



RHINOCEROS: advances towards upscaling

Cluster Hub Materials for Batteries

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20/11/2025



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RHINOCEROS: Batteries reuse and direct production of high performances cathodic and anodic materials and other raw materials from batteries recycling using low cost and environmentally friendly technologies

GRANT AGREEMENT NO: **101069685**

COORDINATOR: **FUNDACIÓN TECNALIA RESEARCH & INNOVATION**

PARTICIPANTS:

 **17 PARTNERS FROM 9 COUNTRIES:**



DURATION:

01/09/2022 TO 30/08/2026



PROJECT BUDGET:

EUR 8.9 MILLION



Cluster Hub Materials for Batteries 2025



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RHINOCEROS – Main Objectives



-To DEVELOP A SMART SYSTEM FOR AUTOMATED CLASSIFICATION, DISMANTLING AND REASSEMBLING OF LIBS , WHICH WILL BE VALIDATED WITH 60% GAIN IN DISASSEMBLY/ASSEMBLY TIME COMPARED TO SoA MANUAL OPERATIONS, AND AUTOMATING THE CURRENT MANUAL OPERATIONS BY UP TO 75%.



-To DEVELOP A SET OF COST EFFICIENT, FLEXIBLE AND ENVIRONMENTALLY FRIENDLY ROUTES TARGETING THE RECYCLING OF ALL MATERIALS PRESENT IN LIBS – TARGET >95% OF ACTIVE MATERIALS AND BASE METALS AND >90% ELECTROLYTE, PE/PP AND FLUORINATED COMPOUNDS



