The 8th RD20 Conference

Accelerating Clean Energy Innovation: From Africa to the World

Resilient Value Chains for the Energy Transition:
A Circular Economy approach on Critical Battery Materials

Stéphanie Riché, Circular Economy of Materials Program Manager, CEA

Agenda

Context and European & French legislation

Critical material demand & offer for batteries

The circular economy approach for batteries

CEA Key Figures

80 years (founded 1945)

+ 22 100
employees

+ 260
start-ups

641
Patents registered
(INPI 2024)

€ 6,4 B
annuel budget
(civil and defence)

+ 700
Industrial partners

+ 4 700
Publications

27	General Motors	United States
28	Foxconn	Taiwan
29	Samsung Electro-Mechanics	South Korea
30	CEA	France
31	Hitachi	Japan

Clarivate™

For the 13th year, in the

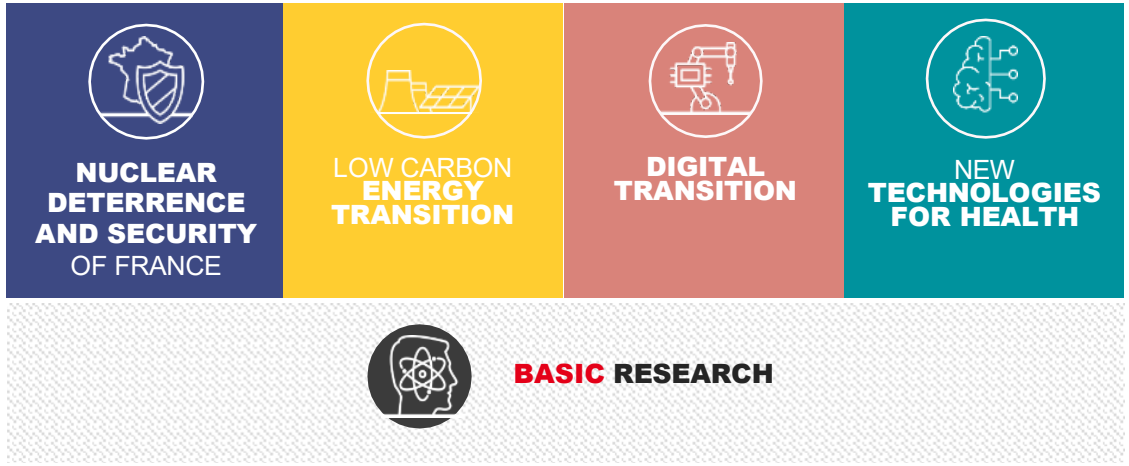
World top 100 innovators

(Ranking 30th – Clarivate 2025)

1st Non-profit Organization

2nd European Innovator

A strategic positioning, focused on four societal challenges



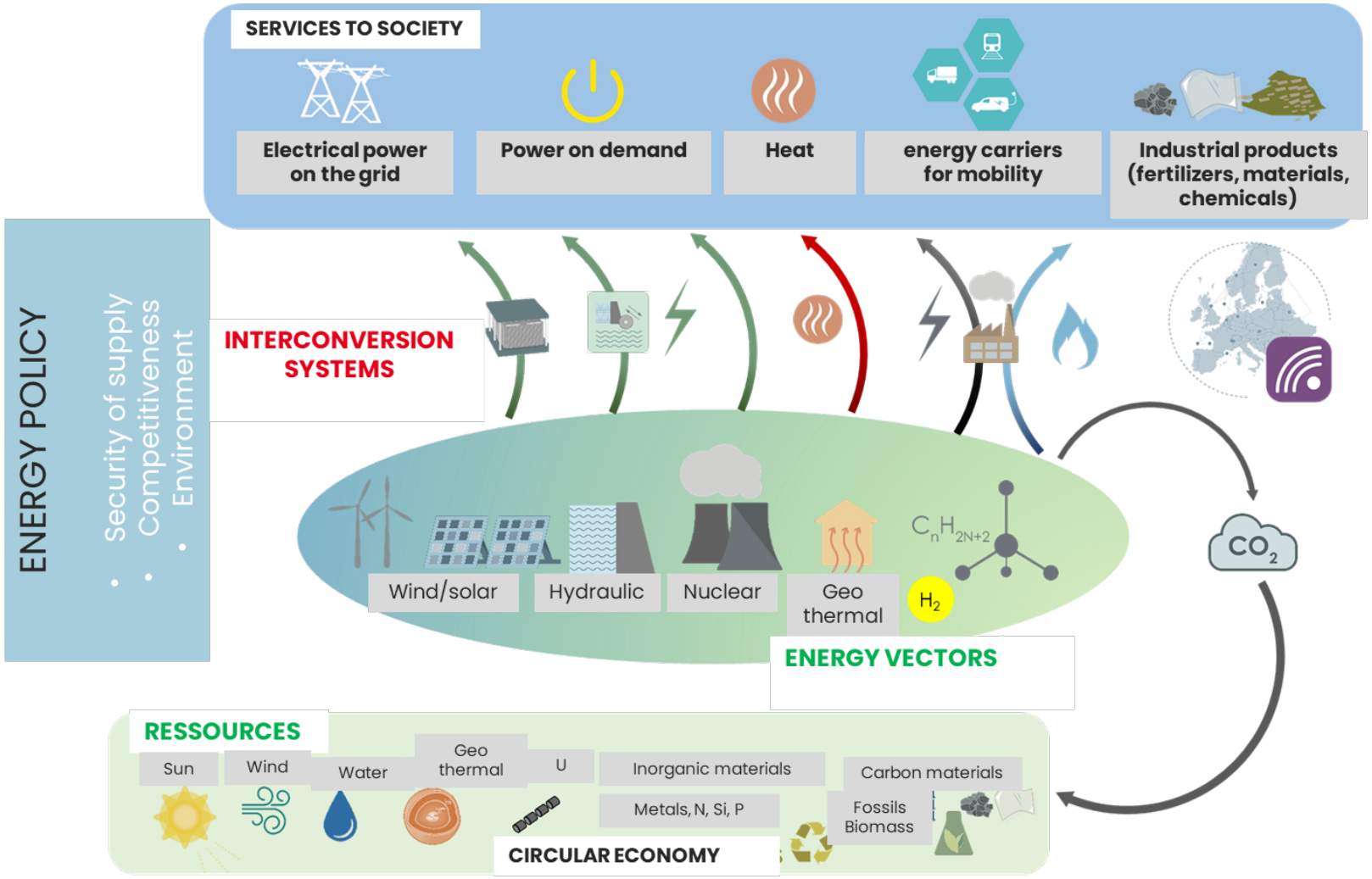
- **SCIENTIFIC AND TECHNICAL OBJECTIVES** organized in 4 areas which all benefit from **BASIC RESEARCH** activities.
- A common priority:

  PROVIDING the industry with **INNOVATIVE TECHNOLOGIES**, to foster its **COMPETITIVENESS.**

CEA'S PURPOSE

"Act to ensure scientific and technological leadership for France and Europe as well as a better controlled and safer present and future for all."

