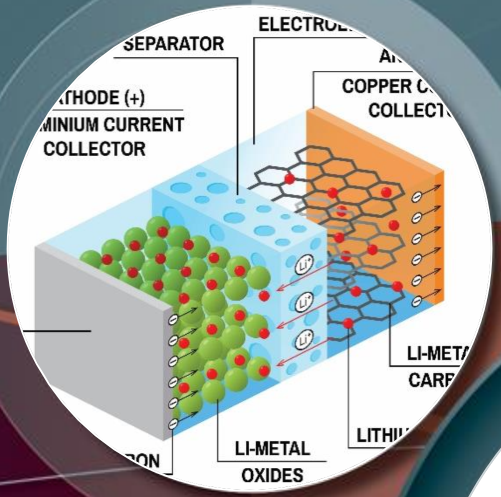
Recycling of Li-ion batteries in South Africa



Mariekie Gericke, Wonder Nyanjowa, Stefan Robertson– 13 August 2021

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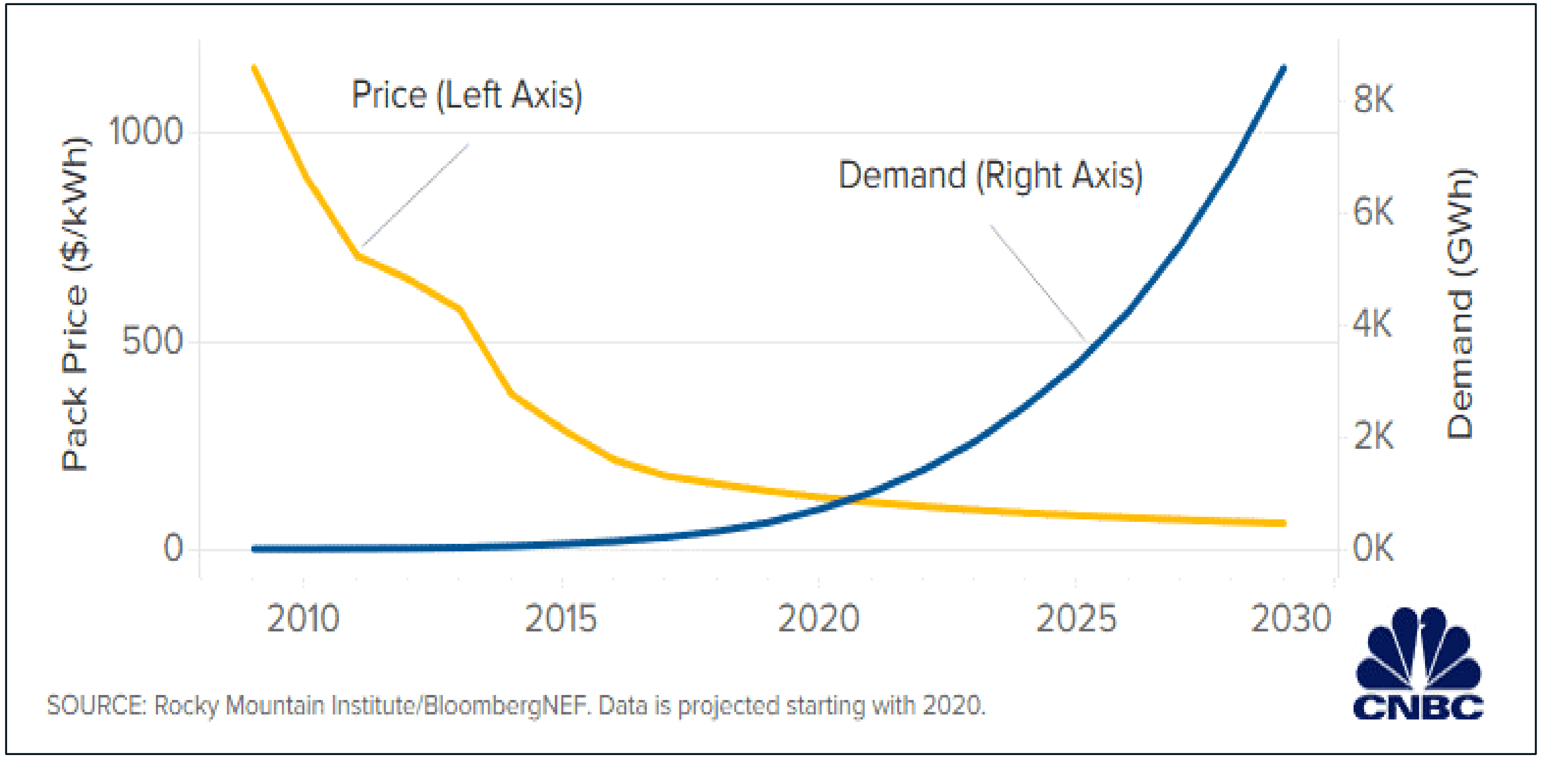
Why lithium-ion batteries (LIB)?



- Extensive cost reductions over the last decade
- High energy and power density
- Easy to charge
- Long life-span

Global production of lithium-ion batteries

Country	Total Capacity (MWh) 2019	Share of Total Capacity (%)	Automotive Capacity (MWh)
China	118 234	62.3	50 670
Japan	22 479	11.8	19 414
South Korea	18 547	9.8	17 874
USA	24 766	13.1	22 016
EU	2 626	1.4	2 400
Rest of the World	3 110	1.6	2 110
Total	**189 762**	**100**	**114 484**

China, Japan and South Korea collectively accounted for 84% of global LIB production capacity for all applications during 2019

Source: Mayyas *et al.*, 2018

Growth in global battery demand predicted between 2020 and 2030

Segment	Expected demand	Expected compound annual growth rate (CAGR)
Automotive and transport	8.6TWh	+21%
Energy storage	418GWh	+16%
Portable electronics	604GWh	+3%

(IHS Markit Sept 2020)

The automotive and transportation sectors are poised to become the single largest and fastest growing segment of the global LIB market, reaching 8.6TWh by 2030

99% of stationary energy storage deployments in 2019 used Li-ion technologies (Wood Mackenzie Power & Renewables, 2020)

Drivers for recycling Li-ion batteries

- Economic considerations - metals contained in LIBs include Li, Co, Ni and Cu of which Co is the most valuable
- Compliance with environmental regulations and policies
- Reducing reliance on primary mining activities
- Increasing consumer education and social awareness of the waste problem
- Increasing efficiency in recycling technologies
- Generation of local economic activities

