Reverse Logistics for Lithium-Ion Battery Recycling

2023 Stellenbosch Engineering
Industry Showcase, Sandton

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Photo by Stefan Els

Growth in lithium-ion batteries

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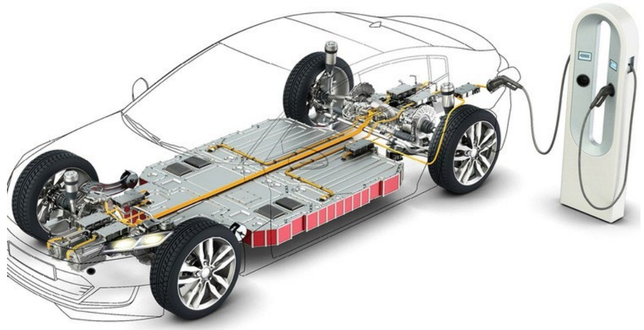
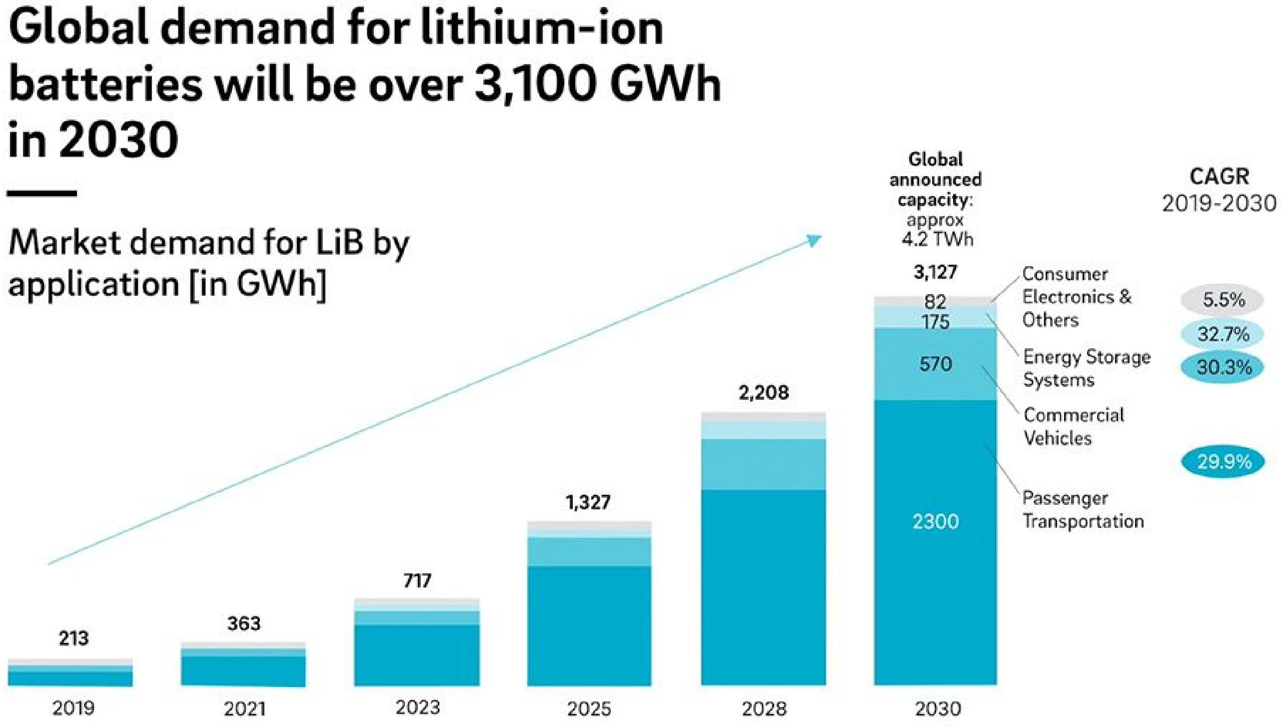
- Global demand for lithium-ion batteries is increasing, driven largely by the imperative to reduce climate change through electrification of mobility and the broader energy transition.



Source: https://www.udemy.com/course/electric-and-hybrid-vehicle-engineering/

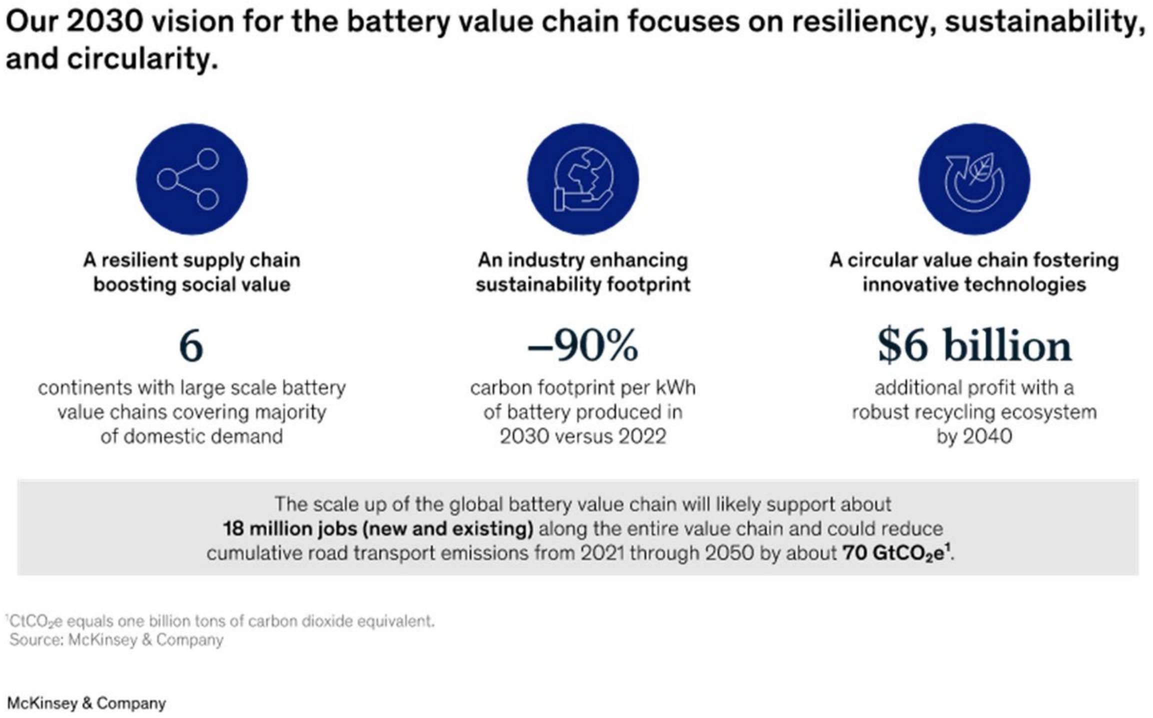
Source: https://www.teriin.org/blog/why-battery-energy-storage-key-renewables-growth



Sources: Avicenne, Fraunhofer, IHS Markit, Interviews with market participants, Roland Berger

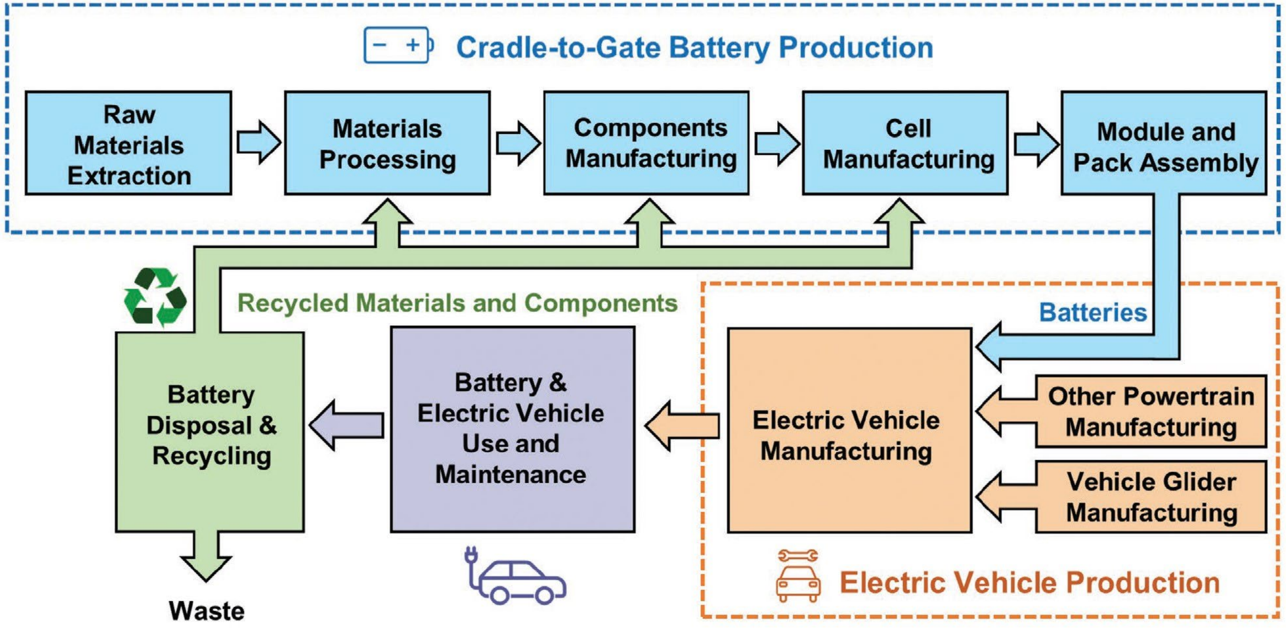
Establishing value chain circularity

- Moving from fossil-fuel based to electric mobility is a clear positive for the environment, but overhauling our transportation system requires new supply chains to be designed and scaled.
- With this challenge comes an opportunity—to scale a supply chain that is more stable, more resilient, more efficient, and more sustainable than that of the fossil-fuel and internal combustion engine (ICE) vehicle industry.