An integrated vision of the energy system of tomorrow to reach a "carbon neutral 2050"



ENERGY SYSTEM

EXECUTION CONDITIONS:

- ✓ Nuclear "convergence" and new energy technologies
- ✓ Technological innovations
- ✓ Industrial & economic models/regulation
- ✓ A societal window (distribution, adhesion and appropriation)

Critical materials for low carbon energy systems at CEA

Solid state & Metal-ion
Li, C, (Si), Cu

Lithium-ion LFP
Li, Fe, P, C, (Si), Cu

Lithium-ion NMC
Li, Ni, Mn, Co, C, (Si), Cu

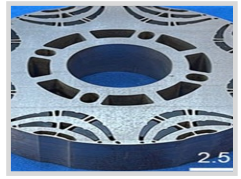


Batteries

Magnets Gen3
RE-free

Magnets Gen2
RE_1Fe_{12}

Magnets Gen1
Nd, Ce, Dy, Tb



Electric machines

Tandem cells
Cu, Si, (Pb), (Sb)

HTJ cells
Ag, In,, Si, (Sb), Cu

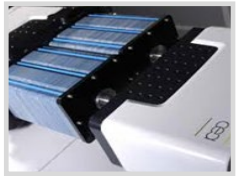
PERC cells
Ag, Cu, In, Si, (Sb), Cu



Solar Panels

Catalyst
(Pt, Co, Ir), Nafion

EHT
Y, Ni, Zr, Co, La, Pr, Mn, Ce, Cu

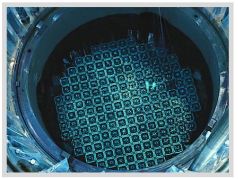


Electrolyzers and fuel cells

Fuel cladding
Zr, Nb, (Ni, Sn, Cr)

Fuel controls
B4C, Hf, Ag/In/Cd

Nuclear plant
Alloy(*Ni, Cr,...*), *Al, Cu*



Nuclear plants

Electronics
Cu, Au, Ag, Pd et Pt, Ga, Ge

Circular economy of materials for low carbon energy systems



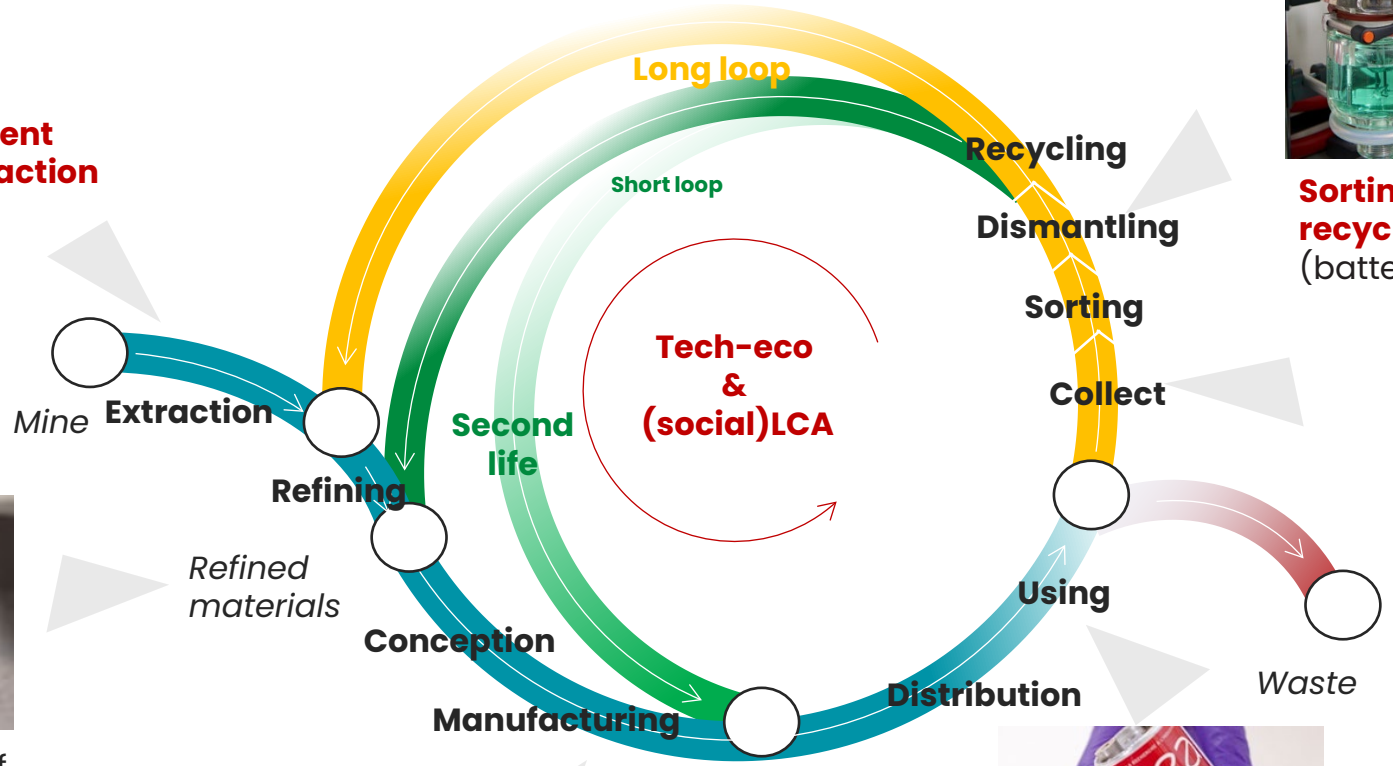
Clean (effluent) and **efficient** (yield, water, energy) **extraction** of raw materials (mine)



Reduction or **substitution** of **critical materials** (RE for magnets, …)



Material-saving **Manufacturing processes**





Sorting, dismantling and **recycling** (batteries, PV, magnets…)



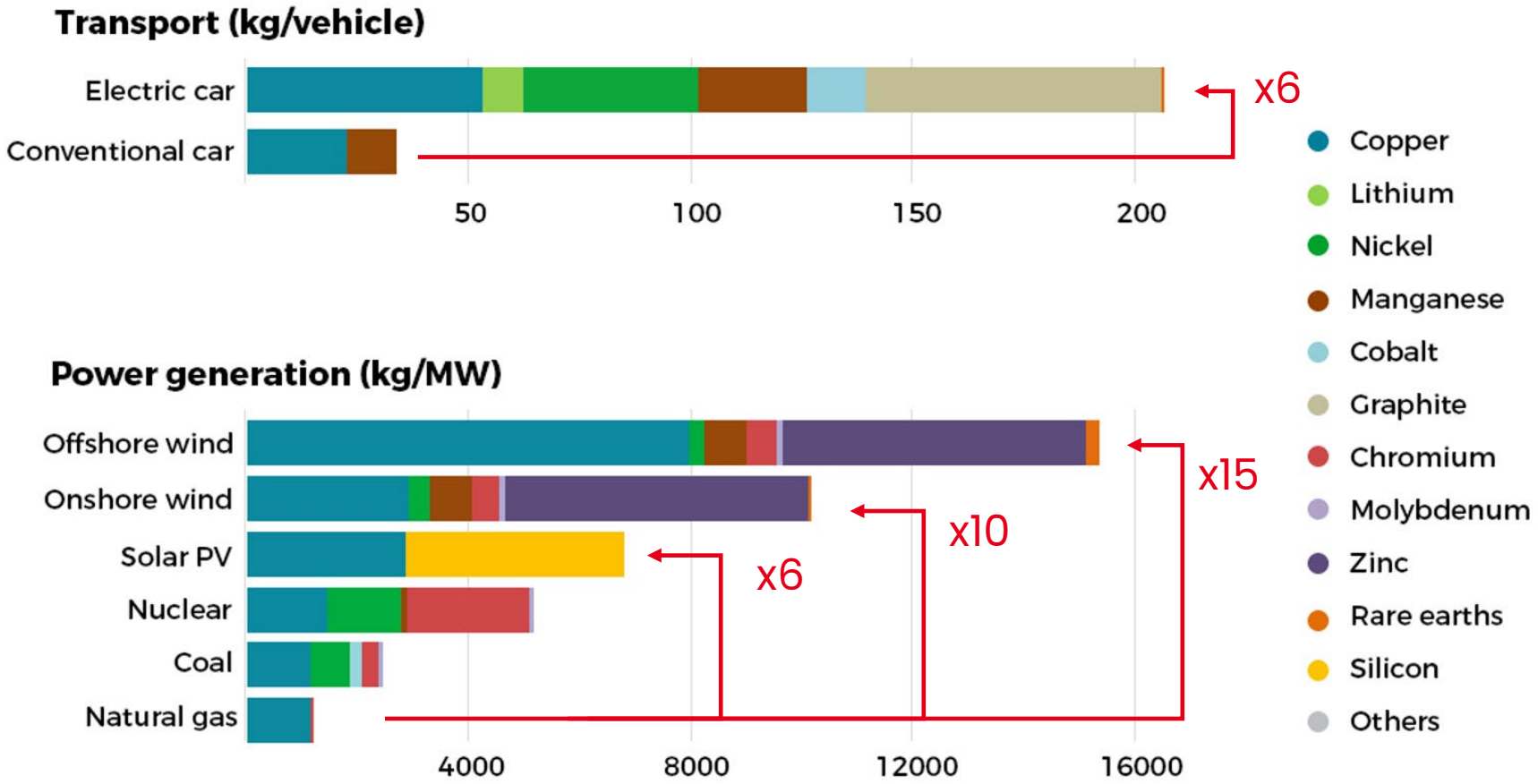
Second life
Instrumentation of batteries, PV, electrolyzers fuel cell, PE for diagnostic



