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Low-carbon footprint **Bio-diluents for** Solvent Extraction in **Battery Recycling**

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The beginning of Solvent Extraction (SX)

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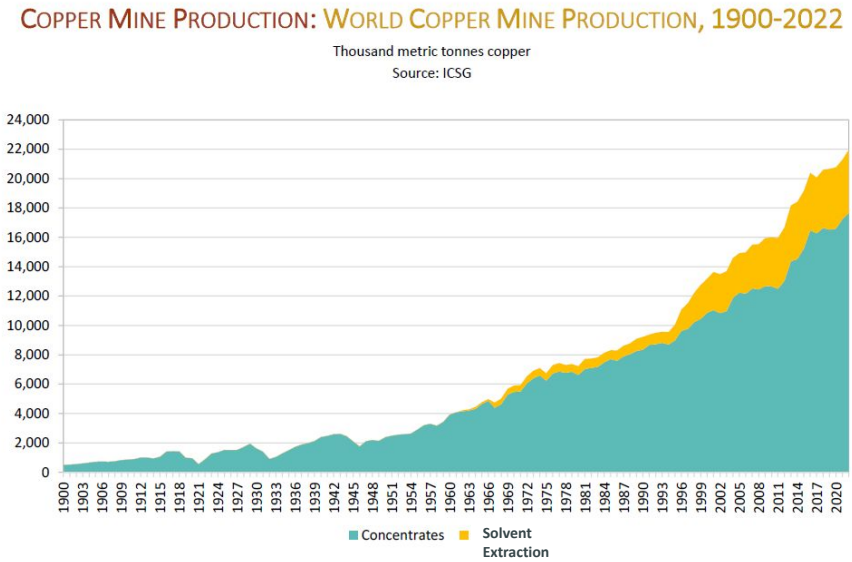
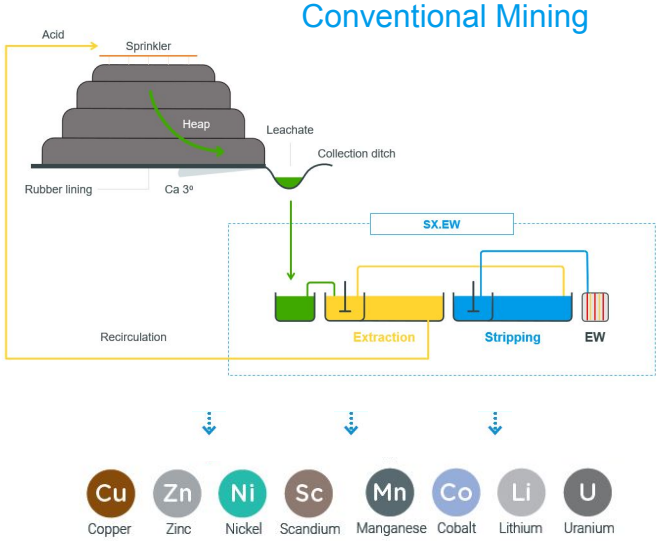


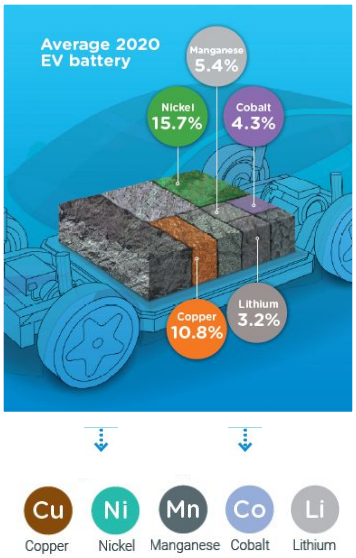
- SX introduced in 1960s
- Today: **~20%** of Cu Extraction via SX
- Advantages vs the conventional process:
  - Suitability for low & variable copper ores
  - High Purity: up to 99.99% Cu
  - Improved **HSE**
- Diluent in SX process:
  - **Kerosene**
  - Readily and cheaply available

Today… the applications of Solvent Extraction (SX)