Establishing value chain circularity

- The battery industry has to move from a linear to a circular value chain—one in which used materials are repaired, reused, or recycled.
- Battery recycling is the key to pursuing that opportunity

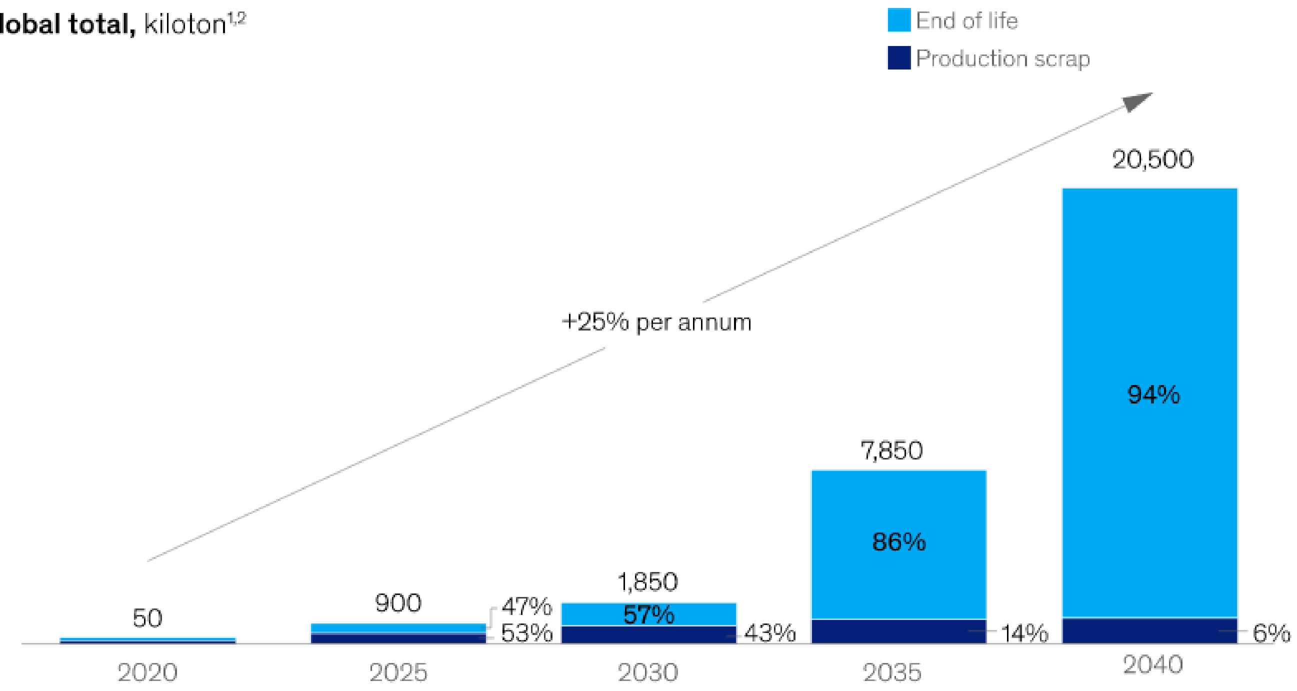


(Image: Advanced Energy Materials)

Establishing value chain circularity

The global supply of EV batteries for recycling is steadily increasing, driven primarily by production scrap before 2030 and end-of-life batteries after 2030.

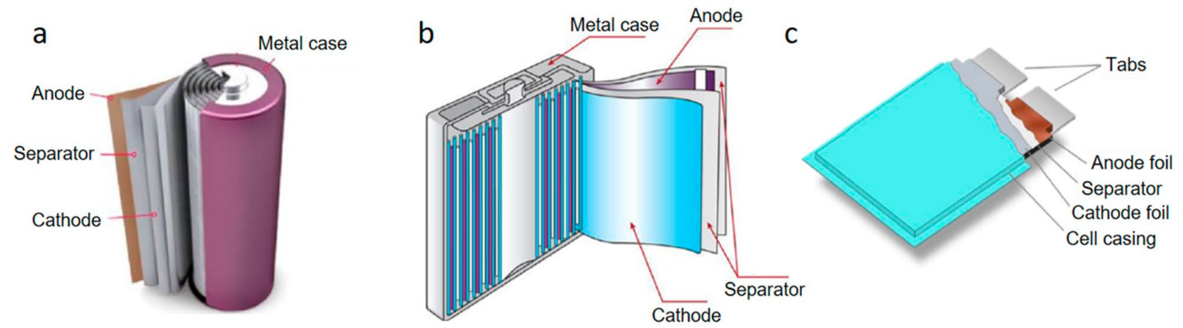
Global total, kiloton[1,2]



[1]Numbers are rounded.
[2]2023 Q1.
Source: McKinsey Battery Insights

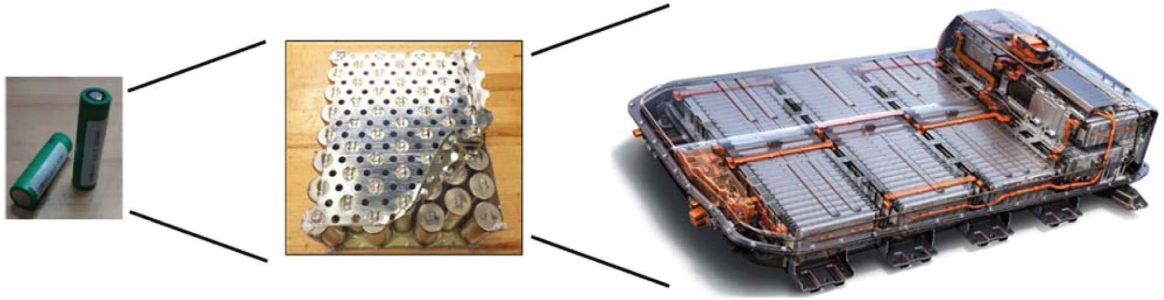
McKinsey & Company

Lithium-ion battery cell components and geometries



Source: https://www.teriin.org/blog/why-battery-energy-storage-key-renewables-growth

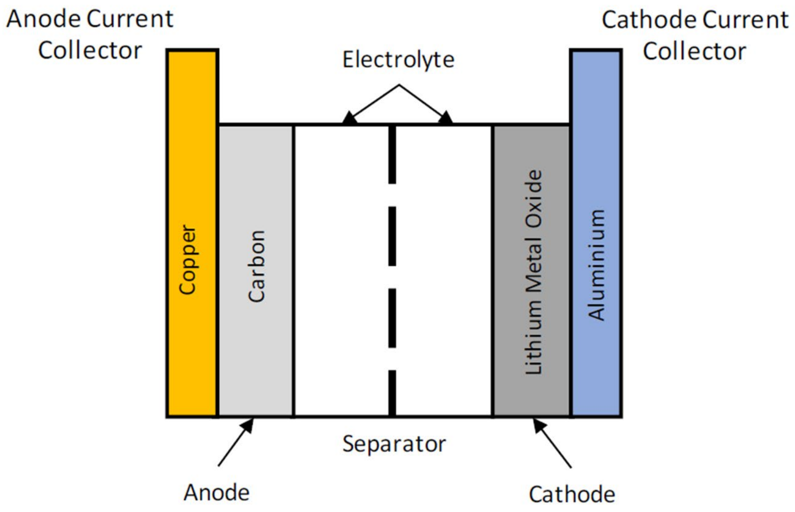
Commonly used cell geometries for battery pack construction: a) cylindrical cell, b) prismatic cell, c) Pouch cell



Single Cells

Battery Module
Mini Cooper EV: 106 cylindrical cells

Battery Pack
Chevrolet Bolt EV: 288 pouch cells



Lithium-ion battery chemistries and materials

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- BYD

- Toyota, General Motors, Volkswagen, Audi, Porsche, Nissan, Hyundai, Ford, Fiat, BMW, Kia, Mitsubishi

- Tesla, Mercedes-Benz B-class E Drive

Comparison of key attributes across EV battery chemistries

LFP: lower cost, lower density, higher discharge cycles
NMC/NCA: higher cost, higher density, lower discharge cycles