Increased lifespan
Battery, PV, Electrolyzer, fuel-cell, Power Electronics instrumentation for predictive maintenance

Context and European & French legislation

The energy transition is material-intensive

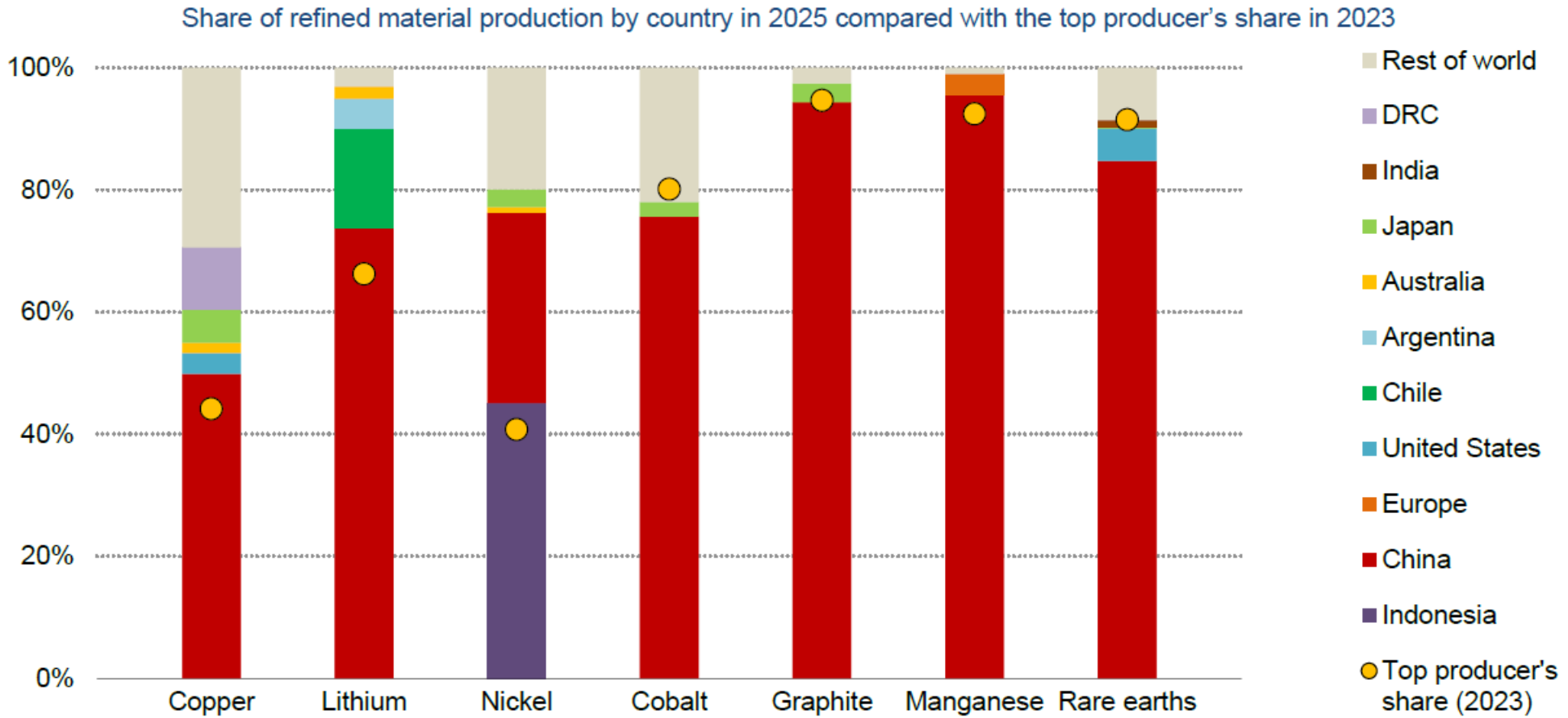


Minerals used in a selection of energy transition technologies and fossil fuels

Source : IEA- The Role of Critical Minerals in Clean Energy Transitions - 2021

→ On the road to Net Zero Emissions (NZE), the circular economy is a necessity! Lithium demand alone grew +30% in 2024 (IEA, 2025).

An exacerbated geostrategic concentration of refined critical materials impacting the battery sector



Evolution of Geographic concentration of refined products

Source: IEA – Global Critical Minerals Outlook 2026

Critical Raw Materials in Europe

Critical Raw Materials (CRM)

Raw materials considered essential to the EU economy and subject to supply risks

Strategic Raw Materials (SRM)

A subset of critical materials that are essential for strategic sectors: **energy and digital transitions, defense, and aerospace**

The definitions and the list currently comprising 34 **critical materials** (including 17 **strategic** ones)—are set by the EU in the CRM Act (Regulation 2024/1252, adopted May 2024)

Rare Earths

The 15 lanthanides in the periodic table, along with scandium and yttrium.
Light rare earths (La, Ce, **Pr**, **Nd**, Sm)
Heavy rare earths (Eu, Gd, **Te**, **Dy**, Er, Y, Ho, Tm, Yb, Lu)

Aluminium/ Bauxite	Coking coal	**Lithium (battery grade)**	Phosphorus
Antimony	Feldspath	**Rare-earth**	Scandium
Arsenic	Spath fluor	**Magnesium metal**	**Silicon metal**
Barite	**Gallium**	**Manganese (battery grade)**	Strontium
Beryllium	**Germanium**	**Graphite (battery grade)**	Tantalum
Bismuth	Hafnium	Niobium	**Titanium metal**
Boron (grade metallurgical grade)	Helium	**Platinium group metals**	**Tungsten**
Cobalt	Phosphorite	Vanadium	**Nickel (battery grade)**
Copper			

Table : EU CRM and **SRM**

→ CRM Act legislation targets : 10% of extraction & 40% of refining on the EU territory and 25% of recycled SRM in products in 2030