Conventional Mining



Today, SX is similarly used for extraction of other metals

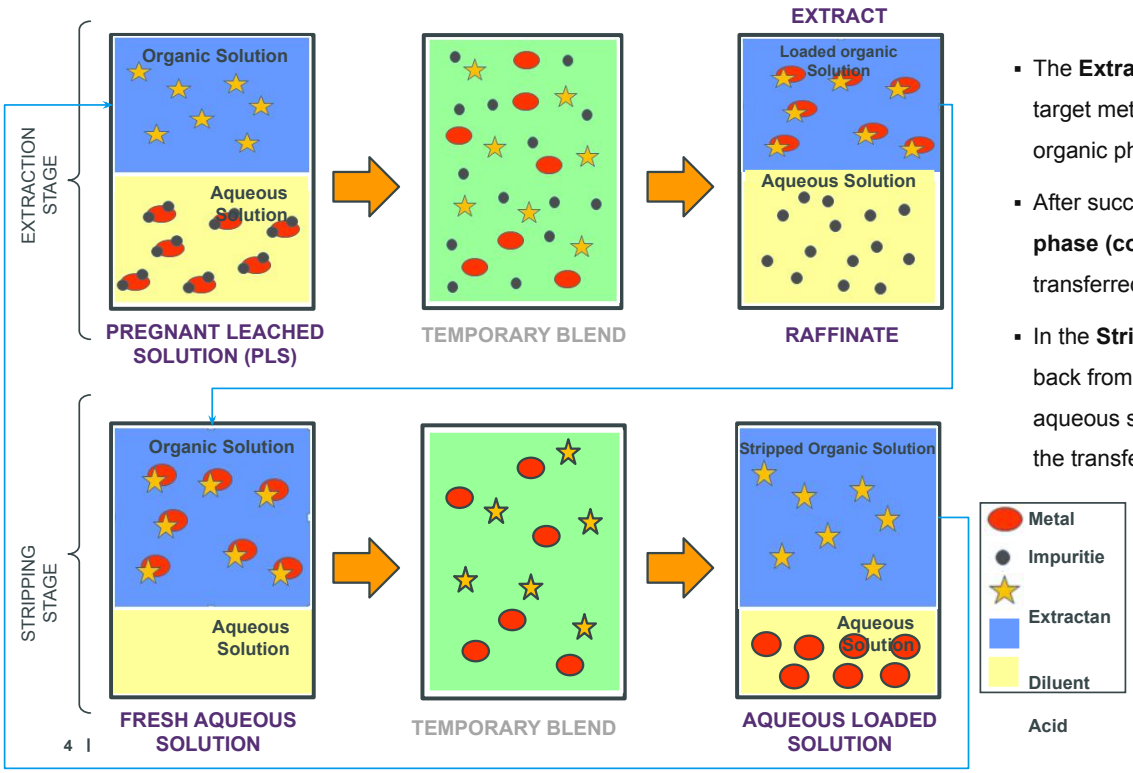


Same metals in Li-ion battery

Why Solvent Extraction for Li-ion Battery Recycling??

- High Recovery: >90%
- High Purity of metals: >95%
- Cost Effective
- High Material Selectivity
- Low Energy Consumption
- Environmentally Friendly

Solvent Extraction Process



- The **Extraction Stage** involves transferring the target metal from the aqueous phase into the organic phase.
- After successful extraction, the **loaded organic phase (containing the extracted metal)** is transferred to the stripping section.
- In the **Stripping Stage**, the target metal is stripped back from the organic phase using a different aqueous solution by adjusting the pH to promote the transfer back to the aqueous phase.
- The stripped organic phase is then **recycled** back to the extraction stage for further rounds.
- As a result, over an year, **only 10-20%** of the **organic solution / diluent is used**

Organic phase: Composition – Role – Properties

Organic phase composition

Extractant
(5 -35%)

Diluent
(60 - 90 %)

Additives (modifiers)
(5-10%)