-To IDENTIFY AND ADDRESS HEALTH RISKS, ENVIRONMENTAL IMPACTS, SAFETY HAZARDS AND NEW SAFETY PRACTICES

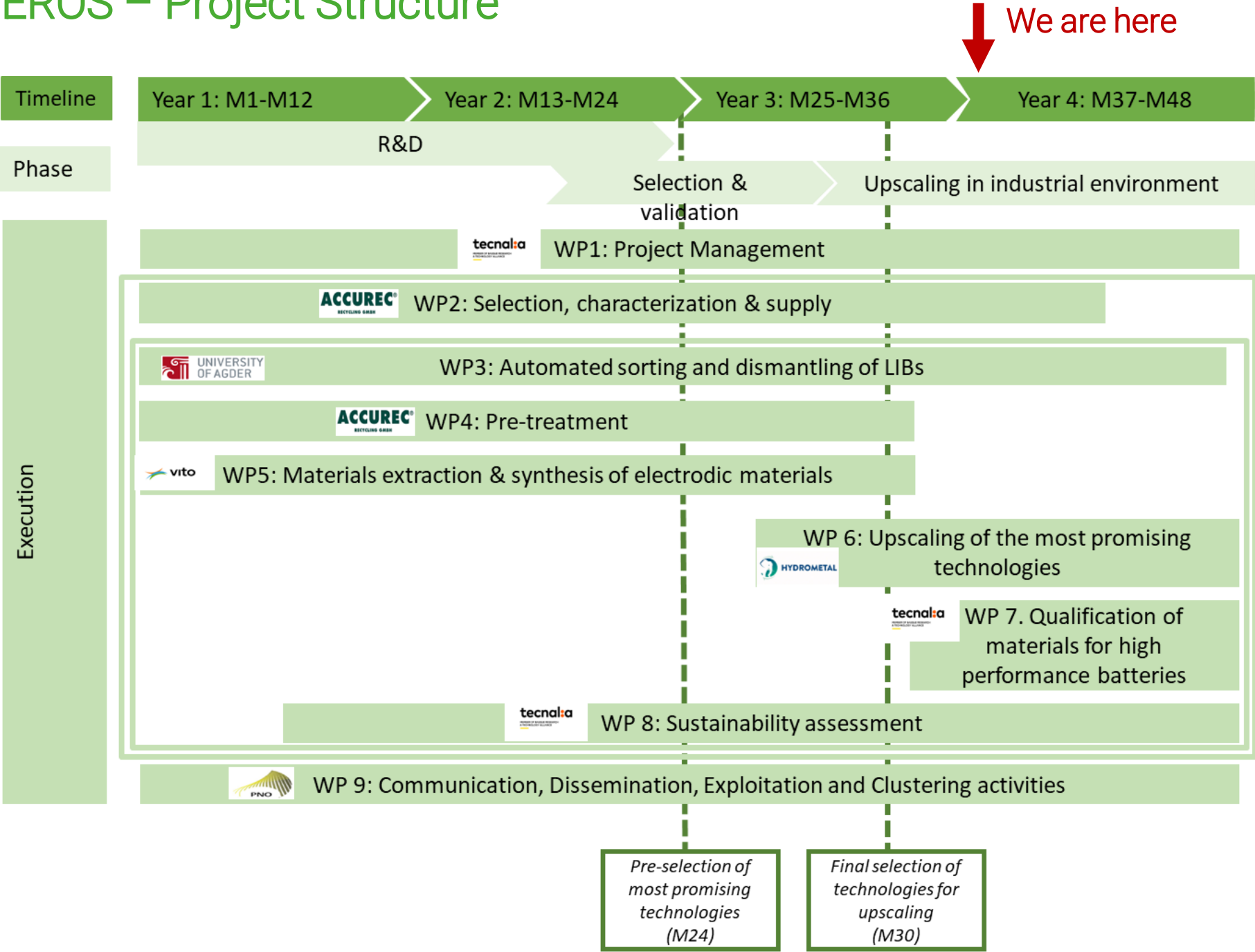


-To VALIDATE THE RECOVERED MATERIALS THROUGH THE SYNTHESIS OF NEW HIGH-PERFORMANCE ELECTRODES AND ELEMENTS FOR NEXT GENERATIONS BATTERIES ABLE TO SATISFY THE TARGETED 2030 BATTERY PERFORMANCES FOR EV BATTERIES