Source: Theminingexecutive.com

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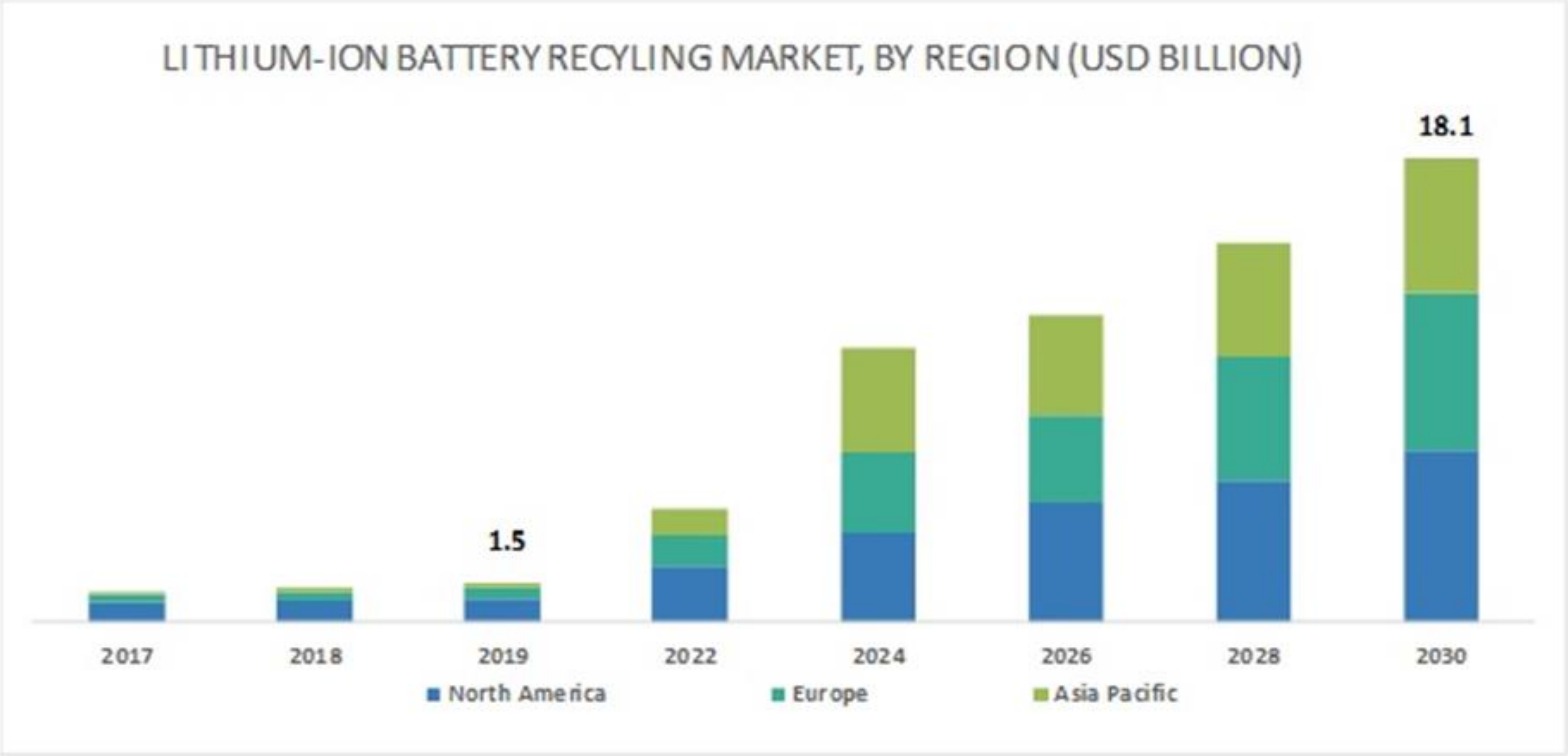
What is the Global LIB Recycling Industry Worth?



- Markets and Markets estimated the global LIB recycling industry to have been worth approximately **$1.5 billion in 2019.**
- The global LIB industry recycling sales will increase to **$12.2 billion in 2025** and reach **$18.1 billion by 2030.**

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Global Recycling Trends

Globally quantities of LIBs being recycled remains small due to:

- Low LIB waste collection volumes
- Difficulties in storage and transportation of LIBs
- The complexities in different LIB designs and numerous battery chemistries
- Limited information on the profitability of LIB waste recycling

LIB recycling takes place in close proximity to LIB manufacturing facilities:

- Closed-loop systems with recycling at the end-of-life provide a source of recycled battery materials that can be re-used by manufacturers for production of new batteries
- Without a local LIB manufacturing sector, the local demand for resources recovered from LIB waste will also be lower

North American and Asian regions are anticipated to lead the growth in LIB recycling activities between 2020 and 2030

Situation in South Africa

- No facility for the recycling of lithium-ion batteries in South Africa and Africa

- Lack of reliable data on:
  - the quantities of the waste LIB material that are potentially available for recycling
  - the origins, flows, intermediate and final markets of LIB fractions

- Such information critical in informing the decisions on technology selection, as well as determining the economic viability of the chosen process

- From a policy perspective it is critical in determining the interventions required to unlock potential business opportunities in the LIB sector

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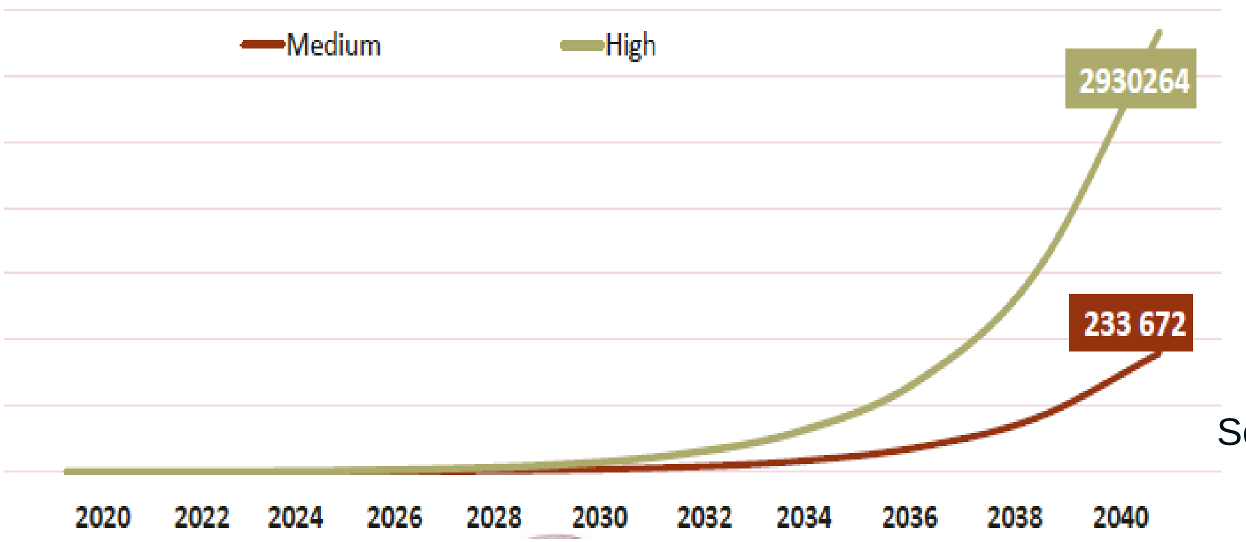
Uptake of Electric Vehicles in South Africa