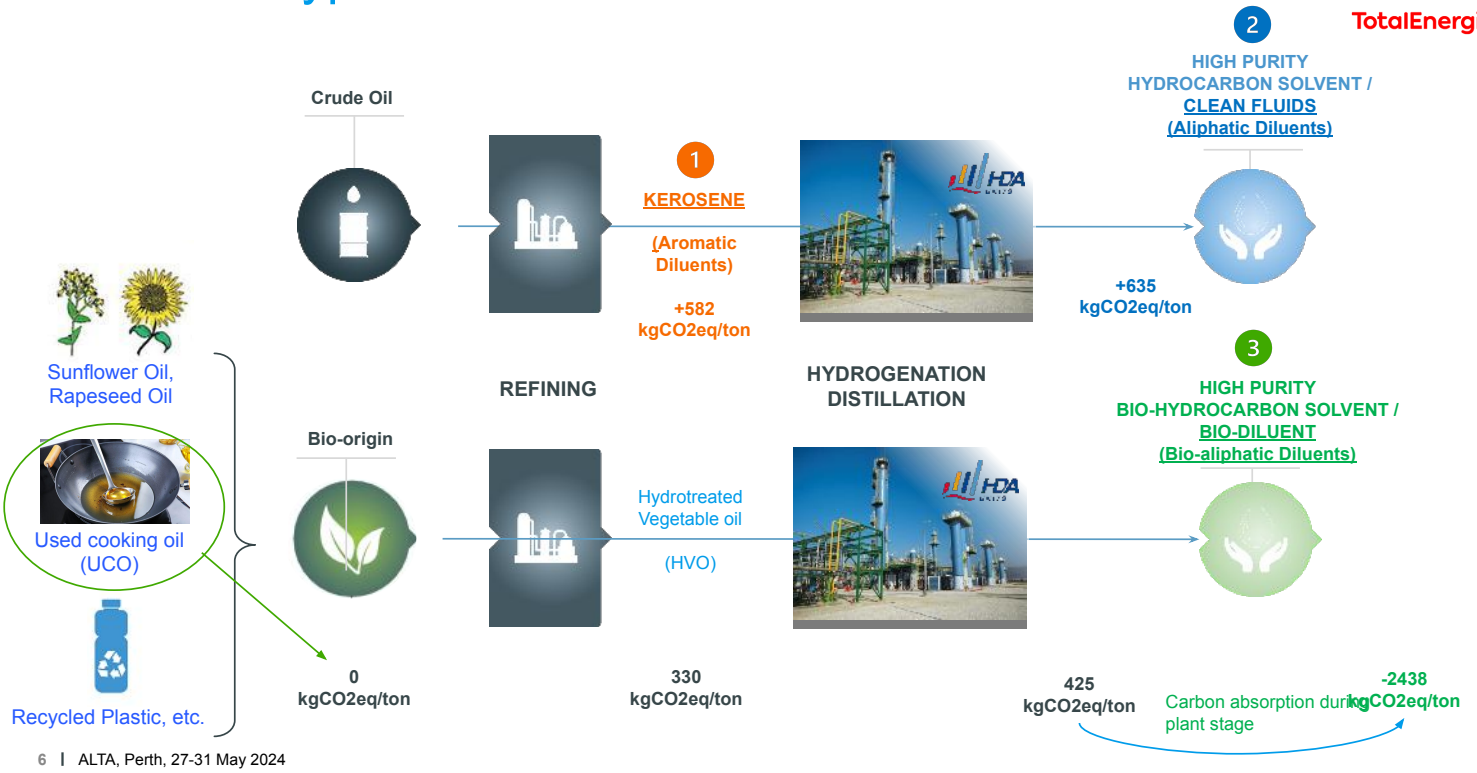
Diluent role

- Primary function is to adjust the extractant concentration
  - Dissolve the extractant and additives
  - Maintain viscosity of organic phase
  - Improve mobility of metal extracts between phases
  - Optimize phase disengagement rate
- Desired characteristics:
  - Minimal solubility in SX aqueous streams to avoid entrainment losses
  - Lower vapor pressure and higher flash point to reduce evaporation losses and fire risk (safety)
  - Minimal amounts of carcinogens such as benzene & PAH (health)