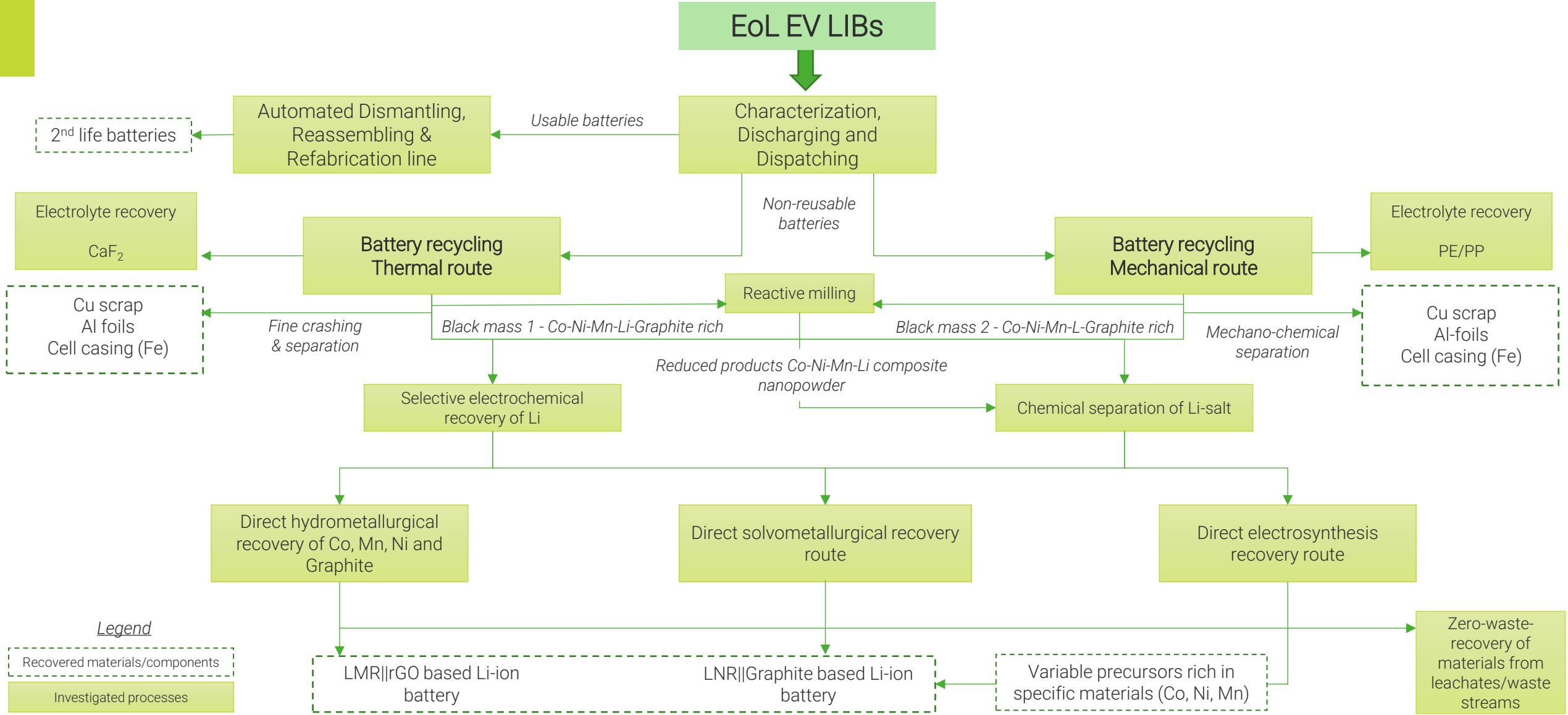


-To VALIDATE THE MOST PROMISING PROCESS AT PILOT LEVEL (TRL UPGRADING TO TRL6)- 10KG ELECTRODE MATERIALS/DAY, 1KG/DAY ELECTROLYTE, FLUORINATED COMPOUNDS AND POLYMERS

RHINOCEROS – Project Structure



RHINOCEROS – Concept

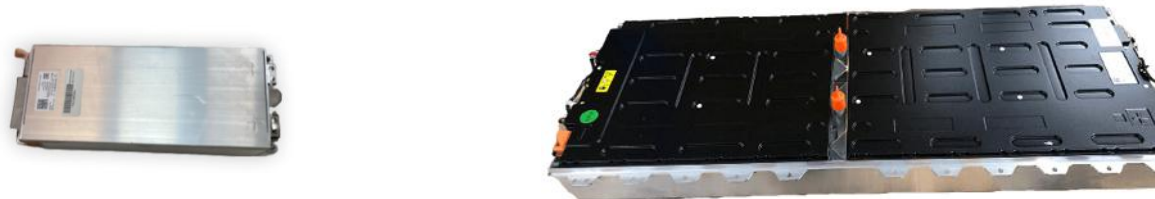


RHINOCEROS – Second Life

BEV BATTERIES FOR 2ND LIFE: ACCEPTANCE AND DISMANTLING CRITERIA

- Database has been compiled with 200 commercial and passenger EV vehicles.
- Recognition criteria for State-of-Art manual dismantling developed by Watt4Ever and ACCUREC.