	LFP	NMC	NCA
Material composition	Lithium	Lithium	Lithium
	Iron	Nickel	Nickel
	Phosphate	Manganese	Cobalt
		Cobalt	
Average cost *US$ per kWh*	\$90/kWh	\$130/kWh	\$130/kWh
Energy density *pack level*	160 Wh/kg	200 Wh/kg	200 Wh/kg
Discharge recommendation	100%	80-90%	80-90%
Discharge cycles *until 80% capacity*	2,500	1,000	1,000

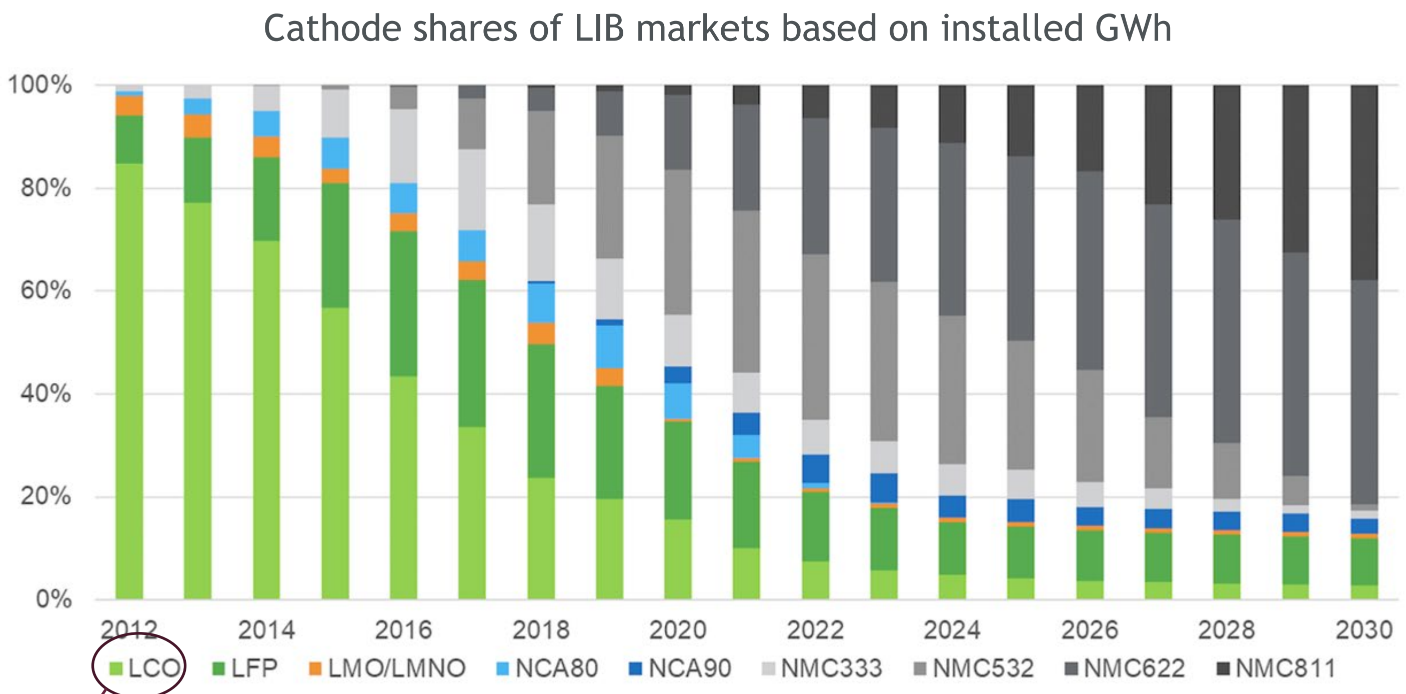
These are estimates only, actual figures will vary depending on make and model of electric vehicle.

Table: zecar • Created with Datawrapper

https://zecar.com/resources/what-are-lfp-nmc-nca-batteries-in-electric-cars

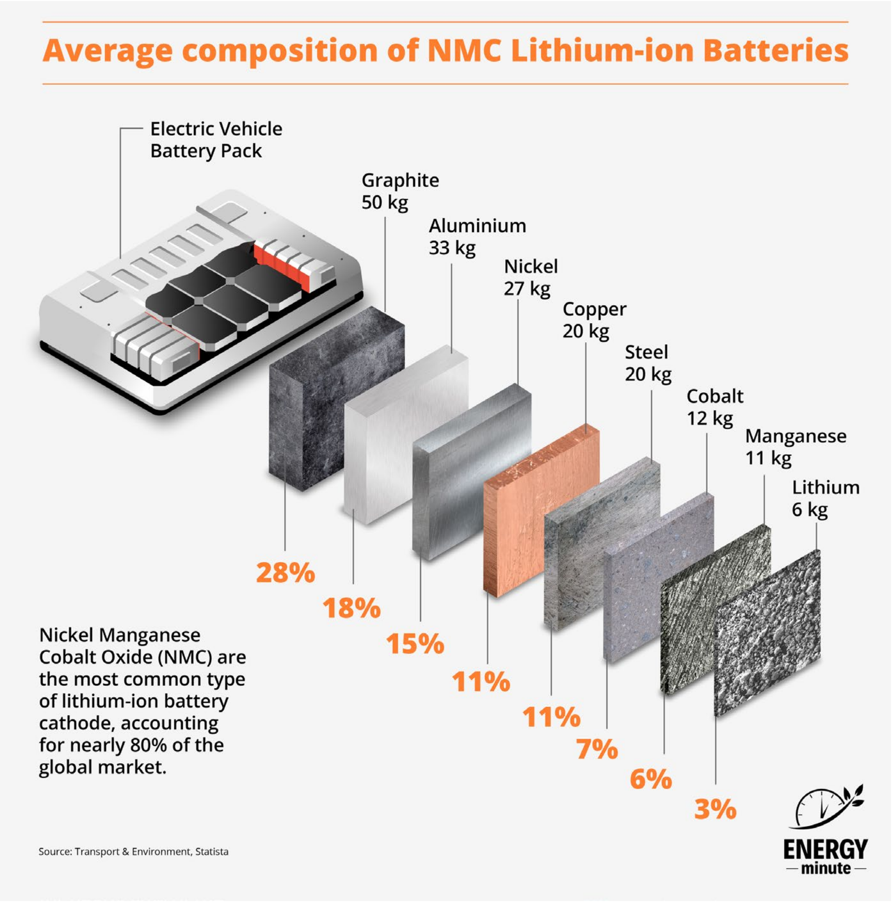
High-nickel cathode battery chemistries remain dominant though lithium iron phosphate is making a comeback

Lithium-ion battery chemistries and materials



Celine, et al., 2020

LCO batteries are in fact the most widely used for smartphones, digital cameras and portable laptops.



https://www.reddit.com/r/dataisbeautiful/comments/12lzo81/metal_components_of_a_lithiumion_electric_vehicle/

Drivers for recycling of lithium-ion batteries

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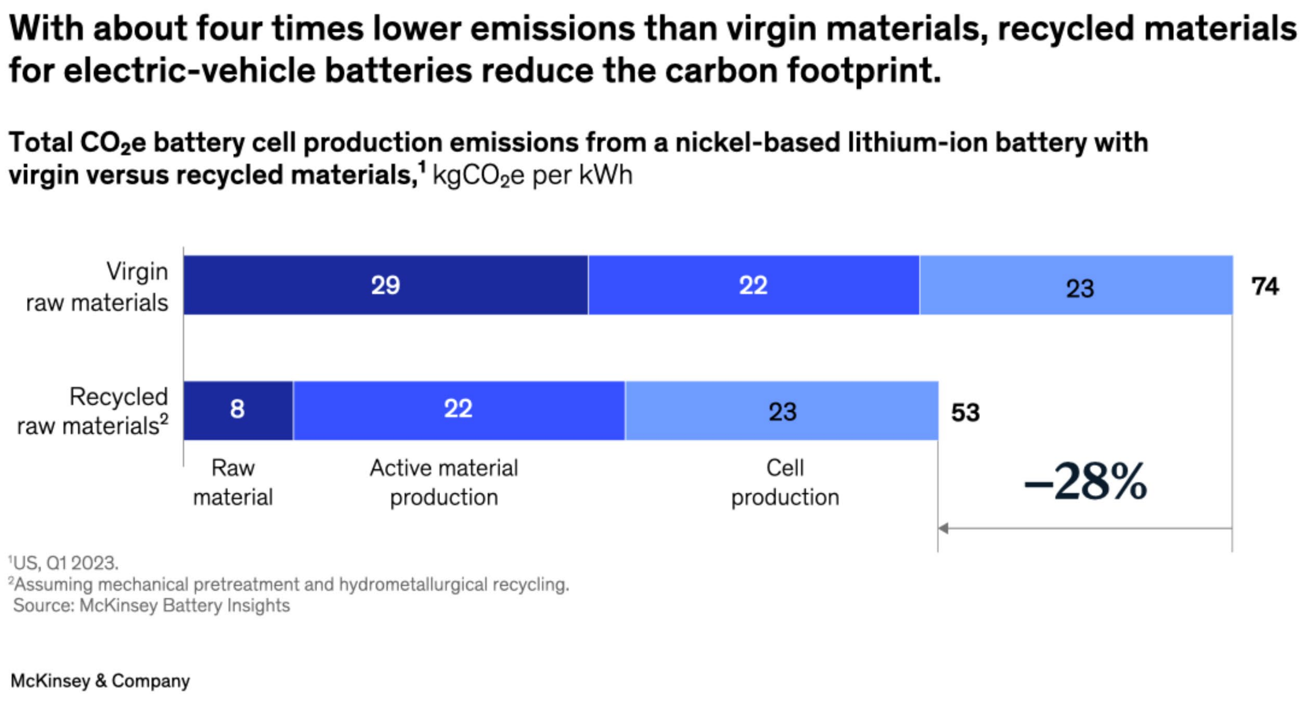
- LIB recycling can play a critical role in alleviating the current and future supply chain concerns,
- prevent possible pollution and environmental hazards, and
- generate sustainable and continuous economic benefits.