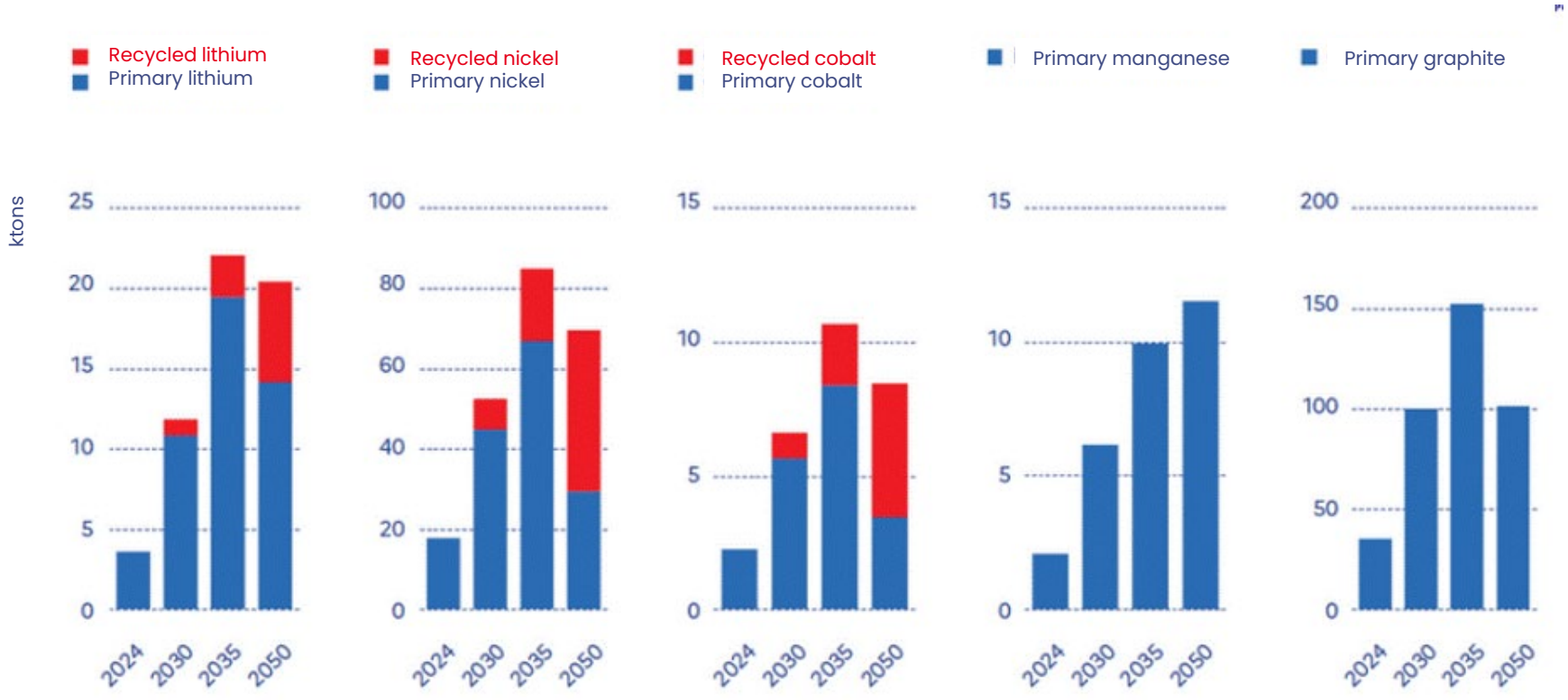
Critical Raw Materials for Batteries,

FR & EU legislation to enforce sustainability and EU material value chains

- **European battery directive & battery passport**(2023/1542)
  - Fund, collect, and recycling of battery waste
  - Define **recycling efficiency** thresholds: **80% Lithium**, **95% of cobalt, copper**, **nickel** in 2031,
  - Define **recycled content** thresholds : **16 % cobalt, 6 % lithium, 6 % nickel** in 2031
  - Define **sustainability goals**: carbon footprint declaration and obligation (2029)
  - **Tracability** & **transparency** (material origin, recyclability,…) through digital passport
- **Waste shipment regulation** (2024/1157) stricter control of **battery waste exportation** outside OCDE
- **French Extended Producer Responsibility** (ERP) according to 2023/1542 :
  → Battery waste can be transported **in a zone of 1500km radius from the collection point** for **pretreatment and recycling**
- **Industrial Accelerator Act** targets 20% of industry in EU GDP
  - Carbon footprint and “Made in/with EU” of 3 key components of VE (including battery cell in 2026 and CAM and anode in 2029) for eligibility to public aids and public markets
  - Foreign investment control (>100M€ and >40% of country market share)

Critical material demand & offer for batteries

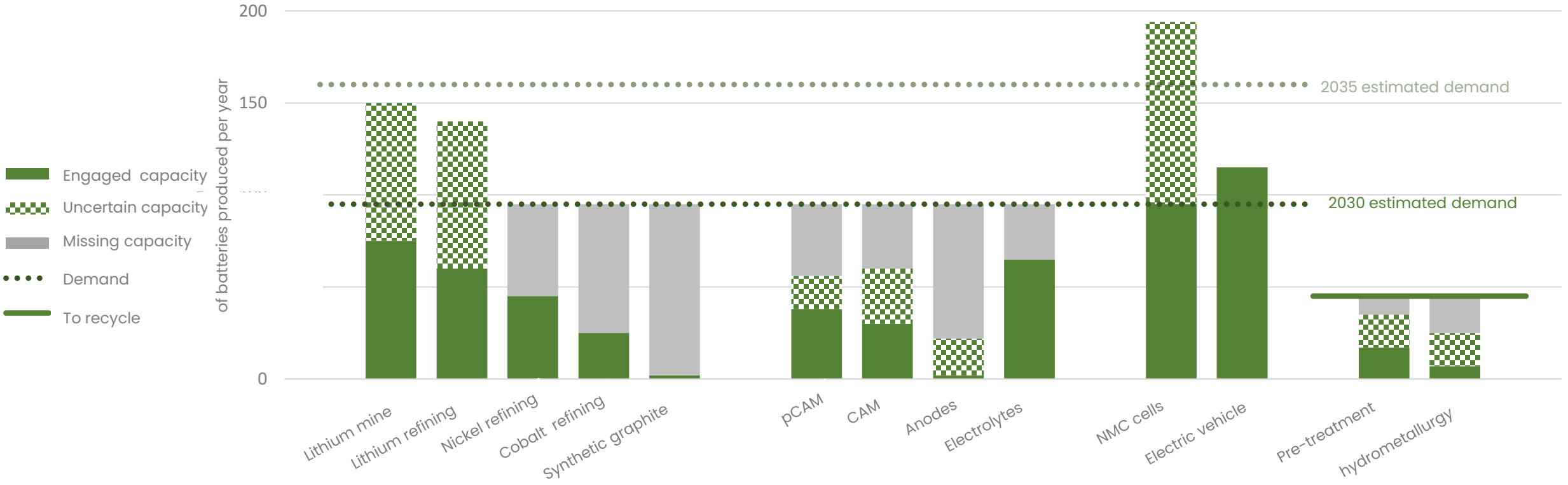
Material demand for french electric mobility



Critical materials demand for battery production of electric vehicule sold in France

Source: OFREMI “Les matériaux critiques de batterie pour la mobilité électrique française”, 2024

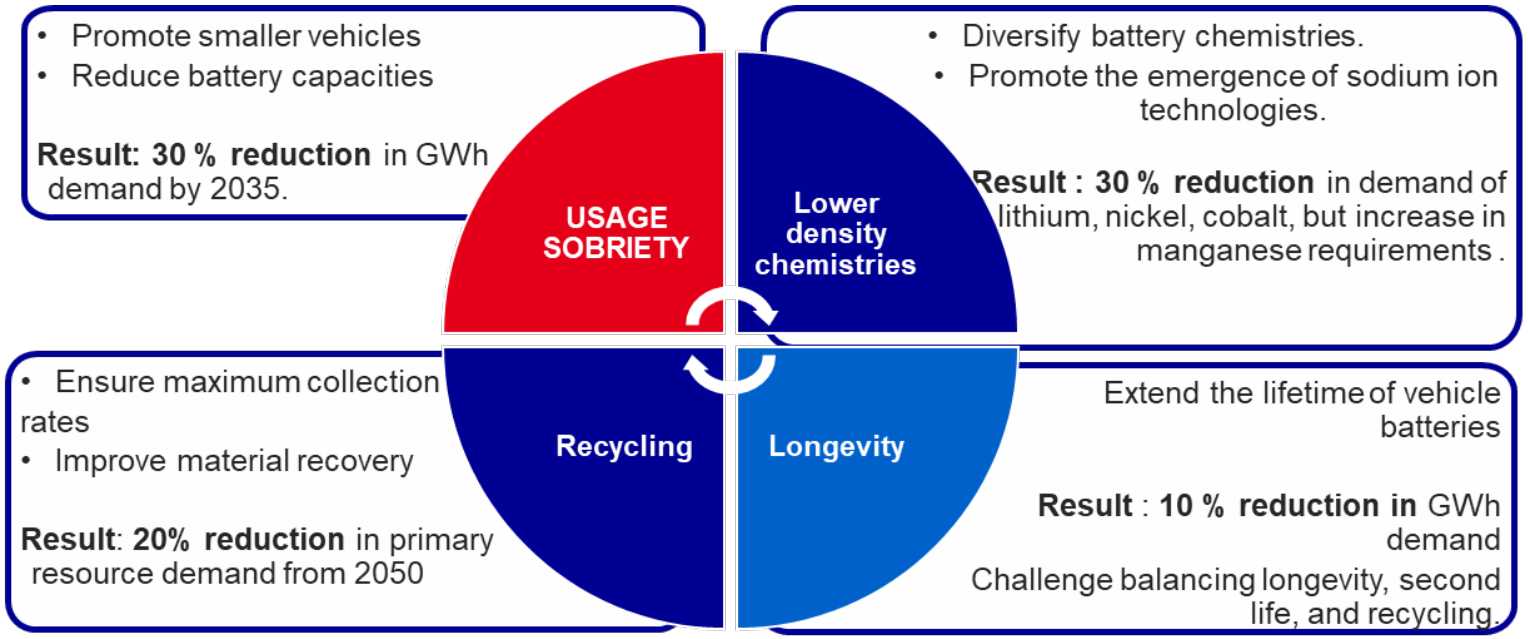
Battery material value chain for French electric mobility