- The necessary **acceptance criteria** to help selecting the best modules for 2nd life BESS applications have been identified:
 1. **State of Health**: any battery module that has at least 80% of the original capacity after 3 charge-discharge cycles and stable cell balance should be reused in BESS.
 2. **Parameters for 2nd Life**: after classification between Low (LV) and High Voltage (HV) systems are the following:

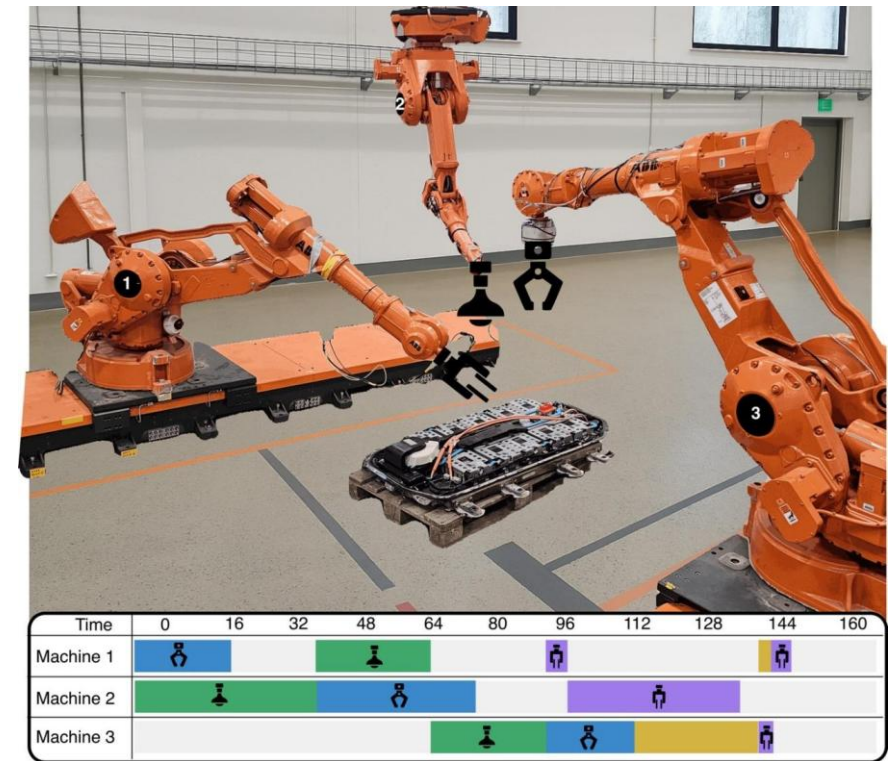
Module size – Capacity – Cell Amount – Cell Management Unit (CMU) – Power Terminals