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Petrol	289 911	343 489	373 022	370 392	360 122	340 982	297 019	302 227	302 440	299 408
Diesel	48 598	56 317	68 260	79 357	78 155	70 908	63 765	65 516	62 605	55 563
PHEV	-	-	-	-	-	124	168	121	89	72
BEV	-	-	-	34	14	117	100	68	58	154
HEV	430	627	766	513	646	266	213	182	55	181

HEV BEV PHEV Diesel Petrol

EV sales in SA (Montmasson-Clair et al., 2020)

Projected electric car sales in South Africa, stimulated market (number of units)[1]



Source: Eskom

- **High purchase prices** major deterrent for EV uptake.
- **High import tax** applied to EVs, making it unaffordable for potential buyers.
- More affordable EV models are expected to enter the country should existing barriers to entry be relaxed.
- A wider variety of models at various price points would help to stimulate the local market.

Current situation in South Africa

Low LIB waste collection volumes	• South Africa is estimated to have collected between 6 tons - 10 tons of LIB waste from WEEE recycling activities in 2019. • However DEFF's banning of landfilling of LIBs (Aug 2021) can change this as was the case with lighting equipment in Aug 2016.
Laptops and mobile phones are the major source WEEE streams for LIB waste recovery	• Laptops and mobile phones are the major source WEEE streams for the recovery LIB waste in South Africa. There is no evidence of LIB waste recovered from industrial equipment (fork lifts, scooters) and electric vehicles joining the recycling value chain.
Storage and transportation of LIBs are major challenges for recyclers	• The storage of LIB waste to accumulate sufficient volumes onsite and transportation of the material to the market are major operational challenges for recycling companies in South Africa due to their highly flammable nature and low collection volumes.

Current situation in South Africa

Non-existent or undeveloped market for LIB waste in South Africa	• **Unlike PCBs, ferrous and non-ferrous metal fractions, the market for LIB waste in South Africa is non-existent or undeveloped.**
LIBs are predominantly being landfilled	• **The bulk of LIB waste recovered from recycling activities in South Africa are primarily landfilled in hazardous landfill sites and at a significant cost to the recyclers. This will change following the banning of the landfilling of battery waste beginning August, 2021.**
LIB re-use market is very small and negligible in SA	• **The re-use market for LIBs is very small and negligible in South Africa. This is due to the relatively smaller size of the computer refurbishment market when compared with the recycling market.**

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Current situation in South Africa

Merchants from North Africa, Middle East and Asia buying LIBs from SA	• As is the case with WEEE plastics and PCBs, there is evidence of some merchants from North Africa, Middle East and Asia that buy LIBs from South Africa for onward sale to their clients in Asia but their purchasing patterns are erratic and unpredictable.
Electric vehicles expected to be the game changer in South Africa's LIB recycling industry	• While electric vehicles are anticipated to be the game changer in SA's LIB recycling industry, there are currently no end of life LIBs from electric vehicles joining the recycling value chain.
Implementation of the extended producer responsibility (EPR) regulations set to radically transform South Africa's LIB recycling industry	• Compelling automotive and ICT OEMs to take ownership of their products from 'cradle to grave' can result in the development of dedicated LIB collection infrastructure, increase in LIB collection volumes and the development of a LIB processing plant in the country.

Lithium Ion Battery Recycling Technologies

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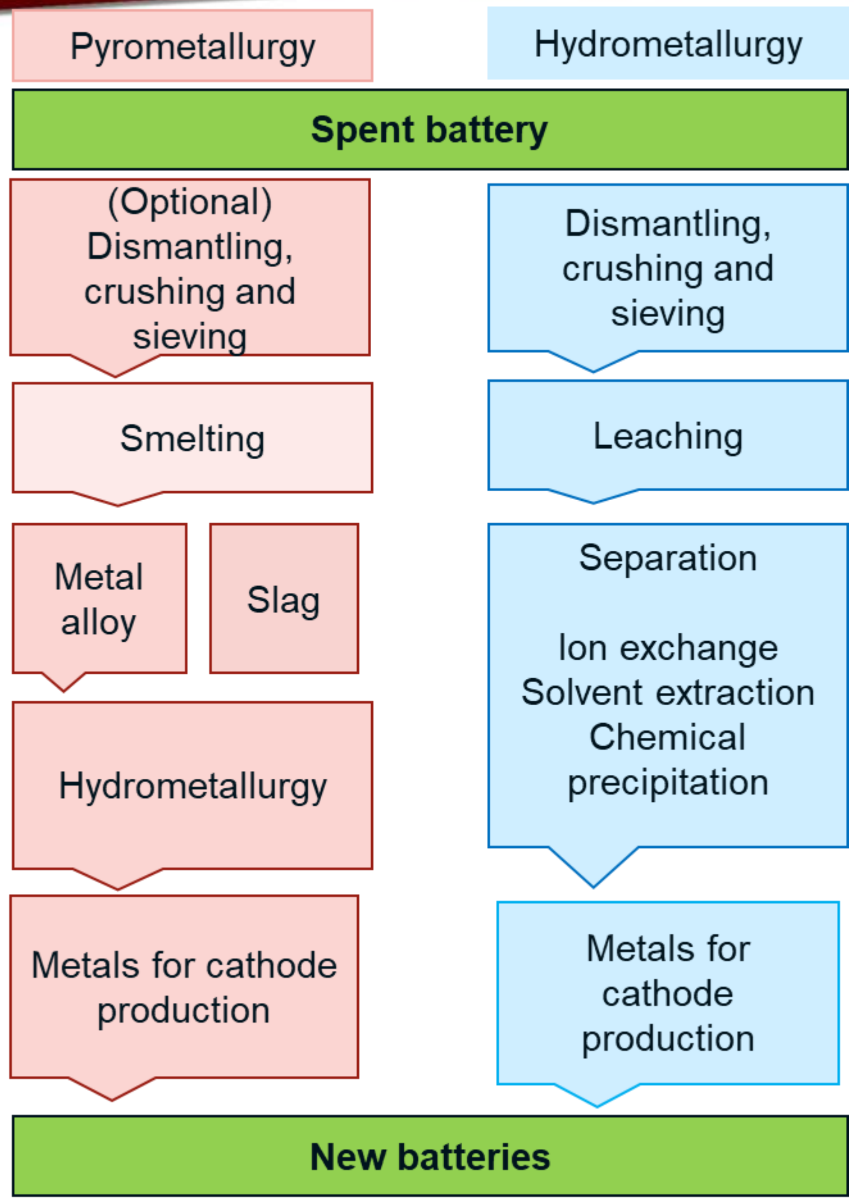
Current commercial recycling use pyro- and hydrometallurgical technologies