Main Properties

• Solvency power	Appropriate density & hydrocarbon chemistry
• Low viscosity	KV40 ~1,5 à 2 mm²/s
• Low flammability	Flash Point > 70°C

3 Diluents Types – Production Routes



Diluent Properties / Characteristics

1 KEROSENE 2 CLEAN FLUIDS 3 BIO-DILUENT

Properties	Method	Units	Kerosene	Elixore 205	Elixore 215	Elixore Biolife EV 205
Density	ASTM	kg/m³	822	819	819	764
Pensky-Martens Flash Point	ASTM D93	°C	**84**	**75**	**85**	**84**
Aromatic content	-	-	~20%	< 300 ppm	< 300 ppm	<50 ppm
Initial Boiling Point	ASTM D86	°C	210	198	213	211
Dry Point	ASTM D86	°C	240	234	241	244
Kinematic viscosity at 40°C	ASTM D445	mm^2/s	**1.8**	**1.7**	**1.9**	**1.6**
Carbon Footprint (LCA)	Cradle to Gate	$kgCO_2eq/ton$	**+582**	**+635**		**-2438**

- Type 1 diluents
  - **Fossil** origin
  - C9-C20 Aliphatic hydrocarbons
  - **2-30% aromatics**
  - Kerosene
- Type 2 diluents
  - **Fossil** origin
  - C9-C20 Aliphatic hydrocarbons
  - **<300 ppm aromatics**
  - Clean fluids (Elixore range)
- Type 3 diluents
  - **Bio-origin**
  - C9-C20 Aliphatic hydrocarbons
  - **<50 ppm aromatics**
  - Bio-Diluents (Elixore Biolife range)

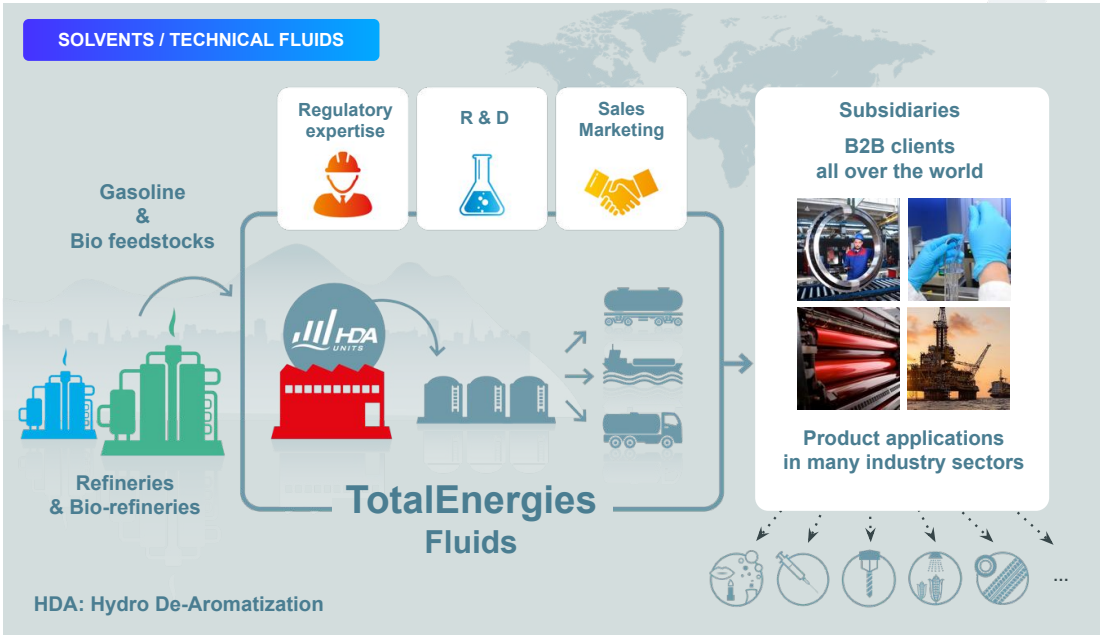
For the same Flash Point, the bio-diluent gives the lowest aromatics, viscosity and carbon footprint