Battery materials : forecasted capacities in the French territory in 2030

Source: OFREMI "Les matériaux critiques de batterie pour la mobilité électrique française", 2024

Assessing levers to reduce critical materials requirements



Main levers for reducing the need for critical materials required for French electric mobility (batteries),

source : « Les matériaux critiques des batteries pour la mobilité électrique française », OFREMI, December 2024

The circular economy approach for batteries

Circular economy of materials for batteries



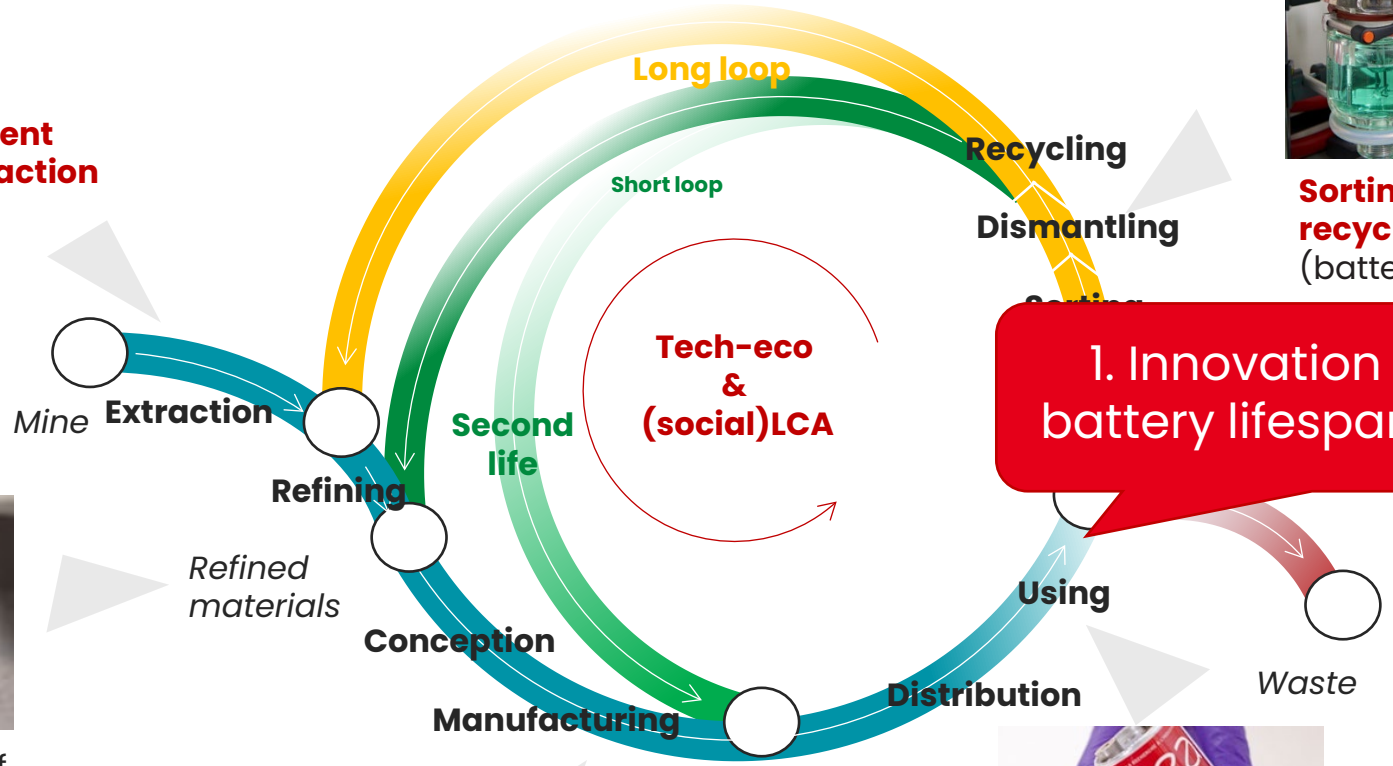
Clean (effluent) and **efficient** (yield, water, energy) **extraction** of raw materials (mine)



Reduction or **substitution** of **critical materials** (RE for magnets, …)



Material-saving **Manufacturing processes**



1. Innovation to increase battery lifespan and 2nd life



Sorting, dismantling and **recycling** (batteries, PV, magnets…)

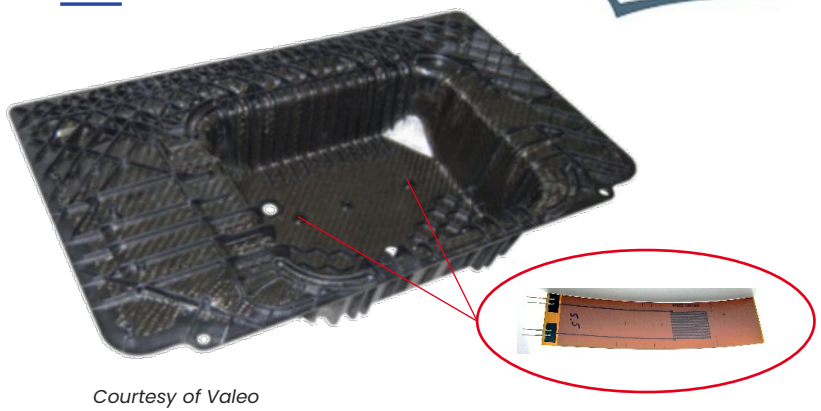


Second life
Instrumentation of batteries, PV, electrolyzers fuel cell, PE for diagnostic



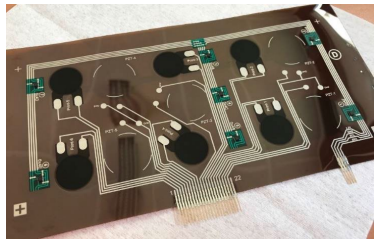
Increased lifespan
Battery, PV, Electrolyzer, fuel-cell, Power Electronics instrumentation for predictive maintenance

Instrumentation to increase lifespan and enable 2nd life



Courtesy of Valeo

Composite Battery Casing with Embedded Temperature and Strain Monitoring





Pouch and cylindric battery instrumentation with acoustic sensors

Monitoring of battery **casing :**

- **Detection** of **damages → Strain gauges**
- Monitoring of cooling fluid **→ T° sensors**

Monitoring of battery **cells → acoustic sensors**

- Detect reversible changes in the physical properties of materials inside the battery;
- Estimation of the state of charge (SoC), state of Health (SoH)
- Early detection of abnormal operation (overcharge, overdischarge, over heating…)
- Quality check on battery batches (abnormal acoustic signature)