RHINOCEROS – Robotic dismantling

BEV BATTERIES FOR 2ND LIFE: ACCEPTANCE AND DISMANTLING CRITERIA

- The **University of Adger** has developed a **robust methodology** that integrates a digital simulator along with an algorithm that automatically generates the **Disassembly Process Plan [DPP]** for batteries which also targets to reduce the total disassembly process duration.
- Reinforcement learning algorithms applied:
 - Proximal Policy Optimisation (PPO)
 - Q-learning with Tsetlin Machines (QTM)
 - Classic deep Q-learning.



RHINOCEROS – Pre-treatment optimisation

TES – MECHANICAL ROUTE FOR BLACK MASS PROCESSING

- TES has optimised its process with a pre-drying step to minimise solvent residues and enhance delamination and separation efficiency:
 - Electrolyte recovery rate: > 95 %
 - Polymer (cell) separation rate: > 80 %
 - Lithium recovery rate: > 95 %, with the majority retained in the black mass
 - Impurity levels of Cu and Al: < 1 %
- Chalmers University of Technology has developed sc-CO₂ based processes for:
 - Electrolyte recycling: > 95% recovery (>99 % for DMC, EMC, and DEC and 95 % for EC)
 - Polymer (binder) recovery: PVDF dissolution requires extreme conditions. Applying co-solvent+mild conditions achieved > 55% PVDF recovery rate.

RHINOCEROS – Pre-treatment optimisation

ACCUREC – THERMAL ROUTE FOR BLACK MASS PROCESSING

- ACCUREC has **optimised vacuum pyrolysis at 550°C**, which enabled the complete **decomposition** of PVDF, for effective removal of binders and separators from LIB waste, while **recovering fluorinated compounds** through HF capture with two routes:
 - Potassium hydroxide [KOH] washing (producing potassium fluoride [KF])
 - Calcite filter --> solid fluoride filter, producing CaF.

KARLSRUHE INSTITUTE OF TECHNOLOGY – BLACK MASS METALLIZATION FOR LI RECOVERY

- KIT researchers applied their **reactive milling** on the BM provided by TES to reduce the cathode material to its metallic form and produce water-soluble lithium salts, **achieving full metallization**.
- The process was optimized using **three types of mills** [two planetary mills of different sizes and a SPEX shaker mill], and studying **three types of reagents: Al, Mg and Ca**.
- Further experiments are needed to scale up the process and ensure that it can be applied to larger batches.

RHINOCEROS – Recovery of cathode active materials

HYDROMETALLURGY UNIVERSITY OF SAPIENZA

- Production of **LMO** from black mass.
- **GO** as recovered **anode material** with low yield but with high purity (>99%).
- **Nearly 100% leaching efficiency Ni, Co, Mn**; with both high precipitation yield and purity.
- Based on Hummer's Method: **Safety considerations** concerning the use of KMnO_4 on scaling up.

SOLVOMETALLURGY TECNALIA

- Production of **NMC** from black mass.
- **>95% leaching efficiency for Ni, Co, and Mn**. High precipitation yield and purity.
- **Graphite** is recovered with high yield, with chemical purification applied afterwards.
- Solvometallurgical leaching system **can be regenerated and reused for several cycles**.