Comparative Overview

1 KEROSENE 2 CLEAN FLUIDS 3 BIO-DILUENT

	Environmental Impact	1. Carbon Footprint (Cradle to Gate - kgCO2eq./ton product)	+582	+635	-2438
		2. VOC Emissions	High	Low	Low
		3. Biodegradability	Partially Biodegradable	Readily Biodegradable	Readily Biodegradable
	Health Impact	1. VOC Emissions (Low volatility improves operator environment)	High	Low	Low
		2. Carciogenic, Mutagenic & Reprotoxic (CMR)	Classified	Not classified	Not classified
	Safety	1. Flash Point (for same viscosity) (High Flash Point assists in minimizing fire risk)	++	+++	+++
		2. VOC Emissions (Can lead to explosive mixture)	High	Low	Low
	Performance	1. Extraction Efficiency	+++	+++	+++
		2. Average Phase Separation time (Aqueous Continuous / Organic continuous)	+++	+++	+++
	Circuit Stability (Maintenance)	1. Rate of Oxidative Degradation	Standard	Low	Low
		2. Crud Formation	Standard	Low	Low
	Diluent Consumption	1. Organic in Acqueous Entrainment	Standard	Low	Low
		2. Rate of Evaporation	High	Low	Low
	Cost	1. Price	+	++	+++
		2. Diluent consumption	Standard	Low	Low
		3. Savings related to diluent consumption and maintenance (circuit stability)	None	up to 10%	up to 10%
		4. TCO (Total Cost of Ownership)	+++	++	+++

TotalEnergies Fluids… our expertise



OUR FIGURES

Sales: 800 KT / 80% in Europe

No. 3 in the world, Joint leader in Europe

2,000 customers including 30 key accounts

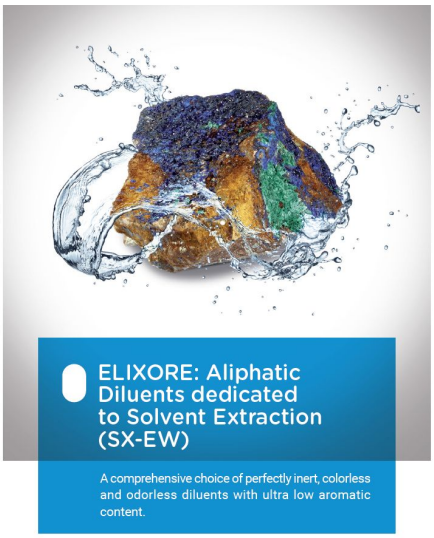
2 plants: Oudalle (France) and Bayport (USA)

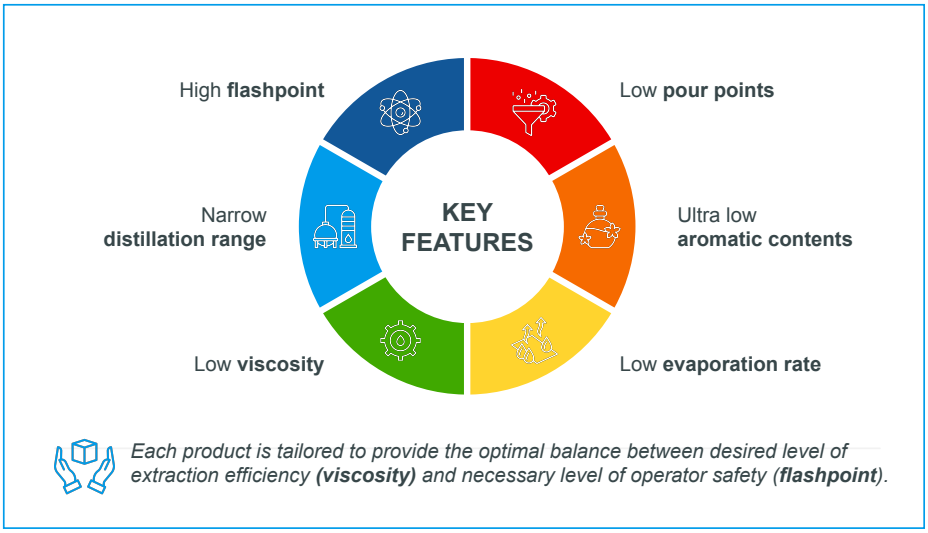
A global network:
50 subsidiaries in more than 70 countries, 250 employees