Circular economy of materials for batteries



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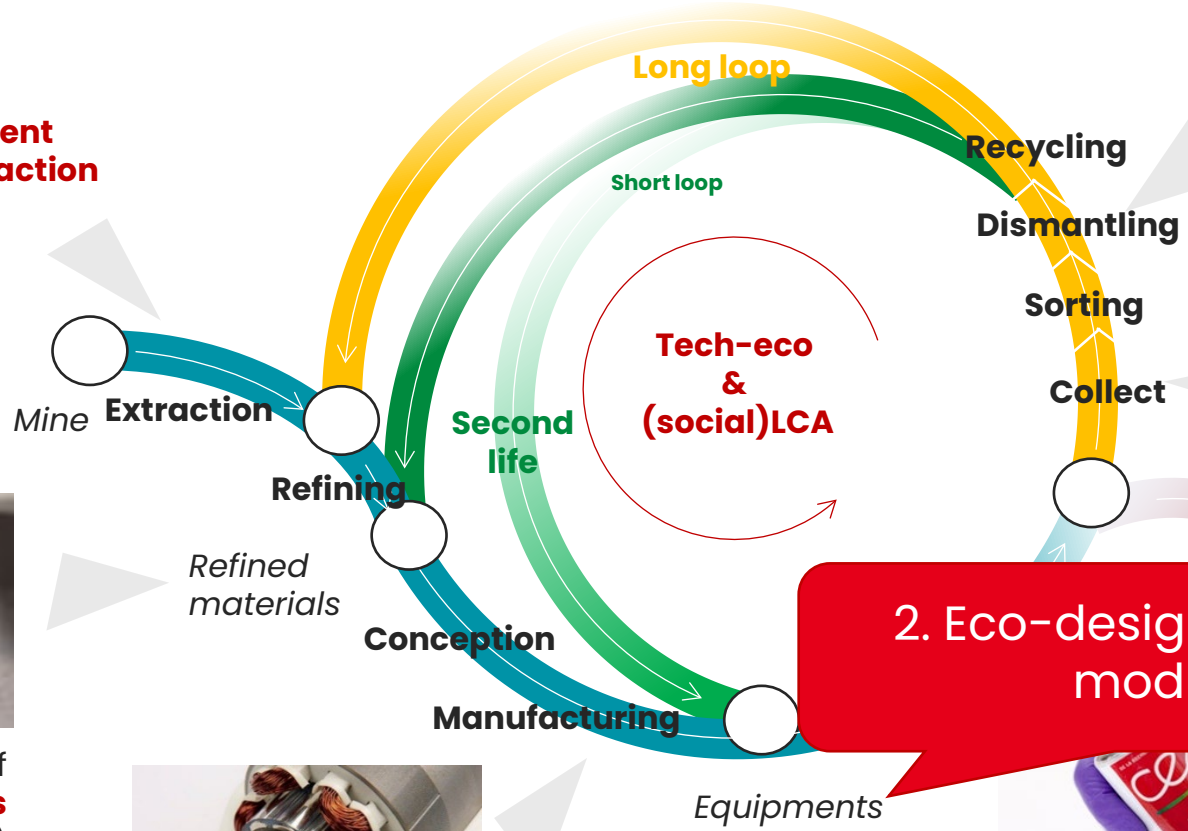
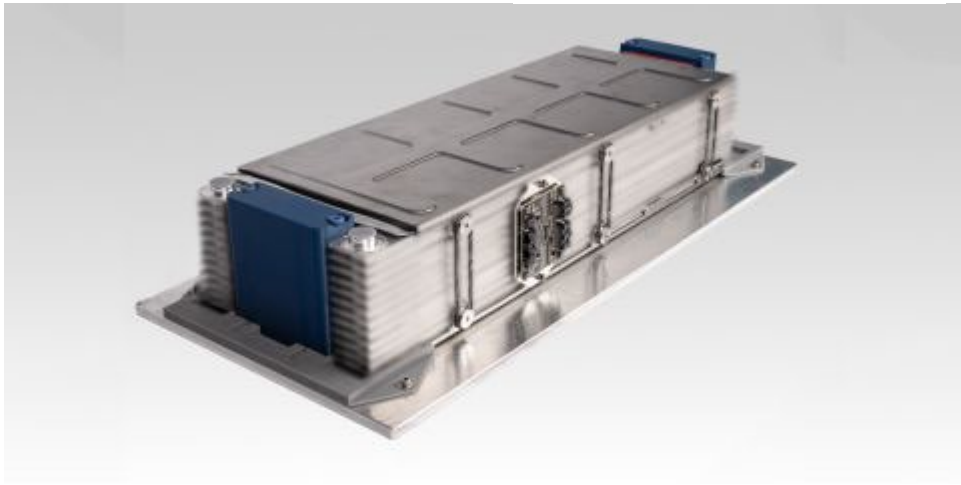


2. Eco-design of battery modules

Battery pack eco-design

Design-for-Disassembly module for solid state battery to ease **reparability**, **recyclability**, and **reusability**

- **Non-welded** designs, while maintaining compacity and high energy density
- Based on :
  - Prologium's superfluidised **all-inorganic solid-state lithium ceramic battery cells**.
  - CEA cells to system expertise : **module design**, **prototyping** and **testing** addressing electrical, mechanical and thermal management & BMS



Solid-State Battery Module" jointly developed by ProLogium Technology and CEA demonstrated at IAA Mobility 2025

Circular economy of materials for batteries



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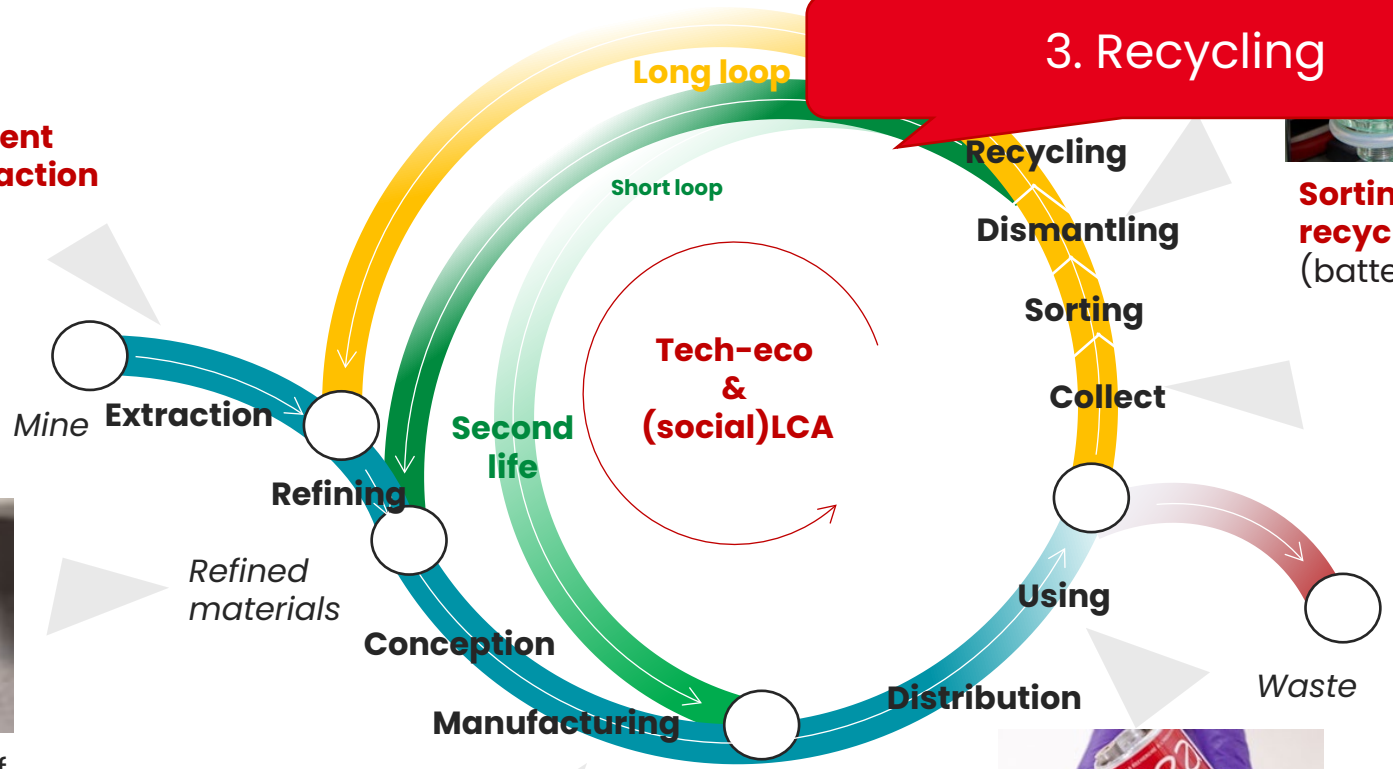
Material-saving **Manufacturing processes**





Sorting, dismantling and **recycling** (batteries, PV, magnets…)



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Innovation for battery recycling