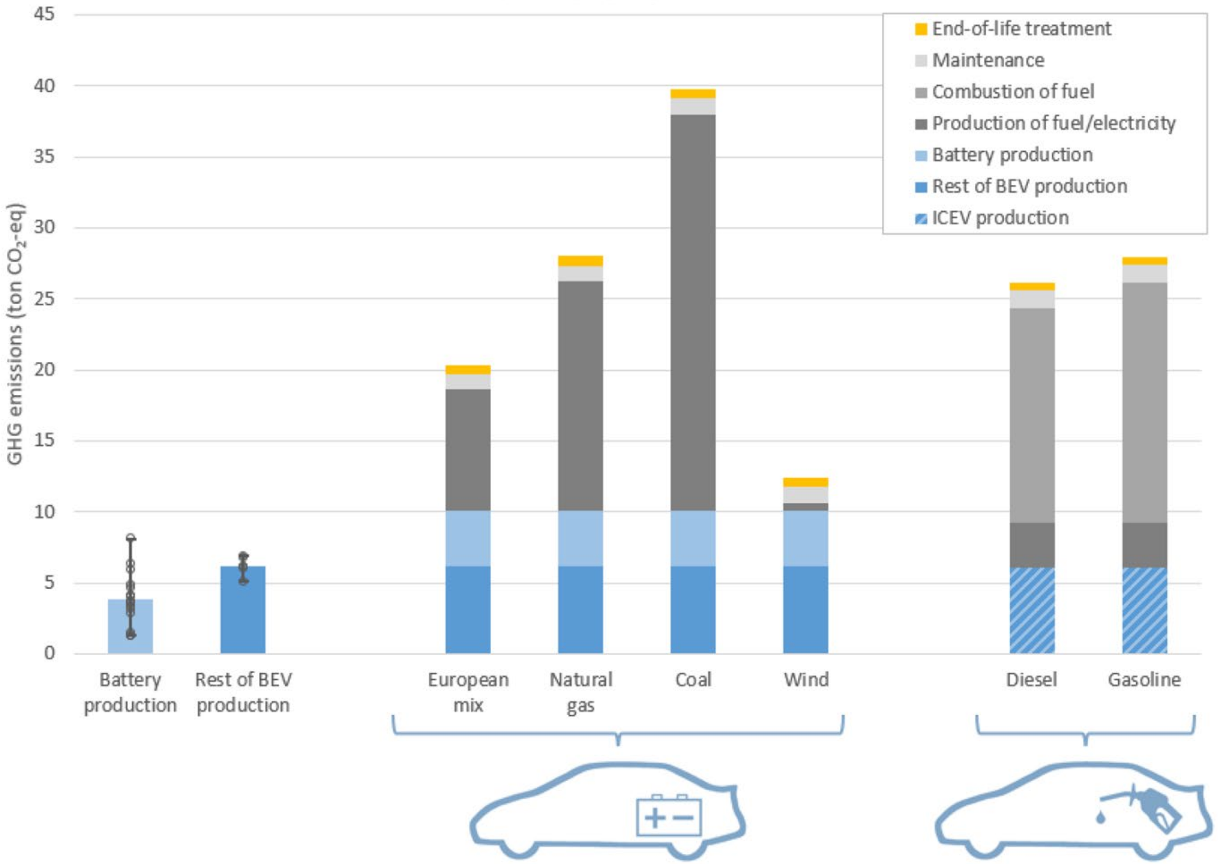
Environmental benefit



Drivers for recycling of lithium-ion batteries

Environmental benefit

Figure E1: Lifecycle GHG emissions of mid-sized 24 kWh battery electric (left) and internal combustion engine (right) vehicles.

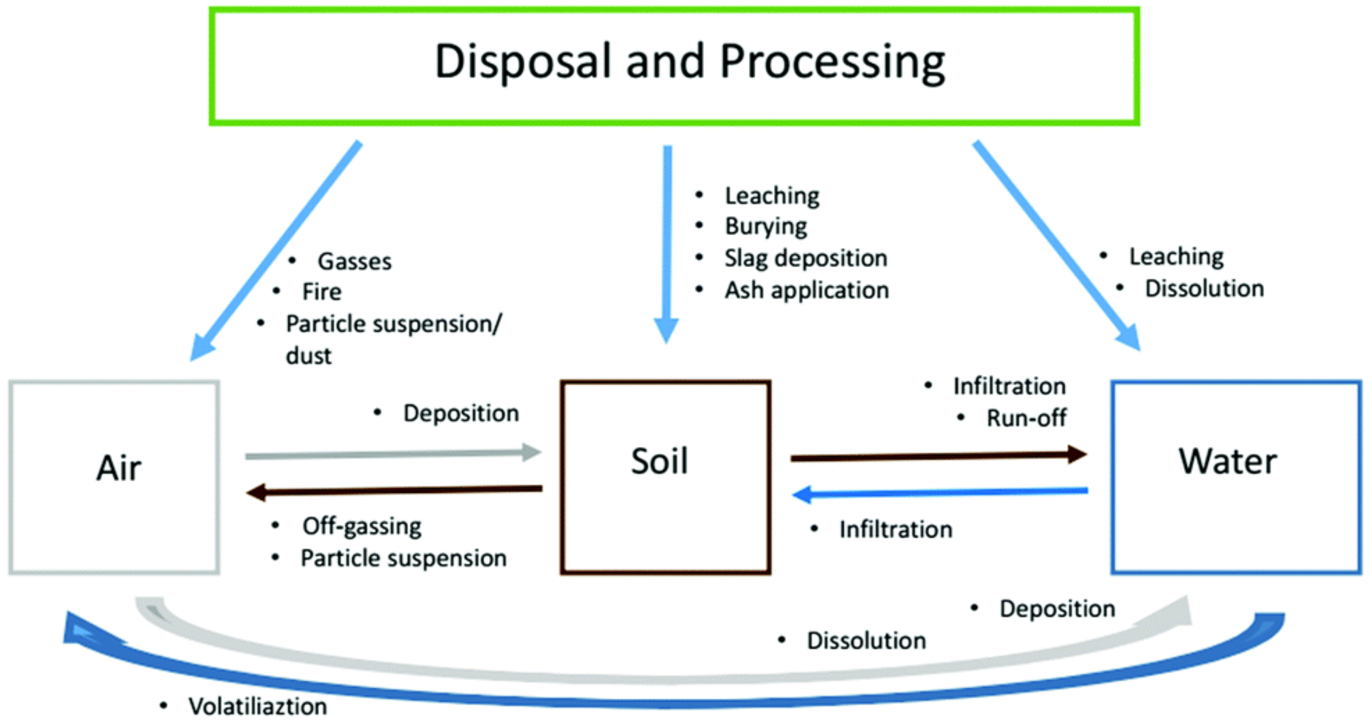


Note: The vehicle's operational lifetime is assumed to be 150 000 km.