A global partner… a local player

- **Diversified logistics facilities**
- **Proximity to customers all over the world**

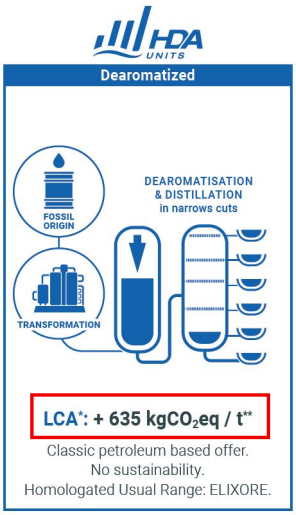
ELIXORE: Aliphatic Diluents for Solvent Extraction

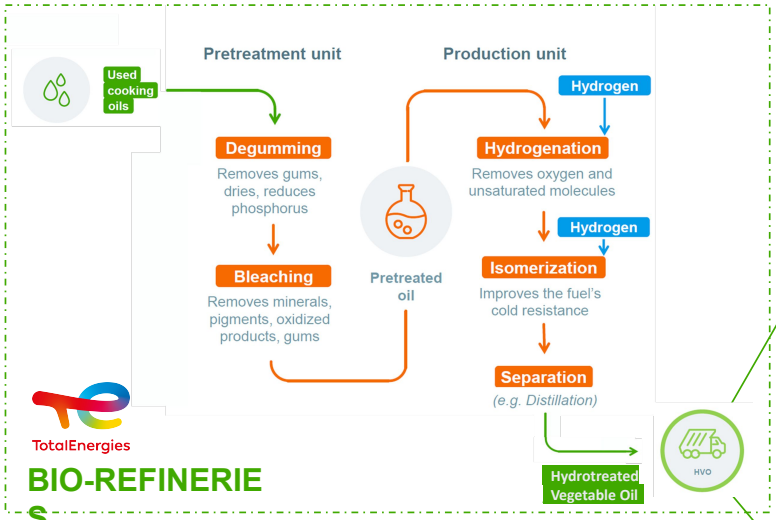


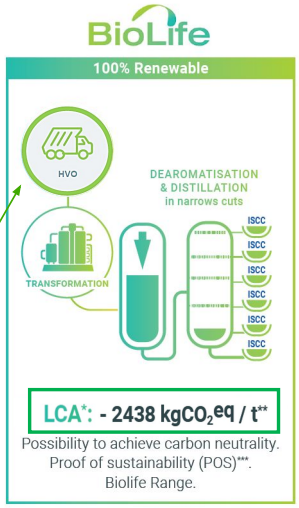


A trusted product in the Mining industry for more than 10 years!

Transition to **Bio-Diluents** (Objective 30% by 2030)

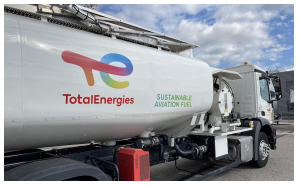






- ✔ **Life Cycle Assessment** carried out per ISO 14040 / 14044 / 14067 standards
- ✔ Calculations are carried out using SIMAPRO modeling & recognized databases
- ✔ The LCA **(Cradle to Gate)** validated by an external critical review