GAS DIFFUSION ELECTROCRYSTALLIZATION - VITO

- Direct recovery route **tested on both synthetic and real leachates** from BM.
- **Chemistry** of obtained products can be **tailored** just by process parameter control.
- **Applied to solvometallurgical leachates:**
 - High recovery yield on secondary metals.
 - Low purity.
- **Applied to UoS Hydrometallurgy leachates:**
 - Low recovery yield
 - High precipitate purity

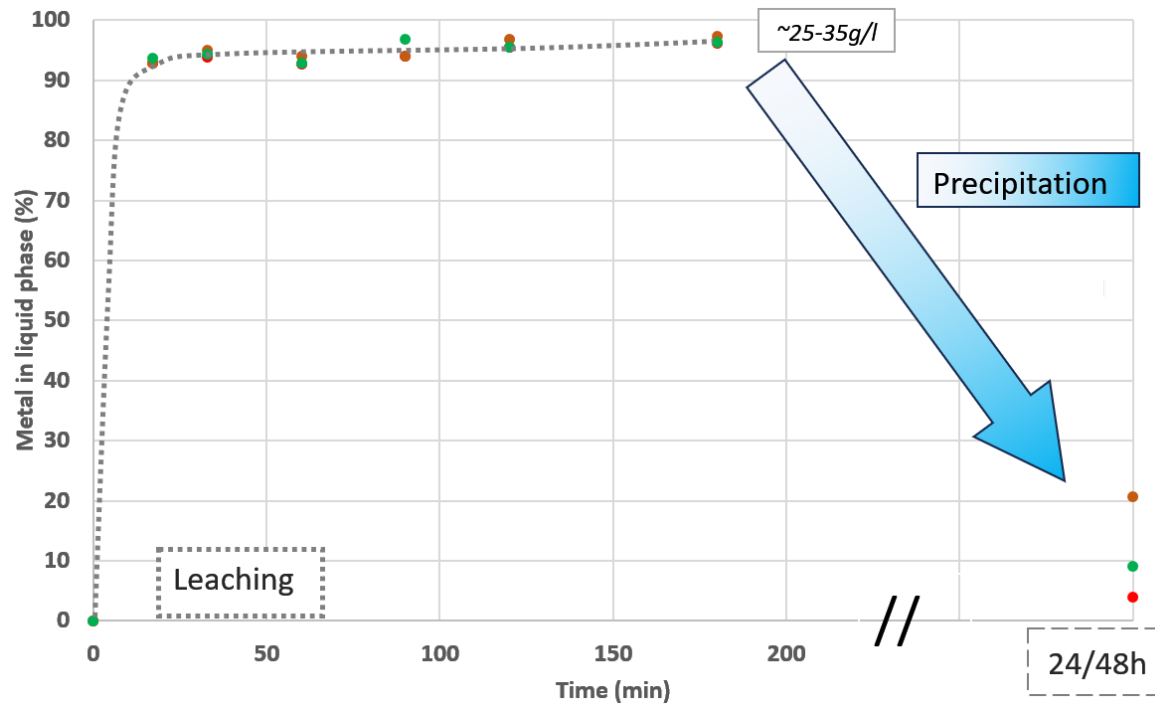


RHINOCEROS – Materials Extraction Upscaling

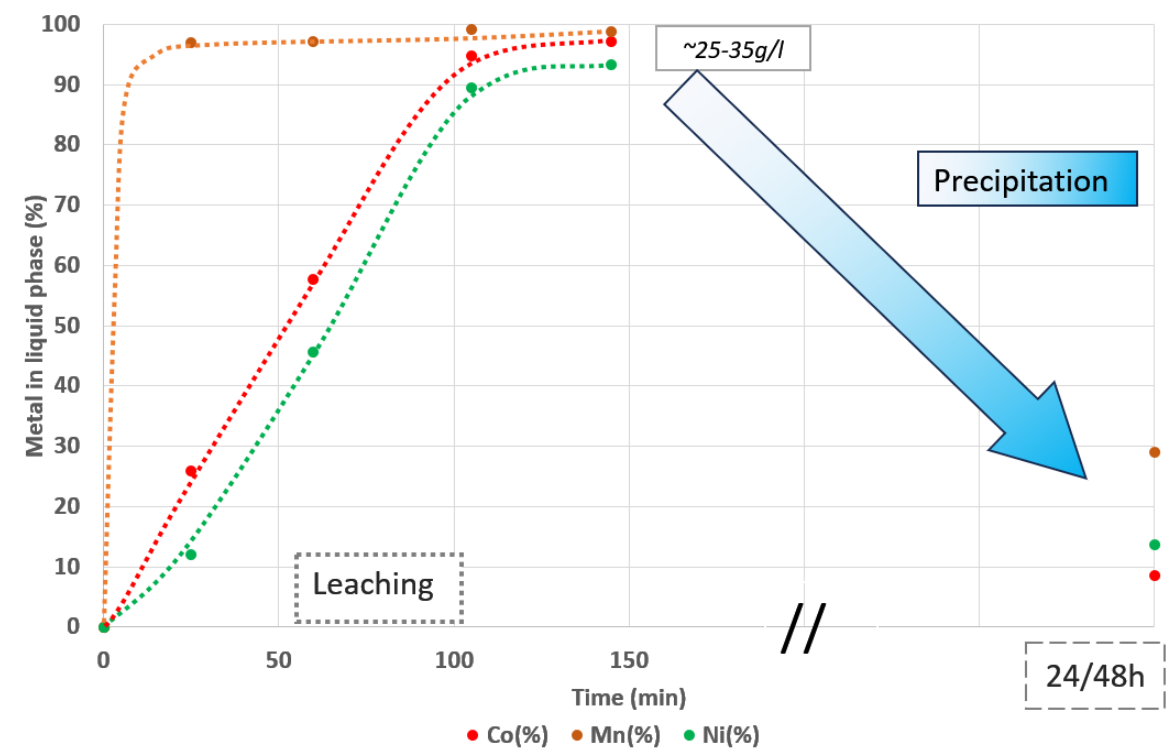
PROCESS SELECTION OUTCOME: SOLVOMETALLURGICAL ROUTE