Research for TRAN Committee - Battery-powered electric vehicles: market devel-opment and lifecycle emissions, report, Manuscript completed in February 2018©European Union, 2018, ISBN 978-92-846-2668-7

Drivers for recycling of lithium-ion batteries

Environmental benefit



Drivers for recycling of lithium-ion batteries

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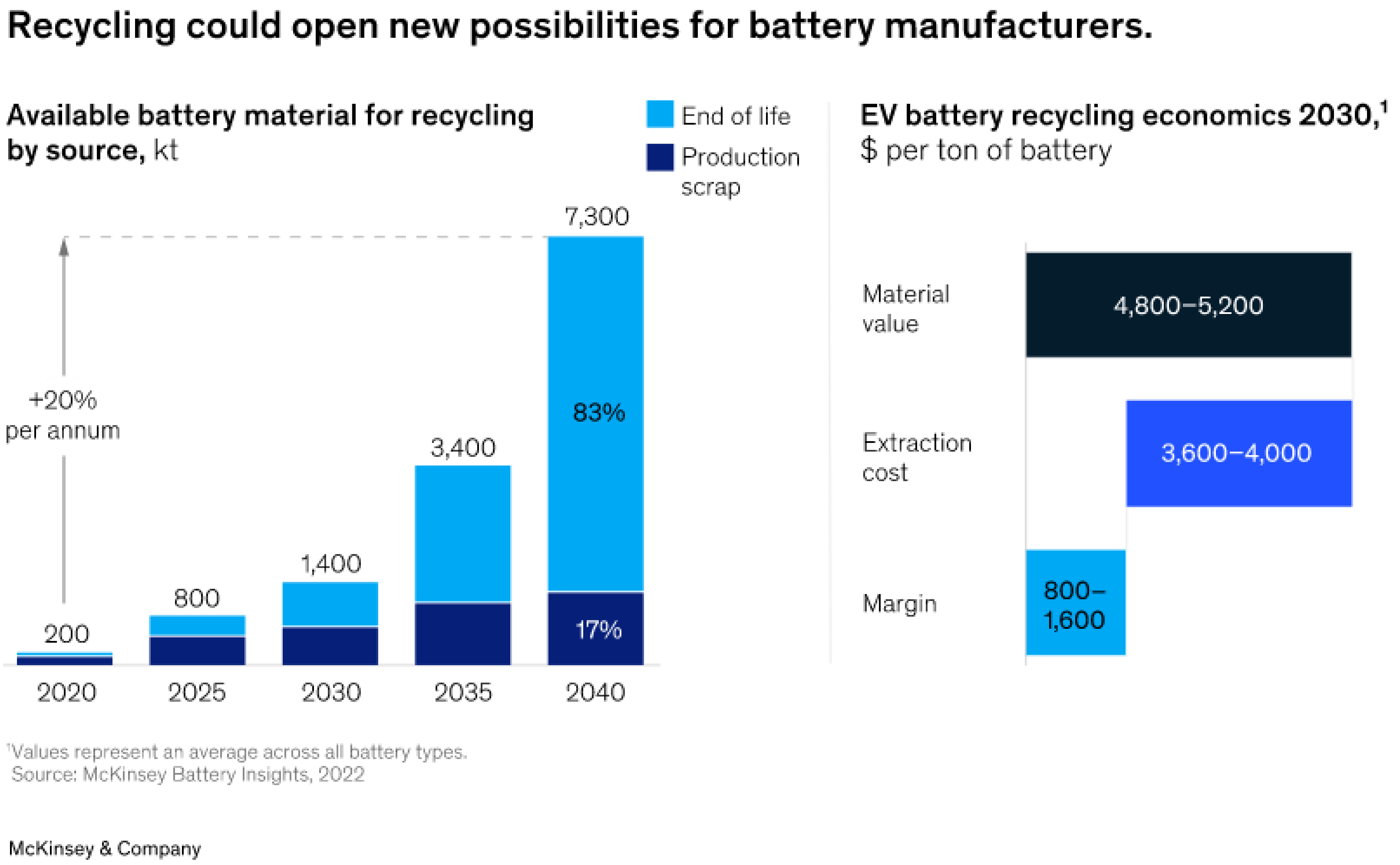
Economic benefit



Drivers for recycling of lithium-ion batteries

Alleviate material supply risks

Figure 3: Relative supply risk indicators and overall supply risk for each element.

Criterion	Indicator	Weighting	Li	Co	C	Mn	Ni	Fe	Cu	Al
Risk of supply restriction	Static reach reserves	8.9 %								
	Static reach resources	5.2 %								
	End-of-life recycling rate	9.2 %								
Risk of demand increase	By-product dependence	3.9 %								
	Future technology demand	14.1 %								
	Substitutability	14.2 %								
Concentration risk	Country concentration	9.7 %								
	Company concentration	13.0 %								
Political risk	Political stability (Worldwide governance indicator)	11.2 %								
	Policy perception index	5.2 %								
	Regulation risk (Human development index)	5.3 %								
Relative overall supply risk										

Note: Comparisons are made across rows, i.e. for each indicator.

Data source: (Helbig et al., 2017).

Drivers for recycling of lithium-ion batteries

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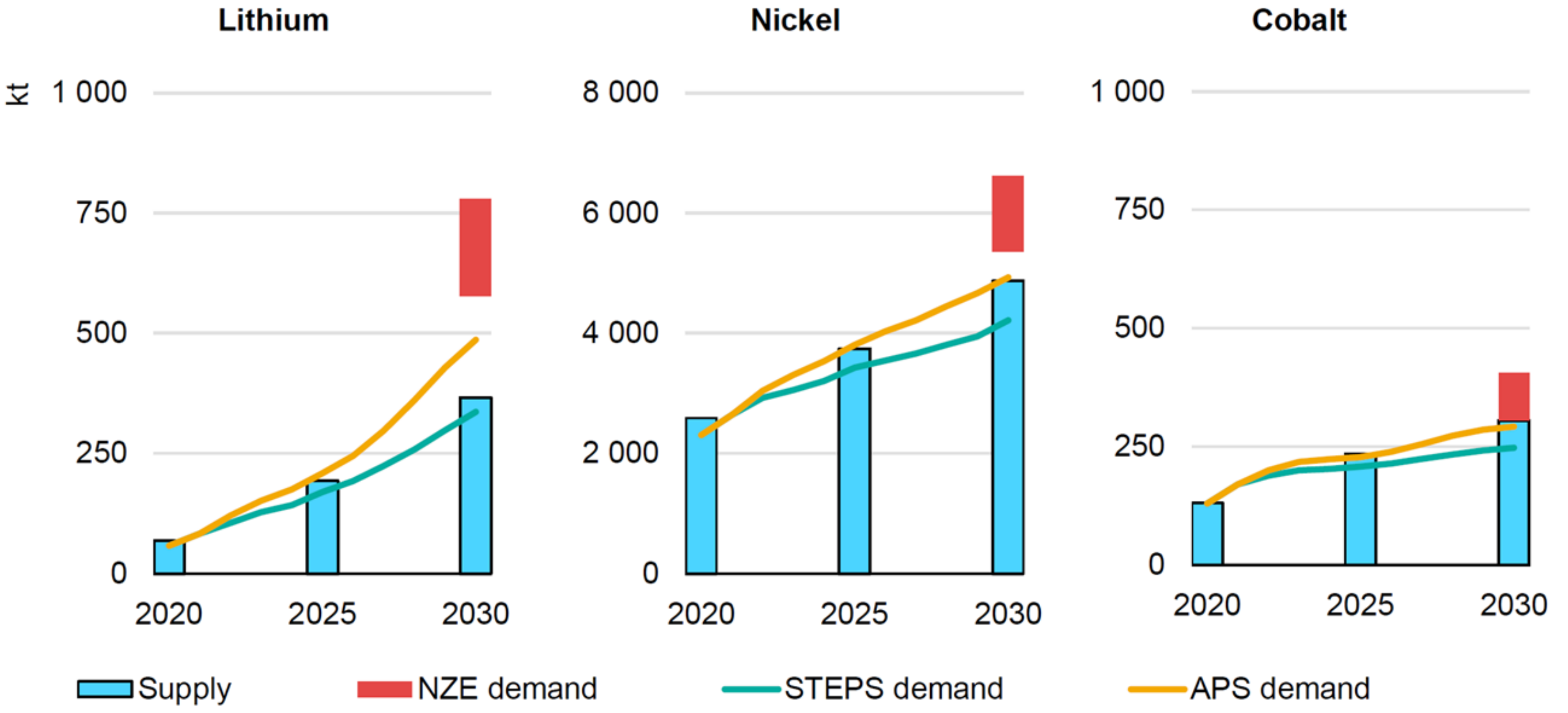
Alleviate material supply risks

Supply projections appear sufficient to meet metal demand in the Stated Policies Scenario…

Total demand and supply for lithium, nickel and cobalt, 2020 - 2030



Notes: NZE = Net Zero Emissions by 2050 Scenario; STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. The NZE bar represents variability in demand if demand-side measures are taken to reduce battery and critical metal demand.
Sources: IEA analysis based on Benchmark Mineral Intelligence for supply capacity.