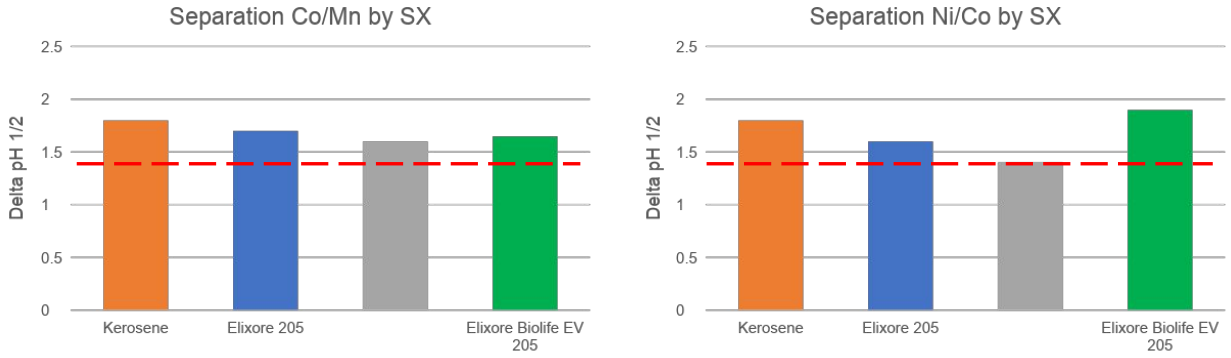
>90% **SAF**



Research & Development

Objective: Study the influence of bio-diluents on the extraction of metals using hydrometallurgy in battery recycling

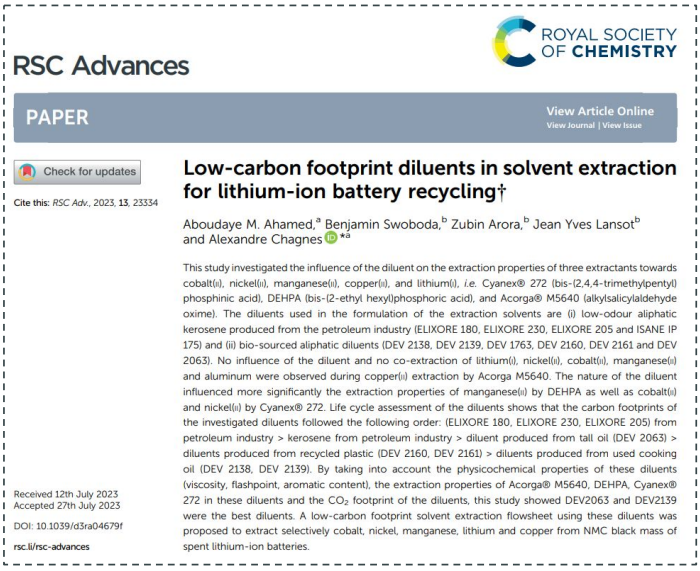
Screening of diluent efficiency



- 4 bio-sourced products were analyzed along with kerosene and Elixore 205
- These products differed in origin, chemical structure, carbon number, viscosity & flash point

Elixore Biolife EV 205 gave the best results – similar to Kerosene & Elixore 205

Elixore Biolife EV 205… Commercialized



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Low-carbon footprint diluents in solvent extraction for lithium-ion battery recycling†

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This study investigated the influence of the diluent on the extraction properties of three extractants towards cobalt(II), nickel(II), manganese(II), copper(II), and lithium(I), *i.e.* Cyanex® 272 (bis-(2,4,4-trimethylpentyl) phosphinic acid), DEHPA (bis-(2-ethyl hexyl)phosphoric acid), and Acorga® M5640 (alkylsalicylaldehyde oxime). The diluents used in the formulation of the extraction solvents are (i) low-odour aliphatic kerosene produced from the petroleum industry (ELIXORE 180, ELIXORE 230, ELIXORE 205 and ISANE IP 175) and (ii) bio-sourced aliphatic diluents (DEV 2138, DEV 2139, DEV 1763, DEV 2160, DEV 2161 and DEV 2063). No influence of the diluent and no co-extraction of lithium(I), nickel(II), cobalt(II), manganese(II) and aluminum were observed during copper(II) extraction by Acorga M5640. The nature of the diluent influenced more significantly the extraction properties of manganese(II) by DEHPA as well as cobalt(II) and nickel(II) by Cyanex® 272. Life cycle assessment of the diluents shows that the carbon footprints of the investigated diluents followed the following order: (ELIXORE 180, ELIXORE 230, ELIXORE 205) from petroleum industry > kerosene from petroleum industry > diluent produced from tall oil (DEV 2063) > diluents produced from recycled plastic (DEV 2160, DEV 2161) > diluents produced from used cooking oil (DEV 2138, DEV 2139). By taking into account the physicochemical properties of these diluents (viscosity, flashpoint, aromatic content), the extraction properties of Acorga® M5640, DEHPA, Cyanex® 272 in these diluents and the CO_2 footprint of the diluents, this study showed DEV2063 and DEV2139 were the best diluents. A low-carbon footprint solvent extraction flowsheet using these diluents was proposed to extract selectively cobalt, nickel, manganese, lithium and copper from NMC black mass of spent lithium-ion batteries.