Pyrometallurgical (smelting) - Applicable to any battery chemistry and configuration, capital-intensive, producing significant GHG emissions.
High recovery of key metals such as Co, Ni and Cu.
Li and Al lost in the slag.

Hydrometallurgical (chemical leaching) - much less energy intensive, high recovery and purity of materials. Reagents costly.

Can be used separately or in combination

Direct recycling - battery materials recovered and can be reintroduced into the supply chain with little additional processing. Electrolyte removed. Cells crushed and parts separated using e.g. density. Has been demonstrated at bench scale

Pyrometallurgical technologies

Technology	Feed	Process	Capacity (tpa)	Country
Umicore ValEas™ (UHT Technology)	LIB, Li-polymer, nickel-metal hydride (NiMH)	Pyrometallurgical processing Cu, Co, Ni, Cu recovered from the alloy by dissolution and precipitation using hydrometallurgy	7 000	Belgium
Sumitamo-Sony	LIB	Pre-processing: Sorting and dismantling. Pyrometallurgical treatment (high temperature calcination)	150	Japan
SNAM	NiCd, NiMH, LIB	Pyrometallurgical Refining (hydrometallurgical)	300	France
Accurec GmbH (EcoBatRec process)	Various including LIB. Originally developed for Ni-Cd batteries	Combination of mechanical treatment (sorting, dismantling), pyrometallurgical (electric furnace) and hydrometallurgical processes	6 000	Germany (batch industrial scale)
Batrec Industrie AG	Developed for Zn and Hg recovery from alkaline and Zn-C batteries.	Stored and shredded under CO_2 atmosphere. Mechanical, followed by pyro- and hydrometallurgical treatment	200	Switzerland
The International Metals Reclamation Company (INMETCO)	Not originally designed for LIB Li and Ni-based batteries secondary feed to plant. Do not take EV batteries	Pyrometallurgical (Rotary hearth furnace, further refined in electric furnace)	6 000	USA
Dowa Eco-System	All lithium batteries	Pyrometallurgical	1 000	Japan
Nickelhütte Aue Gmbh	Secondary raw materials e.g. Co-, Cu- and Ni-bearing spent catalysts. LIB secondary feed to plant.	Pyrometallurgical, followed by acid leaching	20 000	Germany

Hydrometallurgical Technologies

Technology	Feed	Process	Capacity (tpa)	Country
Retriev Technologies (previously TOXCO)	All types, including primary and secondary LIBs, LIB scrap and Pb-acid batteries	Liquid nitrogen deactivation Physical processing include manual disassembly and hammer mill, screening followed by hydrometallurgical treatment	4 500 4 000	Canada USA
Recupyl Valibat	Primary or secondary LIBs and zinc-based batteries	Physical processing (crushing, vibrating screen, secondary screen, magnetic separator, densimetric table) followed by hydrometallurgical treatment (selective precipitation)	110 (pilot) 320 (commercial)	Pilot plant: France Commercial plant: Singapore (TesAMM)
Duesenfeld (Lithorec based)	LIB	Mechanical and hydrometallurgical	3 000	Germany
Euro Dieuze	LIB	Hydrometallurgical treatment	200	France
Green Eco-Manufacture (GEM)	Originally a battery and white goods recycling company	Mechanical pre-treatment and hydrometallurgical. Very limited information available on the process.	300 000 (LIB and waste Co Ni materials)	China (16 recycling industrial parks in China)
Hunan Brunp Recycling Technology (largest LIB recycling company in China)	Various, including LIB, NiMH	Hydrometallurgical leaching in acid (limited information available on flowsheet). Plant which will produce 100,000 tpa of LIB scrap under construction in Hunan province.	Currently 30 000 tpa	China
Shenzhen Green Eco-manufacture Hi-Tech Co	LIB, NiMH	Hydrometallurgical	20 000	China
Bngpu Ni/Co Hi-Tech Co	LIB	Hydrometallurgical	3 600	China
SungEel HiTech	LIB	Hydrometallurgical		South Korea
JX Nippon Mining and Metals	LIB	Focus on cathode materials. Leaching in acid, followed by solvent extraction. Metal recovery: Cu and Ni: Electrowinning. Mn and Li: carbonate precipitation	Pilot plant (2010)	Japan (Tsuruga plant)
AEA Technology	Li	Remove electrolyte, solvent and binder with organic solvent. Leaching of cathode material.	Unknown	UK
Battery Resourcers	LIB	Mechanical (Discharge, shredding, magnetic separation) followed by hydrometallurgical leaching and precipitation.	Unknown	USA