Drivers for recycling of lithium-ion batteries

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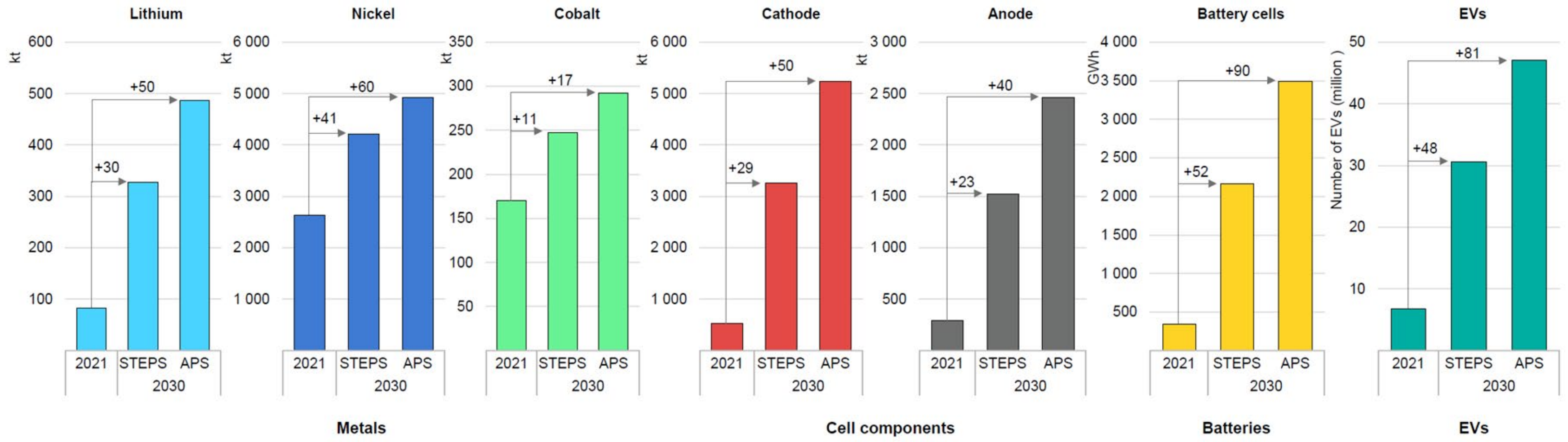
Alleviate material supply risks

All elements of EV battery supply chains expand significantly to meet projected demand

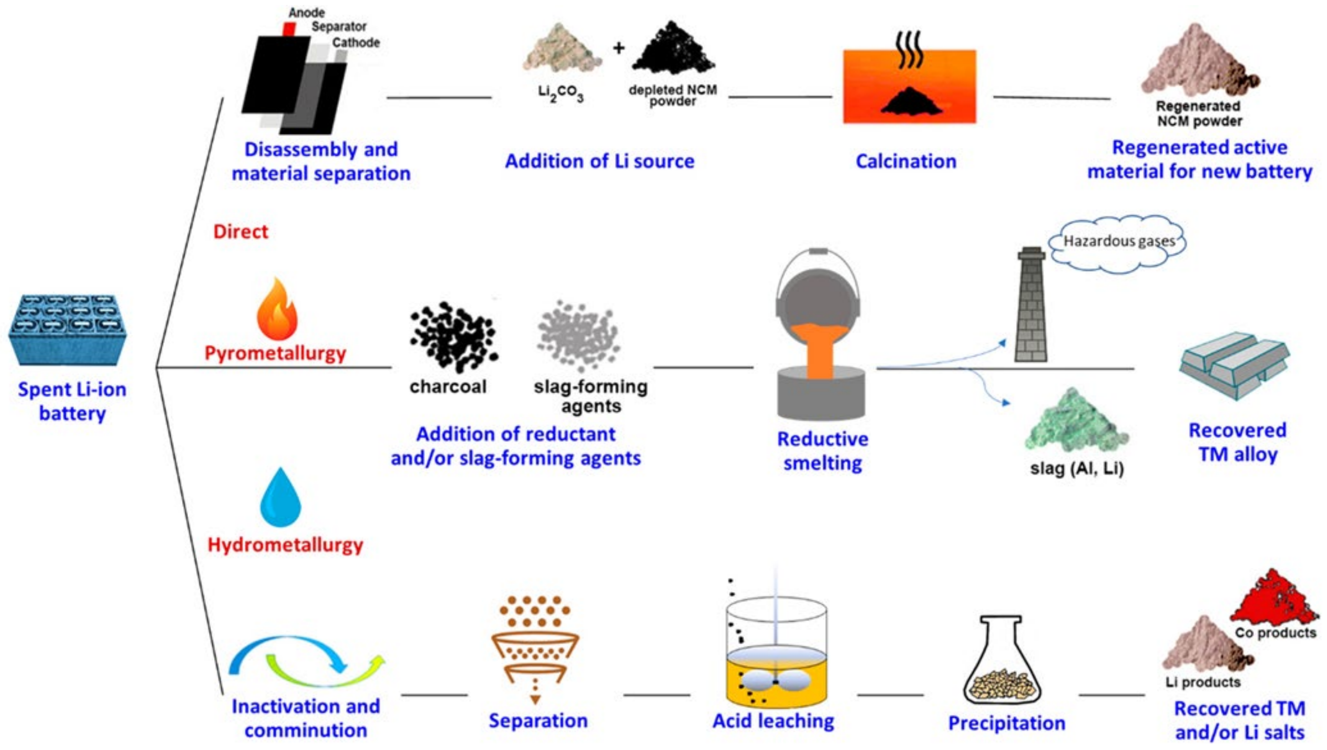
Number of mines to produce required levels of metals, anode/cathode production plants, battery gigafactories and EV plants required to meet projected demand in 2030 relative to 2021



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Number of additional mines/plants/factories required to meet projected demand from the 2021 demand level is shown by the arrows. Projected demand is annual. Metal demand is total demand including EV and non-EV demand. Assumes the average annual production capacities: lithium mine - 8 kt; nickel mine - 38 kt; cobalt mine - 7 kt; cathode plant - 94 kt; anode plant - 54 kt; battery gigafactory - 35 GWh; and EV production plant - 0.5 million vehicles. Nickel demand does not distinguish between Class 1 and Class 2 nickel.

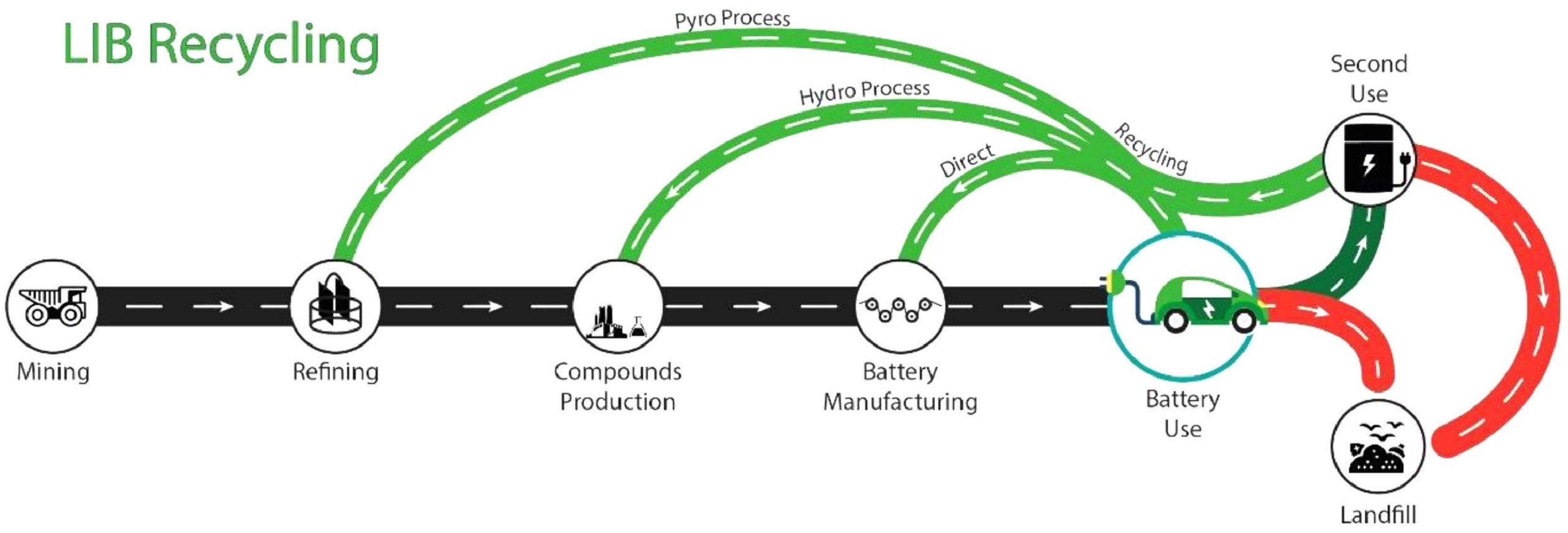
Sources: IEA analysis based on S&P Global ; Bloomberg NEF; Benchmark Mineral Intelligence.