MECHANICAL



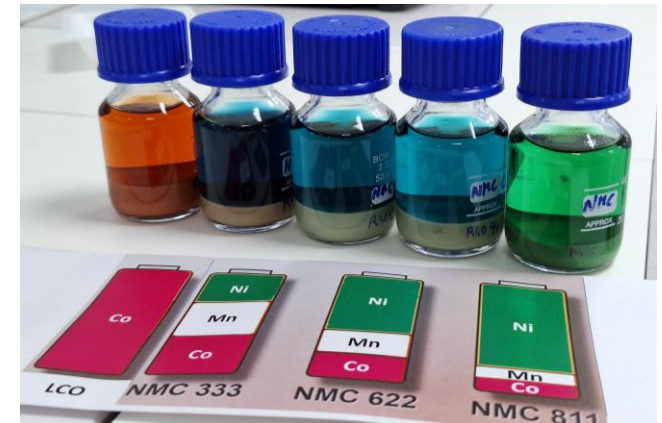
THERMO MECHANICAL



RHINOCEROS – Recovery of cathode active materials

SOLVOMETALLURGICAL PROCESSING OF RHINOCEROS BLACK MASS - RESULTS

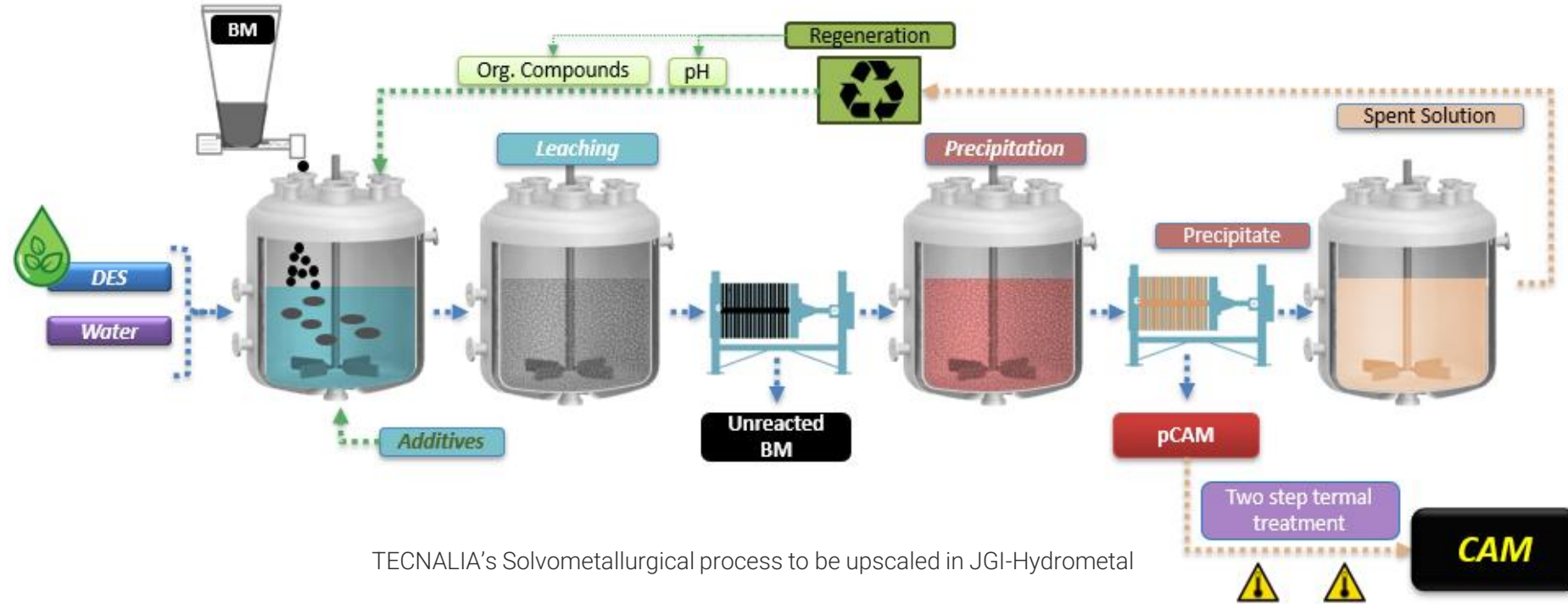
- DES-based solvometallurgical system developed for NMC black mass
 - >95% leaching efficiency on critical metals
 - >60% precipitation yield
 - Applicable to both mechanical, thermomechanical and mecanochemical pre-treated black mass with the appropriate selection and dosing of additives
 - Product as mixed metal organic precipitate with >90% purity
 - Coherent leaching behaviour → Minimum modification required to readjust NMC chemistry.
- Circularity by design
 - Two routes developed for leaching system regeneration.
 - Reuse maintaining high leaching efficiency proven for 4 cycles on each system.



RHINOCEROS – Materials Extraction Upscaling

PROCESS SELECTION OUTCOME: SOLVOMETALLURGICAL ROUTE

- The final process for CAM production will be based on TECNALIA's solvometallurgical route applied to BM from thermal treatment.



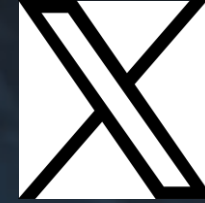
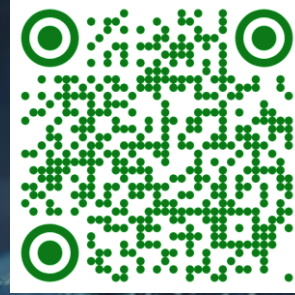
TECNALIA's Solvometallurgical process to be upscaled in JGI-Hydrometal

- JGI-Hydrometal and ECO Recycling will build a pilot plant with a capacity of 10 Kg/day of CAM from recycled black mass.

RHINOCEROS – Next Steps

- On the automated sorting and dismantling of LIBs
 - **DPP integration** into a **digital twin** of the manufacturing environment.
 - **Virtual training simulations** will refine DPP before facing the real-world setup.
- On the upscaling of the recycling routes
 - **Pre-treatment integrated processes** will be defined and verified at larger scale.
 - **ECO RECYCLING** will carry out the detailed engineering design of the pilot plant.
 - **JGI-Hydrometal** will be the responsible for the construction of the pilot plant.
 - **Construction and commissioning** of the pilot plant will follow.





RHINOCEROS EU project

www.rhinoceros-project.eu

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