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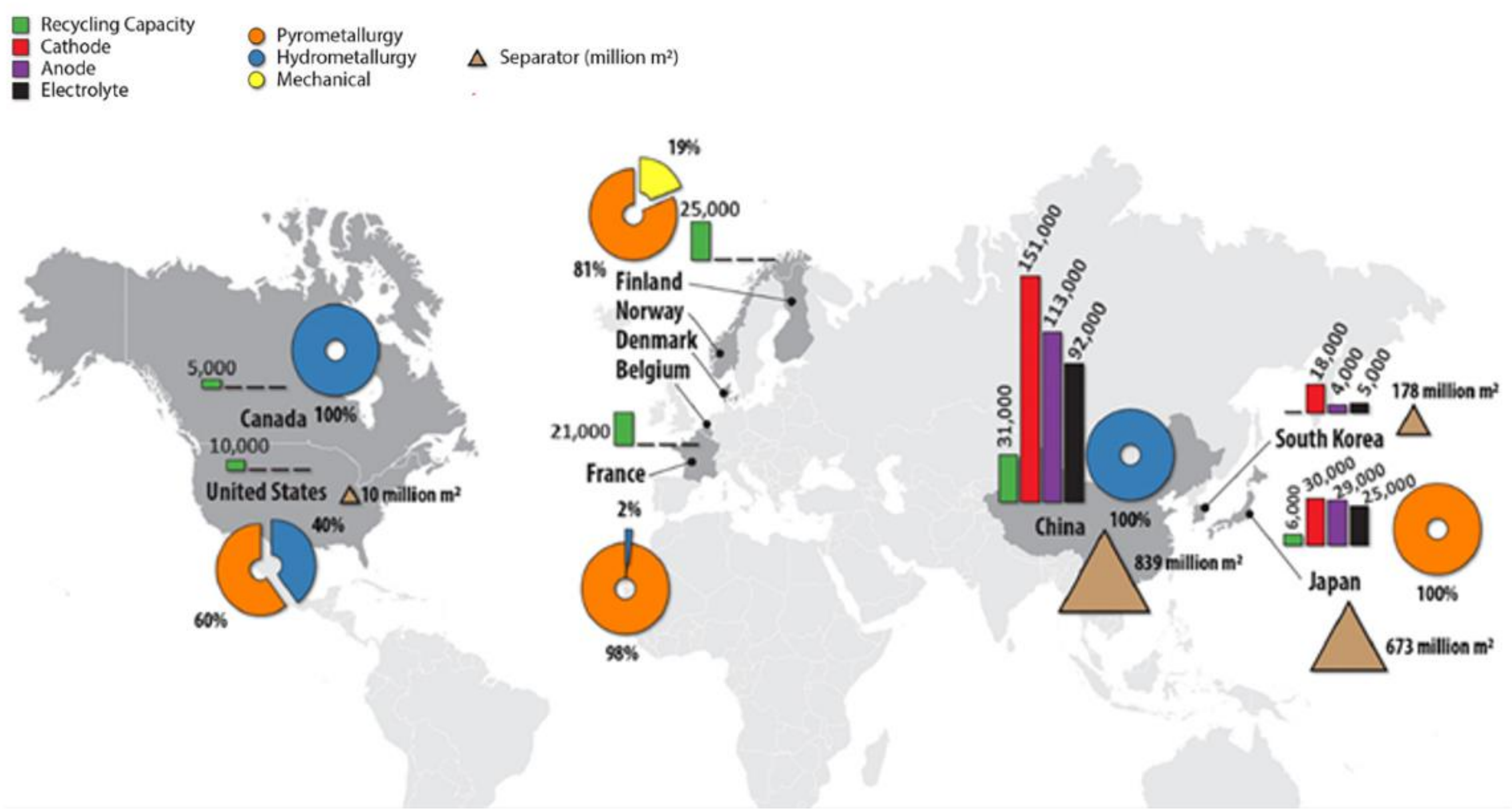
Emerging companies

Technology	Process	Capacity (tpa)	Country
Neometals	Mechanical (shred, remove steel casing and plastic). Upgrade Li, Co, Ni, Cu into black mass followed by 2-stage hydrometallurgical process. Refine to battery material grade.	Pilot plant (100 kg/d)	Pilot plant in collaboration with SGS Canada. Joint venture between Neometals and SMS Group (Primobius GmbH) to demonstrate the technology in Germany (20 000 tpa)
LiCycle Corp	Mechanical size reduction technology processing cathode and anode materials. Hydrometallurgical metal recovery (Rochester plant)	Mechanical processing (5000tpa) Hydrometallurgical plant (365tpa)	Demonstration facility: Canada Commercial scale plant plant planned: New York State (25 000)
American Manganese (RecycLiCo™)	Hydrometallurgical treatment of LIB chemistries, LCO, NMC, NCA	3 t/d LIB Cathode recycling plant in conceptual phase	USA (pilot plant)
Fortum (Crisolteq technology)	Mechanical and hydrometallurgical treatment of mainly NMC		Finland
Northvolt (gigafactory) and Norsk	Mechanical (automated process) Black mass refined hydrometallurgically at Northvolt facility.	Pilot: 8 000 Commercial plant at Gigafactory: 25 000	Norway (pilot) Sweden (refining and commercial plant)
SungEel MCC Americas (SMCC)	Hydrometallurgical	5 000	USA Joint venture partner is SungEel HiTech who has similar facility in South Korea.
Argonne laboratories (ReCell centre)	Direct cathode recycling	Lab-scale, piloting planned	USA

Location of Global Recycling Capacity



Country	Recycling capacity
Asia	47%
Europe	32%
USA/Canada	15%

Country	Recycling activity (2019)
Asia	85 000 tons
Europe	15 000 tons
USA	<10 000 tons
Australia	66-99 tons (2-3%) (exported)
Total	110 000 tons

China and Canada: 100% hydrometallurgical processes
Europe: Focus on pyrometallurgy (mostly existing facilities)
USA: Both pyro- and hydrometallurgy

Source: Mayyas et al., 2018, Danino-Perraud 2020, Steward et al., 2019

Techno-economic study

LIB recycle flowsheet and costing model

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Basis for techno-economic study

- Three generic flowsheets considered:
    - Pyrometallurgical
    - Hydrometallurgical
    - Physical processing to produce a black cathode powder (black mass)

- Variables investigated include battery chemistry and plant capacity
- Capital and operating costs for all the options were benchmarked against similar published studies
- Profitability was assessed by comparing internal rates of return