Recycling methods



ACS Energy Lett. 2022, 7, 2, 712-719

Recycling methods



C.M. Costa, J.C. Barbosa, R. Gonçalves, H. Castro, F.J. Del Campo, S. Lanceros-Méndez,
Recycling and environmental issues of lithium-ion batteries: Advances, challenges and opportunities, Energy Storage Materials, Volume 37, 2021,

The ELiMINATE project: Overview

- ERA-MIN project, 3 years
- Collaboration between South Africa, Sweden and Turkey
- Objective:
  - To develop an implementation framework for LIB recyclers to integrate innovative hydrometallurgical recycling processes in Europe and South Africa

Department of Chemical Engineering: Prof Christie Dorfling, Prof Guven Akdogan

Department of Industrial Engineering: Prof Louis Louw

Coordinator, funded by DSI

Funded by TUBITAK

Funded by Vinnova

The ELiMINATE project: Approach

1. Comparing existing and novel processes:

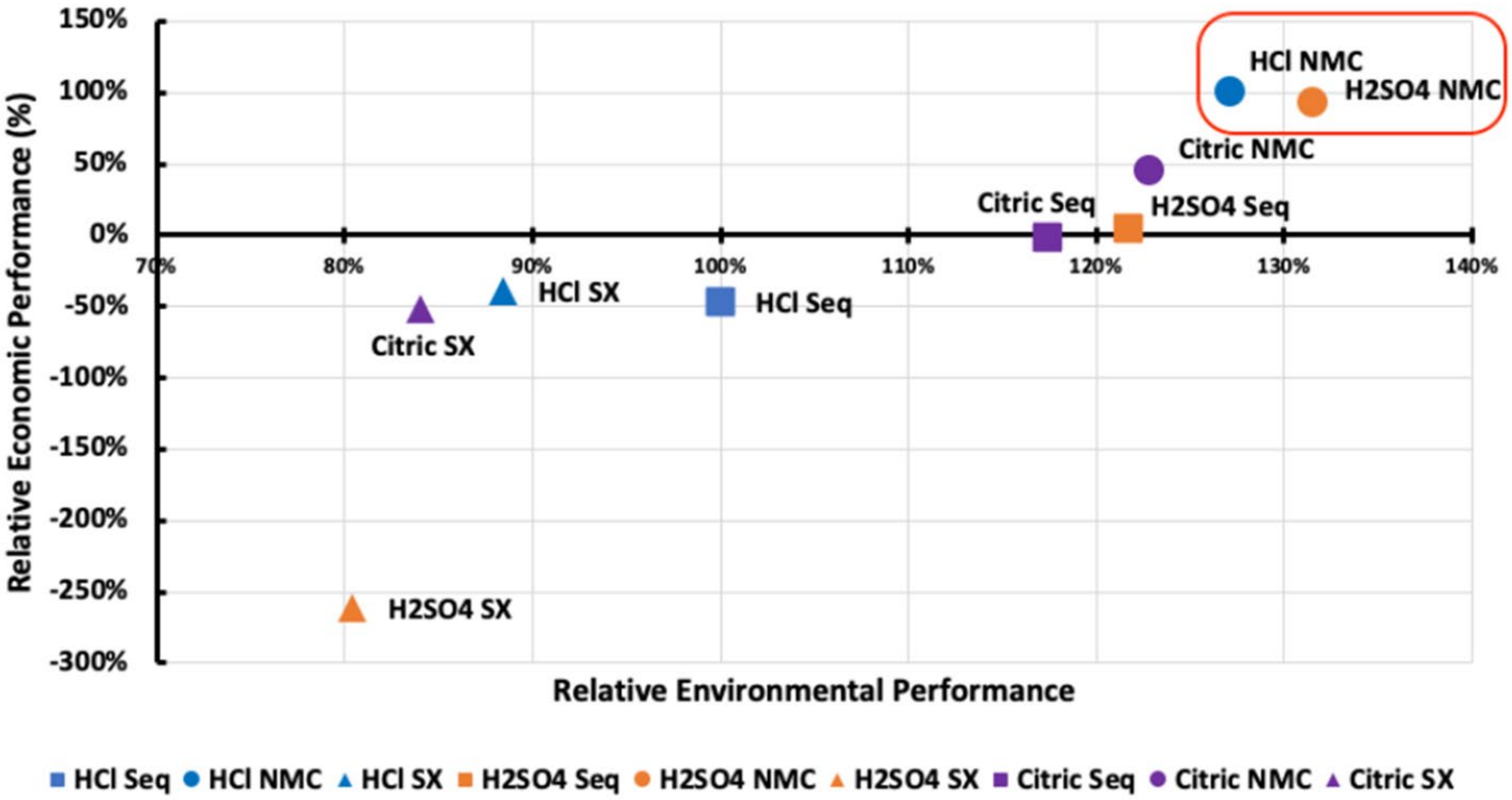
1. **Mineral acid-based**
   - Existing: Hydrochloric or sulfuric acid-based
   - Novel: Sulfuric acid using solvent displacement crystallization (SDC)
2. **Organic acid-based**
   - Existing: Citric acid-based
   - Novel process: Methanosulfonic acid (MSA)-based
3. **Thermal pre-treatment**
   - (to potentially complement hydrometallurgical processes)

2. Making a selection

3. Developing an implementation framework for recyclers, including:

1. Business and economics
2. Lifecycle impacts
3. Reverse supply chain network design for material flow optimization

The ELiMINATE project : Economics and LCA



Maritz, 2022

The ELiMINATE project : SA LIB supply volumes

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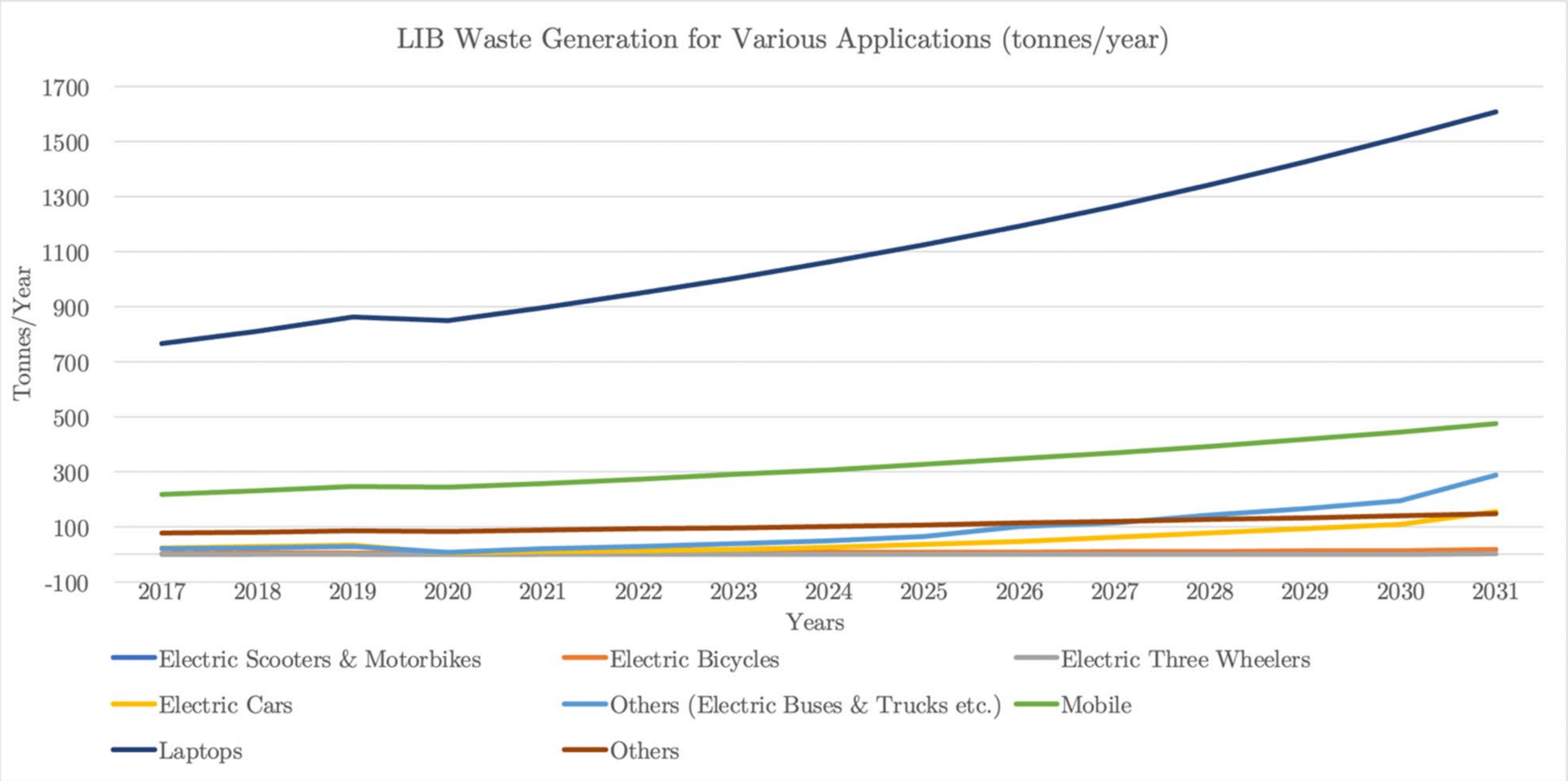
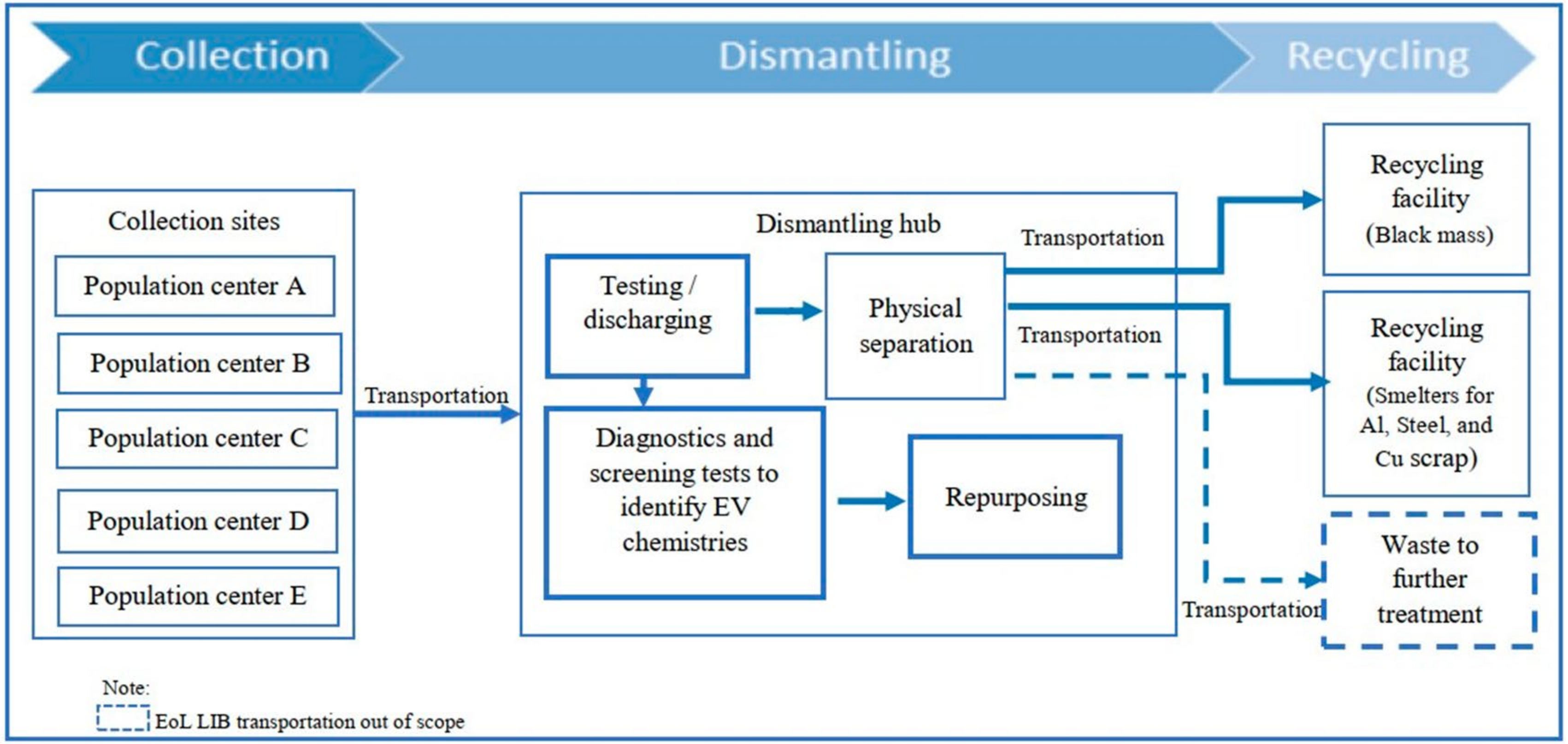