R&D collaboration/funding

orano · LRGP · Respect · BATRAW · France 2030

PATENTED ~ 20 patents

. Packs

~ 200-700 V
~ 100-600 kg
~ 10-100 kWh

. Modules

~ 7-90 V
~ 3-50 kg
~ 0.5-8 kWh

. Scraps

- Electrodes
- Cells (Dry / Wet)
- Ink

. Defective or damaged batteries

- Short way to valorize active materials

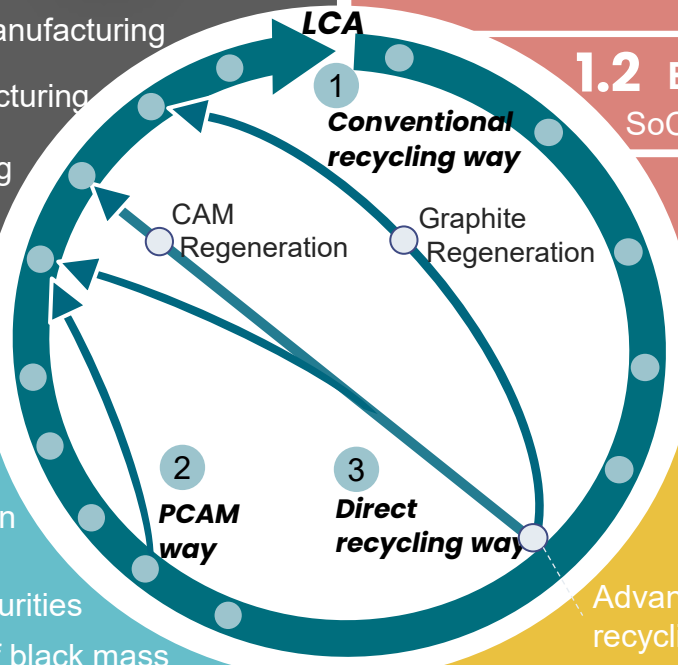
4. COMPONENTS MANUFACTURING
Assembly / manufacturing
Active materials manufacturing
CAM manufacturing
PCAM synthesis


1.1 DISMANTLING

1.2 ENERGY REDUCTION
SoC reduction 100 % → ~ 0 %

1.3 DEACTIVATION
Residual energy release SoC ~ a few % → 0 V

- Universal disruptive technology for removing completely the energy from modules & cells (high charge, CID KO, etc.)



Size reduction & liquid management
Classification of materials (black mass way)
Advanced classification for direct recycling of active materials

2. MATERIAL CONCENTRATION

- Selective extraction of active materials from casing
- Technology to separate active materials

Salt crystallization
Lithium extraction from waste water
Selective extraction (Mn, Co, Ni)
Removal of impurities
Lixiviation of black mass

3. HYDROMETALLURGY

- Selective leaching/extraction of critical metals



Black Mass:
Active materials (Cathode ~60 $\%_{wt}$, Anode ~35 $\%_{wt}$) | Main impurities ~5 $\%_{wt}$: Al, Cu, Fe, F, P, Al_2O_3

Source figure: E. Billy, et al. Chapter book on the recycling of Li-ion batteries_under revision, 2025

Circular economy of materials for batteries



Clean (effluent) and **efficient** (yield, water, energy) **extraction** of raw materials (mine)



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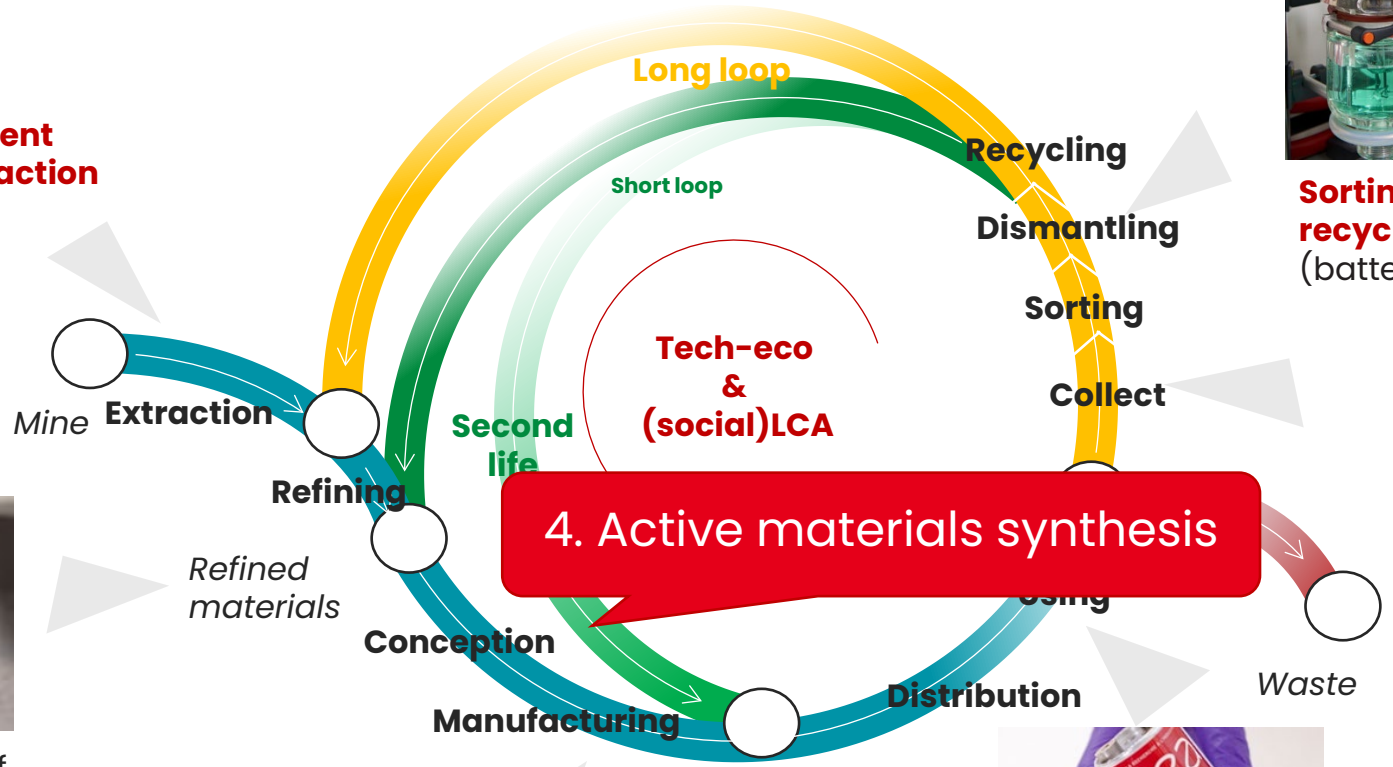



Sorting, dismantling and **recycling** (batteries, PV, magnets…)



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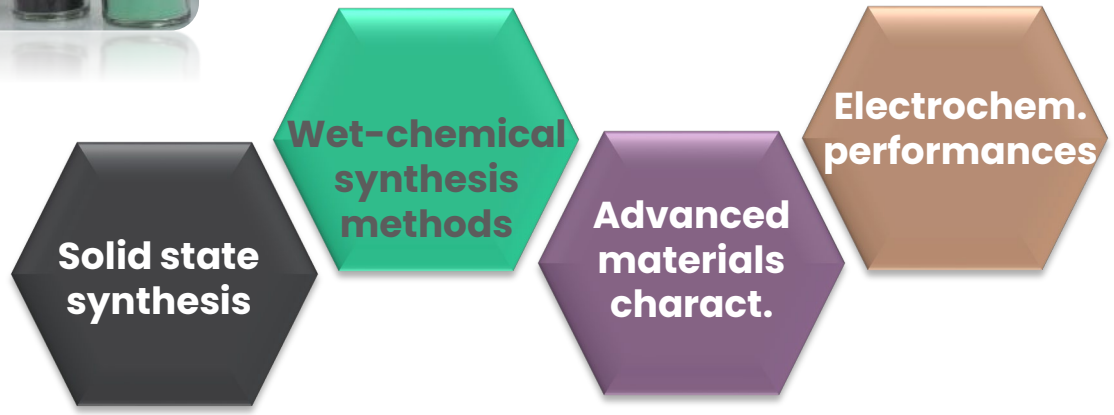
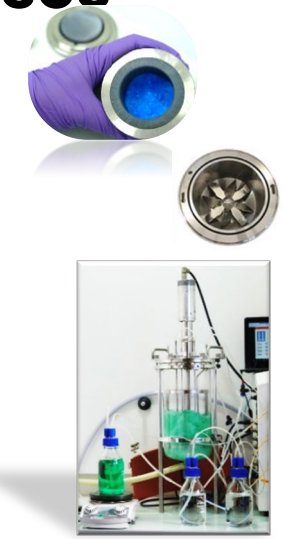
CORE COMPETENCIES on Active Materials synthesis