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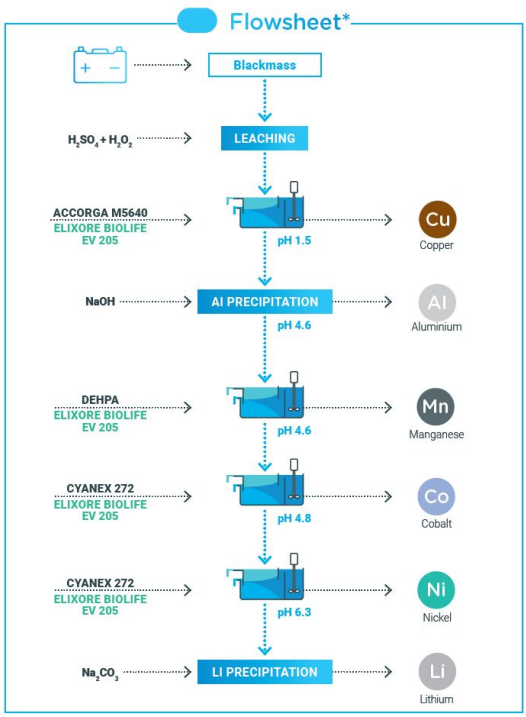


1 **Universal Diluent**

Same diluent in different extraction steps

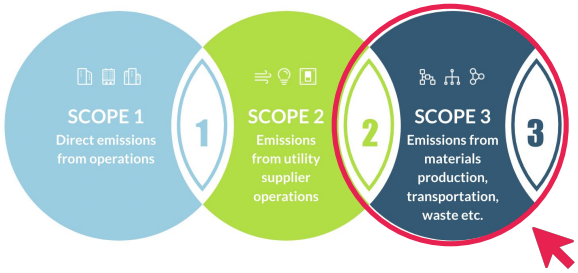
2 **Seemless Transition**

1:1 easy replacement for current fossil-based alternatives

What's the benefit? …Choosing Biolife Range

CARBON REDUCTION BENEFIT BY CHOOSING BIO RANGE

A 20 ktpa battery waste treatment plant that will treat 10 ktpa of Blackmass.



Contribute up to 50% of overall emissions

Diluent	Carbon Footprint mtCO2eq./mt)		
	Kerosene	Elixore Biolife EV 205	Carbon Footprint Reduction
1 mt	0.6	-2.4	3
10 mt	6	-24	30
100 mt (Yearly top-up)	60	-240	300
600 mt (First Fill)	**360**	**-1440**	**1800**
1000 mt	600	-2400	3000

20ktpa Battery Waste Input **1.8kt** Carbon Footprint Reduction

Up to 30% reduction in Scope 3 Emissions

DILUENT COST REPRESENTS <1% OF A BATTERY RECYCLING FACILITY.
HOWEVER, A BIO DILUENT CAN SIGNIFICANTLY REDUCE THE CARBON FOOTPRINT OF THE PROCESS.

Key Takeaway

Battery Recycling Company …operating a plant treating **NMC/LCO/NCA Blackmass**

Hydrometallurgy …using **Solvent Extraction**

You use a DILUENT …potential to use low carbon footprint **Bio-diluent**

Sustainability …to reduce **Scope 3 emissions** to achieve **CARBON NEUTRALITY**

Thank you for your attention!

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