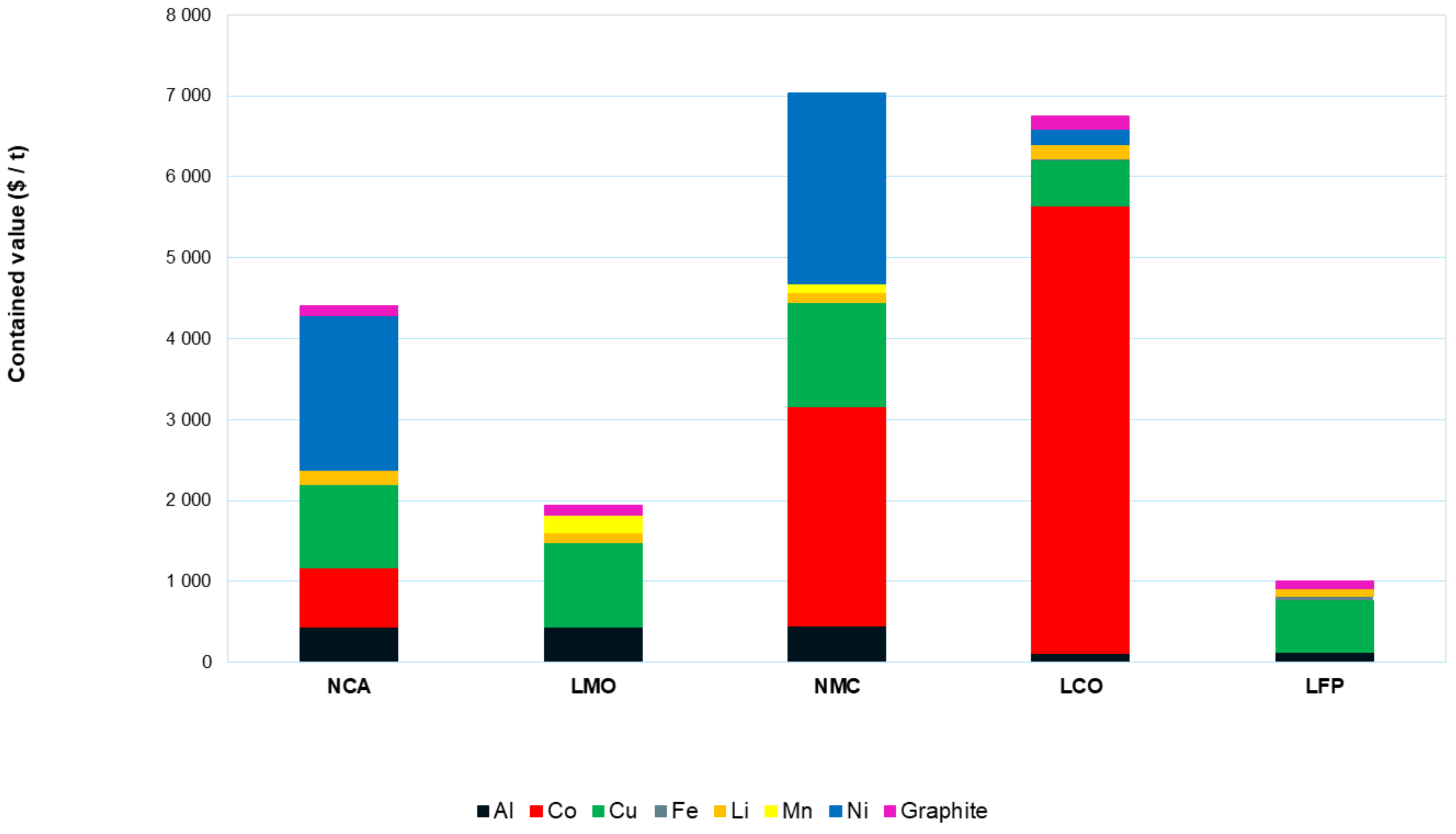
Techno-economic study: Feed compositions

Battery type		NCA	LMO	NMC	LCO	LFP	Blend [**]
Global market share		0.072	0.214	0.29	0.372	0.052	
		Nickel Cobalt Aluminium	Lithium Manganese Oxide	Nickel Manganese Cobalt	Lithium Cobalt Oxide	Lithium Iron Phosphate	
Al	%	21.9	21.7	22.72	5.2	6.5	15.1
Co	%	2.3	0.0	8.45	17.3	0.00	9.1
Cu	%	13.3	13.5	16.6	7.3	8.2	11.8
Fe	%	0.1	0.1	8.79	16.5	43.2	11.0
Li	%	1.9	1.4	1.28	2.0	1.2	1.6
Mn	%	0.0	10.7	5.86	0	0	4.0
Ni	%	12.1	0.0	14.84	1.2	0	5.6
Binder	%	3.8	3.7	1.39	2.4	0.9	2.4
C (non-graphite)	%	2.4	2.3	3.47	6.0	2.3	4.0
Eletrolyte + solvent	%	11.7	11.8	1.66	14.0	14.9	9.8
Fluoride	%	-	-	4.99	-	-	1.4
Graphite	%	16.5	16.3	-	23.1	13.0	13.9
Thermal insulation	%	1.3	1.4	-	-	-	0.4
Oxygen	%	8.3	12.4	4.52	-	-	4.6
Phosphorous	%	-	-	2.04	0	5.4	0.9
Plastics	%	4.4	4.7	3.4	5	4.4	4.4
		100	100	100	100	100	100

[***] Blend according to global market share ratios

Kelleher Environmental [2019]

Techno-economic study: Contained value



Contained value per tonne of LIB feed

<u>Assume current prices</u>:

Al 1.9 $/kg

Co 34 $/kg

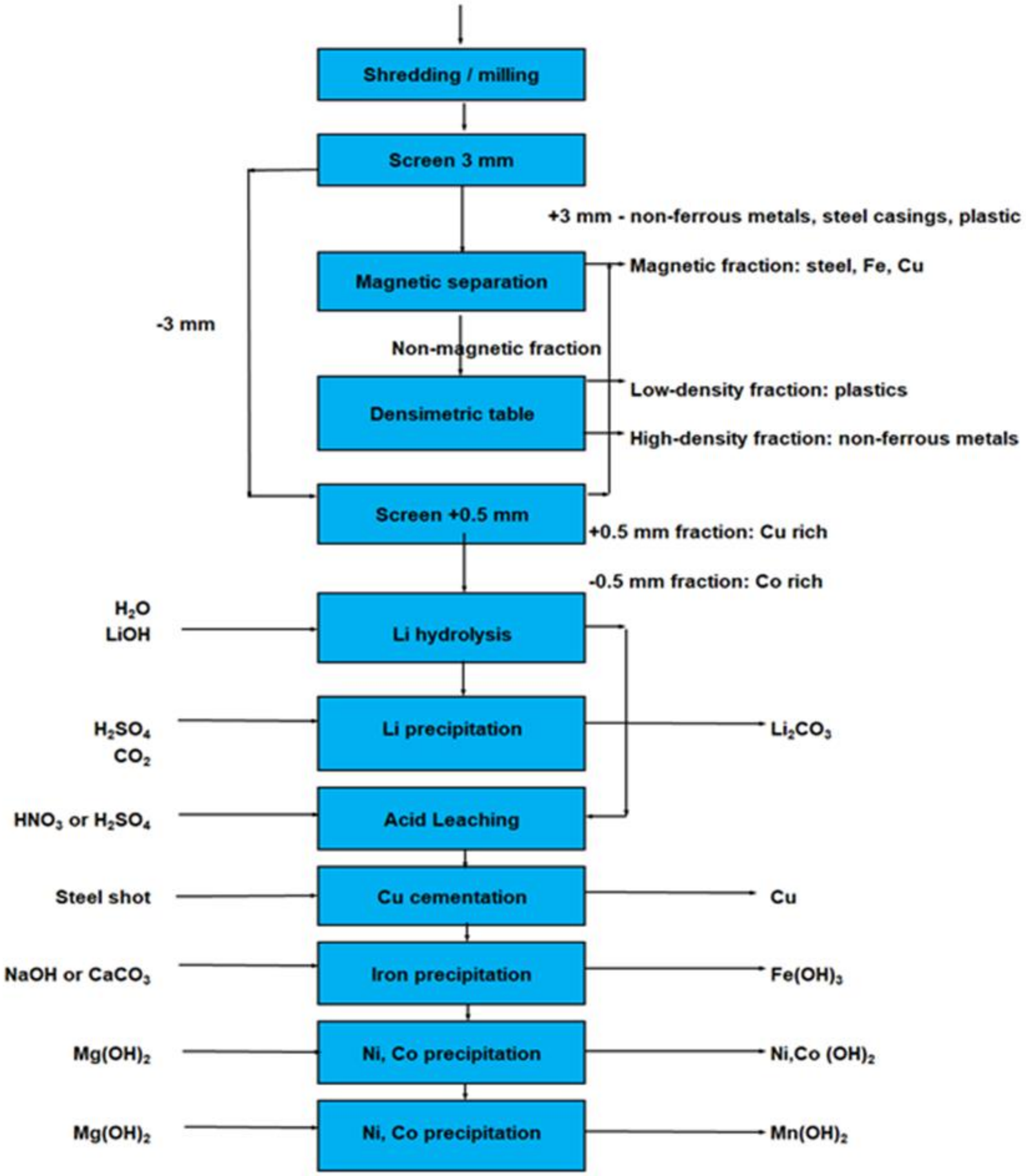
Cu 7.7 $/kg

Fe 0.1 $/kg

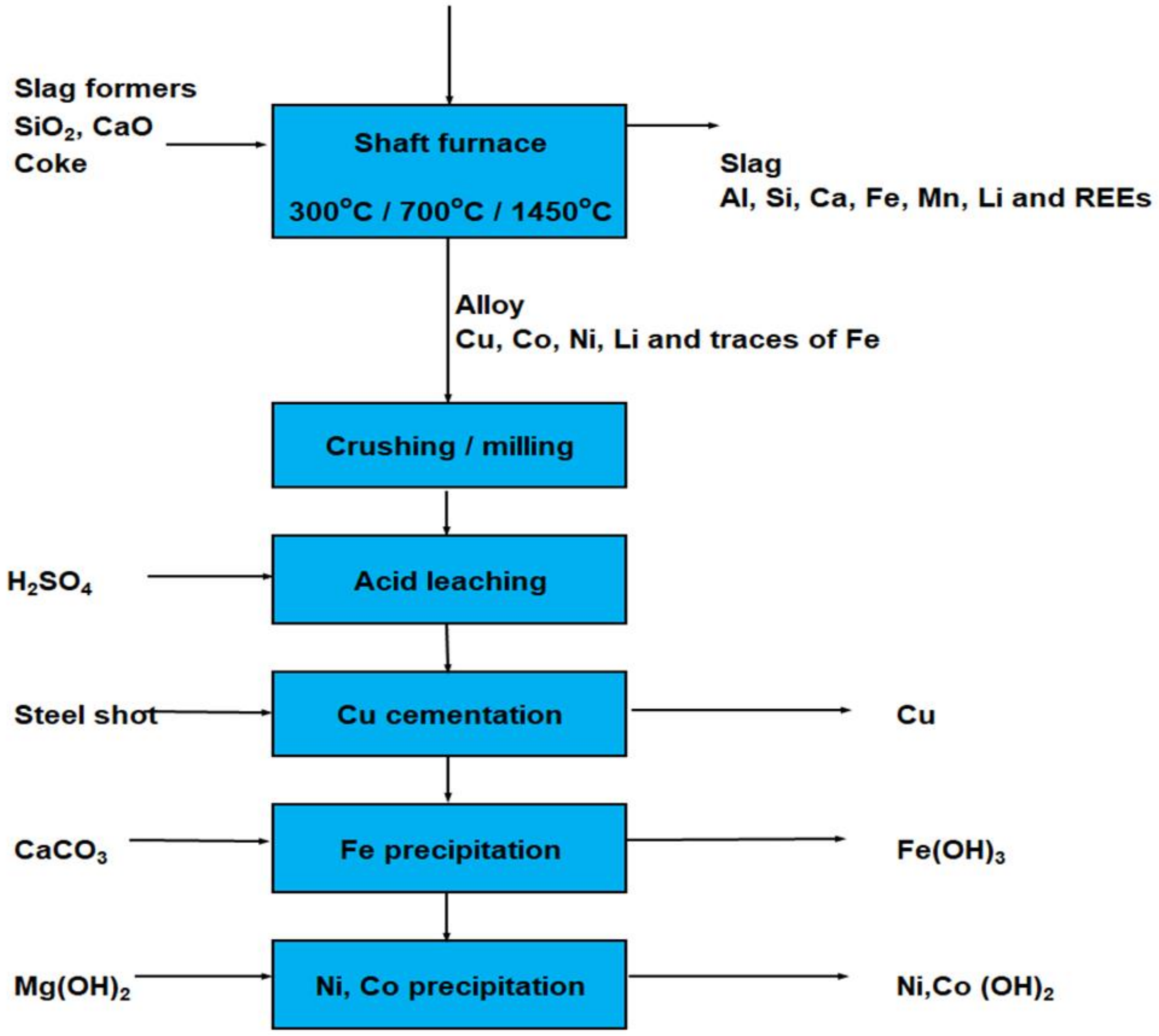
Li 8.8 $/kg

Ni 15.8 $/kg

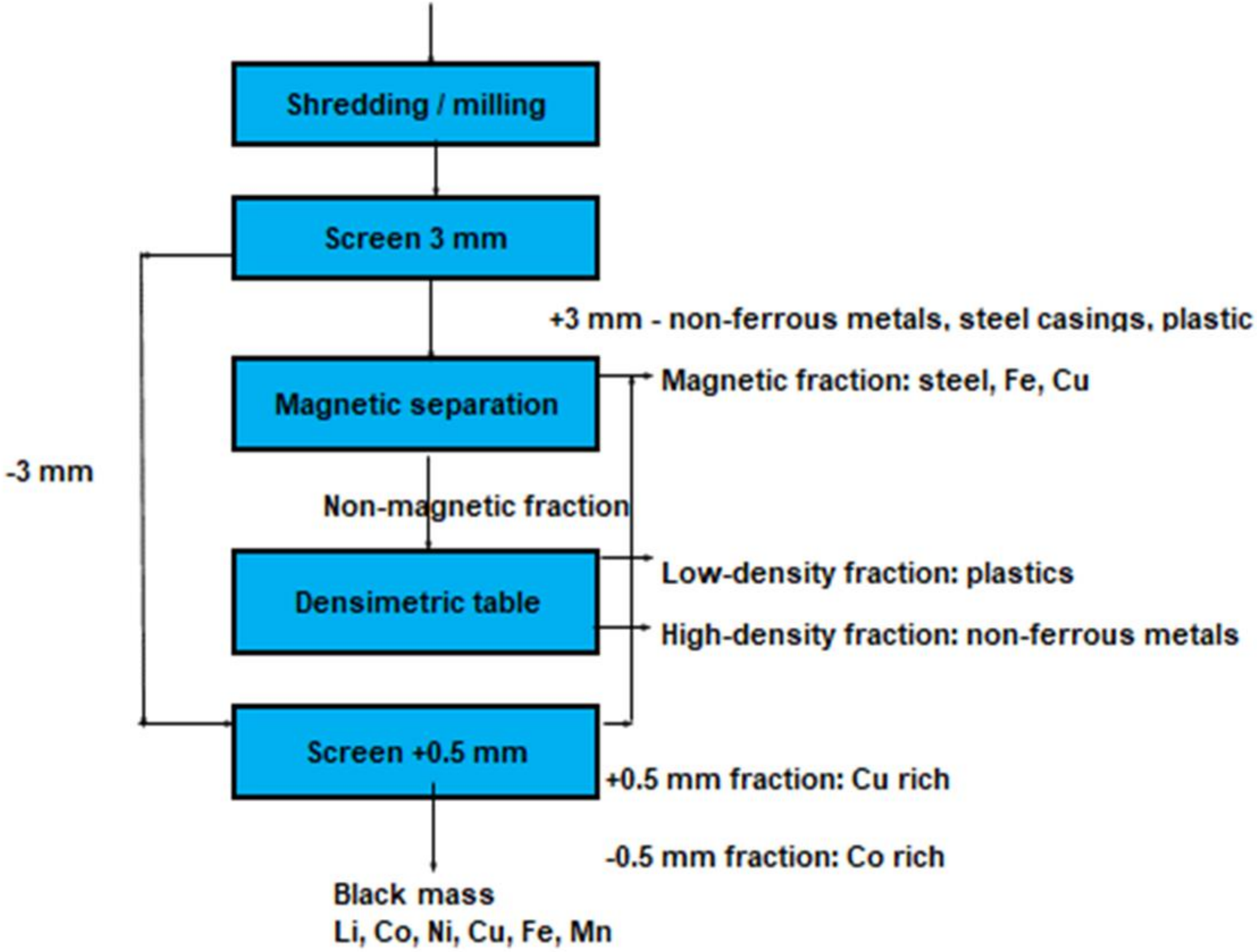