The ELiMINATE project: Reverse logistics



Gonzales-Calienes, G.; Yu, B.; Bensebaa, F. Development of a Reverse Logistics Modeling for End-of-Life Lithium-Ion Batteries and Its Impact on Recycling Viability—A Case Study to Support End-of-Life Electric Vehicle Battery Strategy in Canada. *Sustainability* **2022**, *14*, 15321. https://doi.org/10.3390/su142215321

The ELiMINATE project: Reverse logistics and recycling facility network for SA

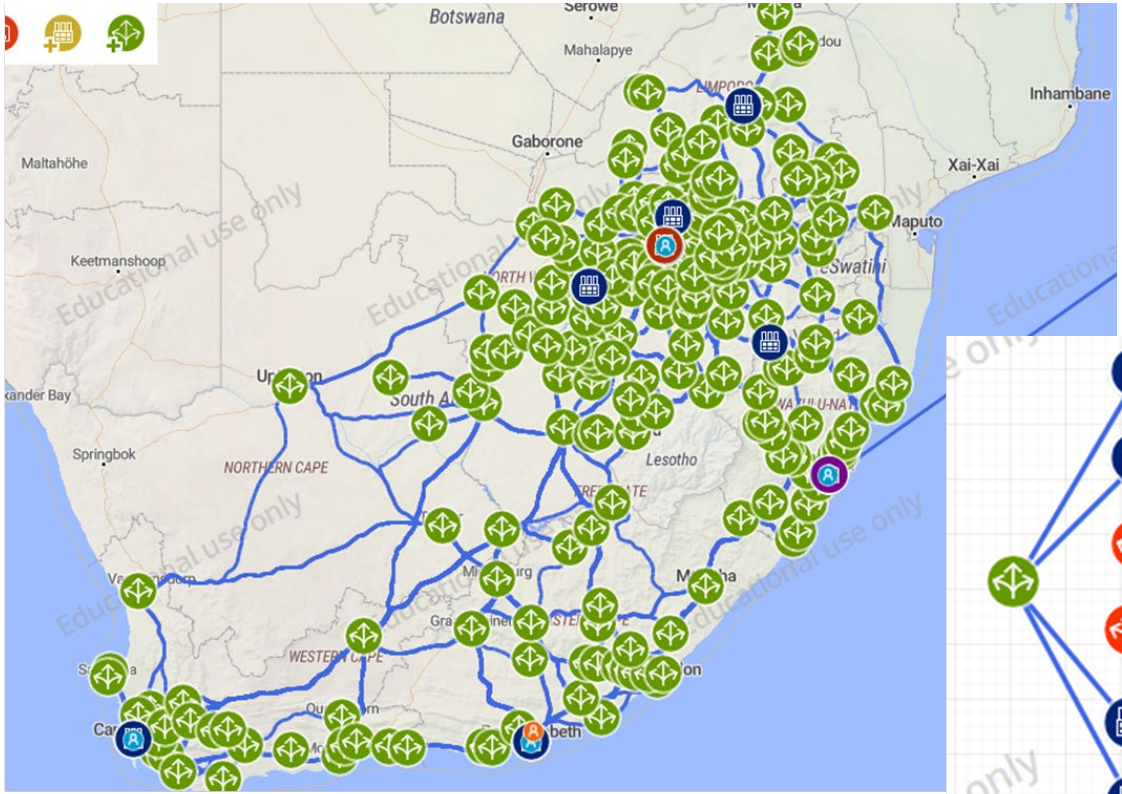


Fig 3: ALX RLN simulation for the HCl_NMC scenario for 2023 – 2033.

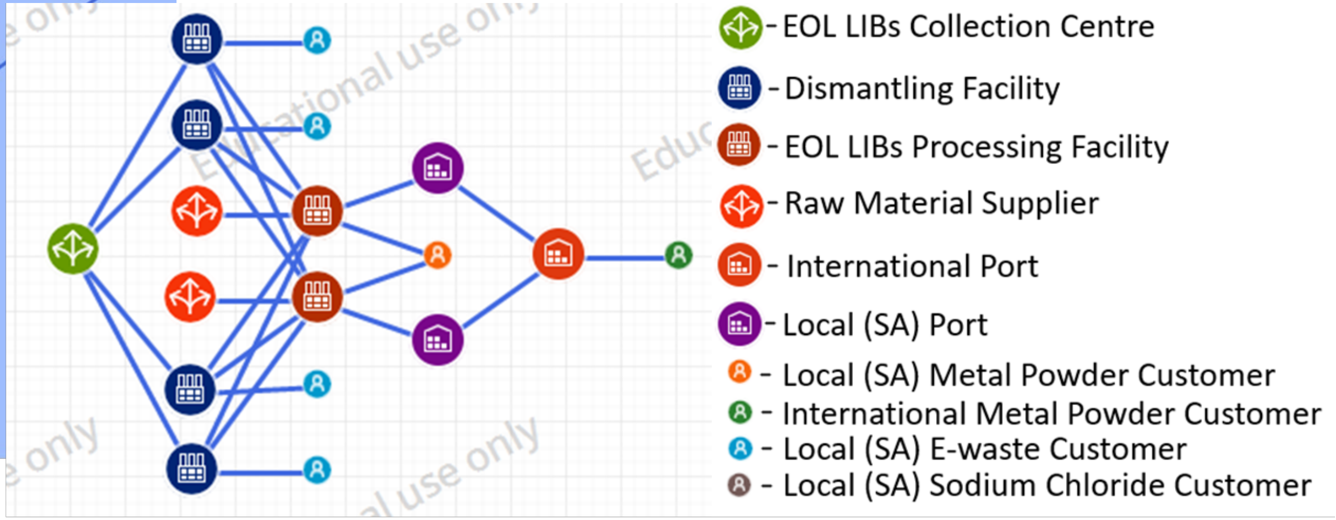


Fig 4: RLN echelon structure for the CA_MP multiple facility scenario for 2023 – 2033.

The ELiMINATE project: Consolidated framework

- Results will be consolidated in a guiding framework for establishing innovative recycling facilities and reverse logistic networks
- One for Europe and one for South Africa
- Includes:
  - Current and future state of the market (including regulatory environment)
  - For the selected recycling processes:
    - Business model and strategy
    - Lifecycle impacts
    - Optimised material flow network

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Thank you
Enkosi
Dankie

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