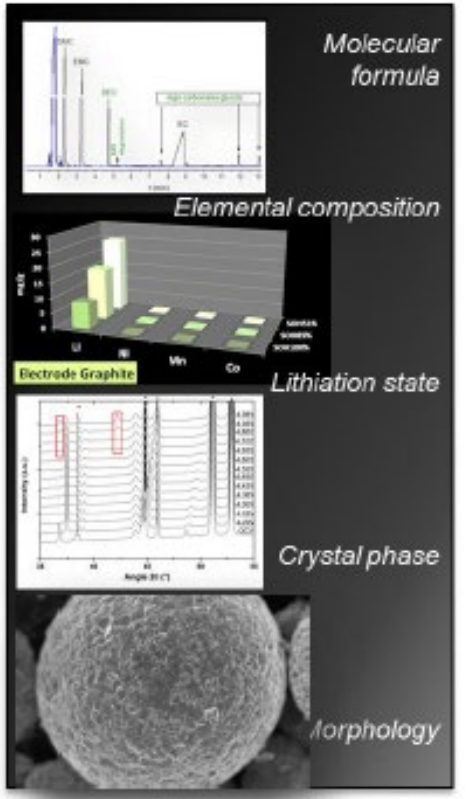
Materials synthesis processes







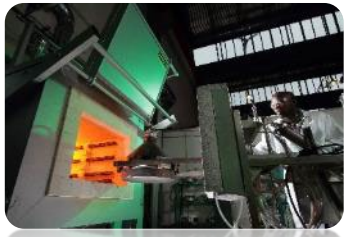
60 people



FROM LAB SCALE (g) TO PILOT SCALE (kg)

Active materials & electrolytes (liquid, solid and gelified)

- ⊕ Oxide, Sulfure and Polyanions
- ⊖ Graphite, Si, Li°









umicore materials for a better life · orano · SYENSQO · saft a company of TOTAL · STELLANTIS

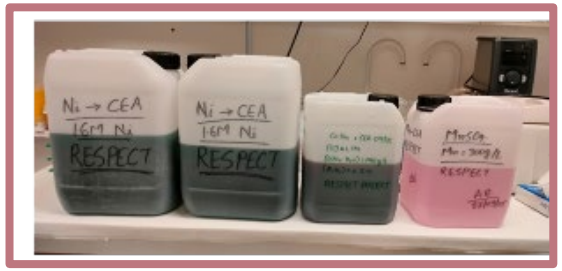
Influence of impurities from recycling process on cathode material synthesis

Goal : Reducing the purification steps of leachates from recycling batteries or scraps by **assessing the impact of impurities** on the **properties and performance of final active materials**

Leachates of BM
(sulphates)



Eluates *(isolated solutions)*



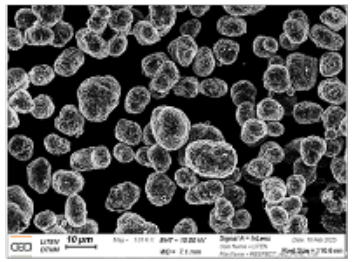
Solvant extraction

Sulfate salts
(isolated salts)



Crystallization

Liquid step parameters
- pH
- Feeding flow
- Mode of injection
- Temperature
- Concentration
- Blades geometry
- Stirring speed





Dry step parameters
- Mixing of precursors
- Lithium source and rate
- Calcination temperature protocol
- O2 atmosphere



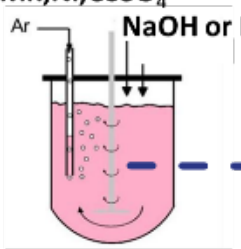
&



$Mn,Ni,CoSO_4$

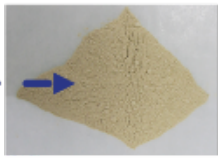
Ar

$NaOH$ or Na_2CO_3



CAM NMC811

PCAM - OH



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1st step: liquid synthesis

2nd step: dry synthesis

Comparaison of different metal sources

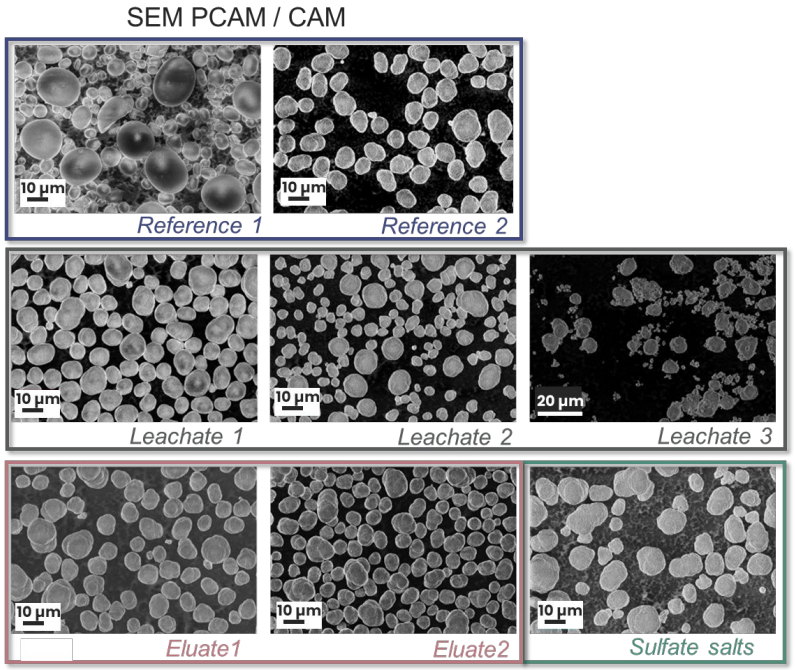
Influence of impurities from recycling process on cathode material synthesis

Approach :

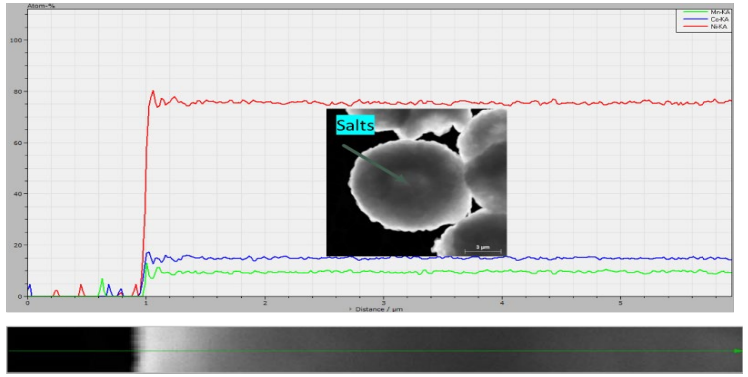
- ✓ **Tracking of impurities** through a complete material balance (ICP-OES at different stages of synthesis and on the final powder),
- ✓ **Detailed characterization** of the final products (hydroxides then oxides) :
  - **Structure** (X-ray diffraction),
  - **Morphology** (electron microscopy, particle size distribution, and BET surface area measurement),
  - **Chemistry** (TOF-SIMS),
  - **Electrochemistry** (galvanostatic cycling in half-cell and Li-ion soft cell facing graphite),
  - **Post-mortem characterizations** (XPS)

Perspectives:

- ✓ **Optimize synthesis methods** to improve resilience to impurities
- ✓ **Explore other contaminating elements**



*Particle size distribution of PCAM and **CAM***



STEM-ELLS : Homogeneity of Co, Ni and Mn concentration of CAM

Key take-aways

- ✓ Achieving **strategic autonomy** in battery materials involves **securing every link in the value chain**, from mining to battery pack production.
  → Collaboration with research organizations and industry partners in Africa is key to reaching this objective!
- ✓ **Legislation** is evolving in order **to support the emergence of diversified value chains** and **enforce their resilience**
- ✓ **Efficiency** and **sobriety** in **material use is mandatory** to support the energy transition
- ✓ **Innovation at every stage of the battery circular economy** can contribute to obtain material **efficiency gains**
- ✓ **Short loops** such as direct recycling offer opportunity to **reduce cost and environmental impact** hence contribute to the competitivity of battery material recycling

Thank you for your attention