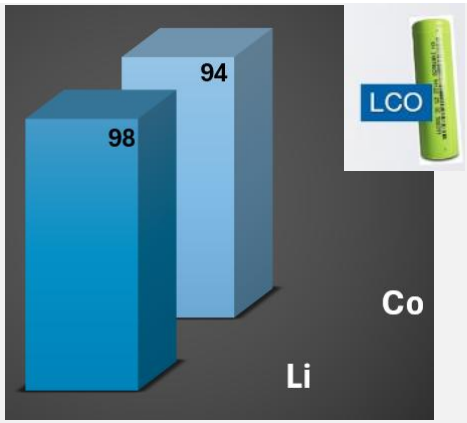
MONOLITHOS chlorine hydrometallurgy

Extraction/purification

Recovery & reuse of CRMs







Recovery rates

- ✓ >99% Li, Fe
- ✓ >80% other CRMs

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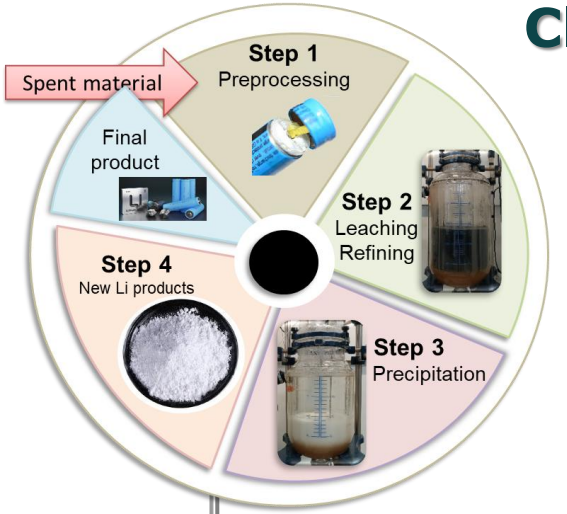
Closing the loop in LIBs recycling: the LFP case

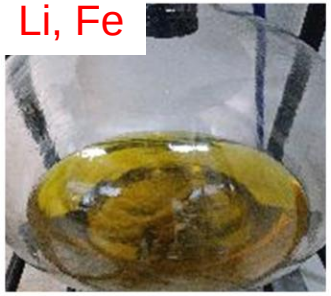


LFP
black mass

Leaching

HCl based solution containing Li and Fe

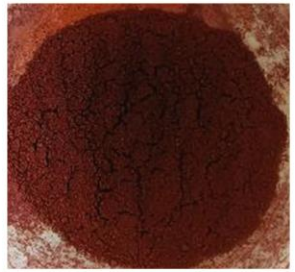
100% Li



Purification

Purified leachate

Fe recovery



Precipitation

>80% of Li is recovered as Li_3PO_4 or Li_2CO_3

Li_3PO_4/Li_2CO_3

New LIBs production

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PEACOC pilot for CRMs recovery from LIBs

Complex Composition of LIBs Requires Selectivity

- Selective leaching of metals using tailored reagents
- Sequential separation of metals via **solvent extraction, ion exchange**, or **precipitation**.
- Adaptability to varied LIB chemistries (LCO, NMC, LFP, etc.).

Microwave-Assisted Leaching: Enhancing Efficiency

- **Enhanced reaction kinetics** and reduced leaching time.
- Improved **selectivity and efficiency.**
- Lower **energy consumption** due to direct coupling with polar molecules/ solvents.

Gas-Diffusion Electrocrystallization (GDEx): Green Metal Recovery

- **Reduce metal ions electrochemically** (e.g., Co^{2+} to Co, Mn^{2+} to MnO_2)
- Enable **nucleation and controlled crystallization** of pure metal phases or oxides directly from leachates.

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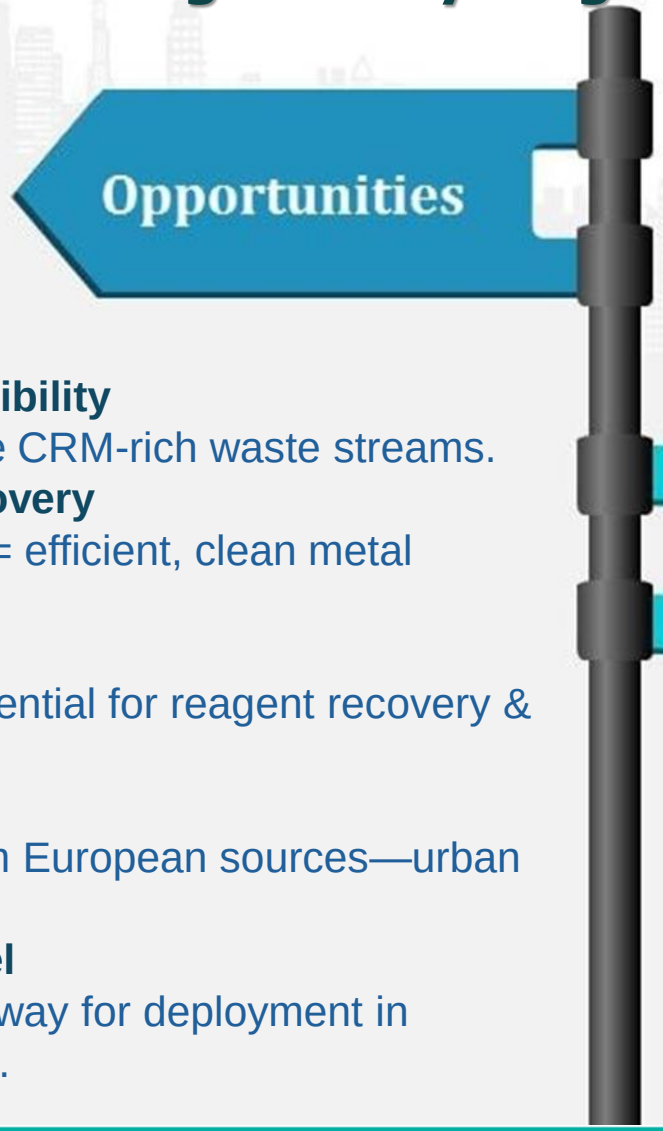
Hydrometallurgical recycling of PGMs from spent ACCs



Opportunities for Impact

- **Modular, Multi-Material Flexibility**
  One platform handles multiple CRM-rich waste streams.
- **Selective, Low-Energy Recovery**
  Microwave leaching + GDEx = efficient, clean metal separation.
- **Near-Zero Waste Vision**
  Closed-loop systems with potential for reagent recovery & valorization of residues.
- **Strategic Autonomy for EU**
  Strengthens CRM supply from European sources—urban mining over mining imports.
- **Scalable & Replicable Model**
  Pre-industrial success paves way for deployment in recycling hubs across Europe.

Challenges at Pre-Industrial Scale

- **Heterogeneous Feedstocks**
  Variability in composition and contaminant load.
- **Process Optimization**
  Need to fine-tune leaching, separation & GDEx conditions for industrial consistency.
- **Throughput vs. Selectivity Trade-offs**
  Maintaining high purity and recovery rates at higher volumes.
- **Logistics & Supply Chain**
  Collection, sorting, and pretreatment of diverse e-waste streams.

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