Techno-economic study: Hydrometallurgical flowsheet



Techno-economic study: Pyrometallurgical flowsheet



Techno-economic study: Black mass flowsheet



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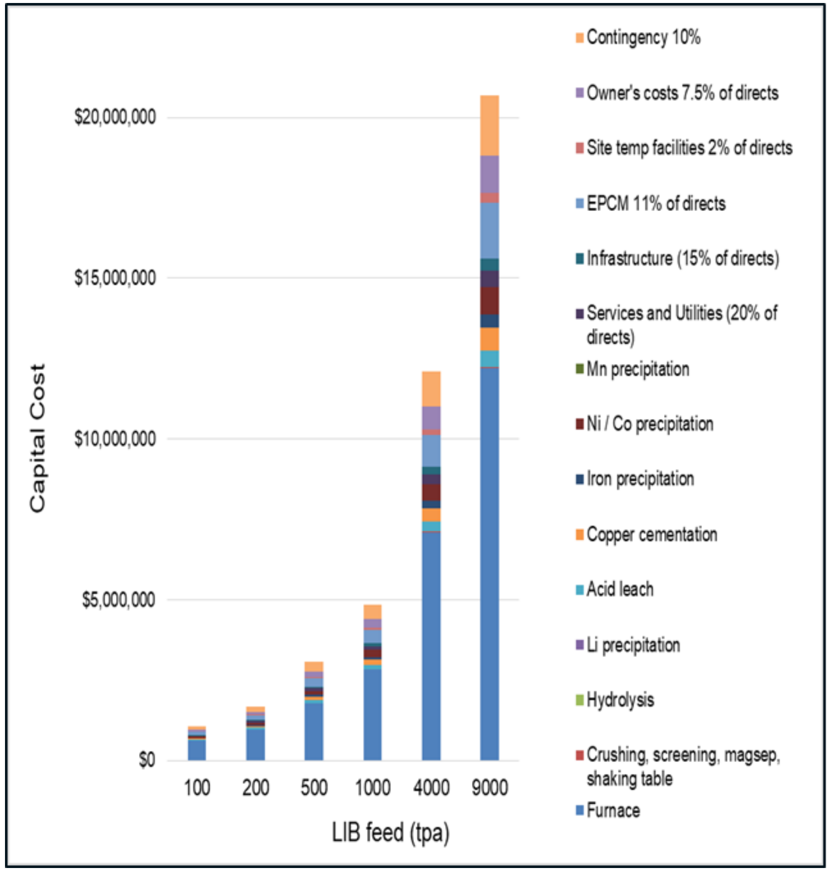
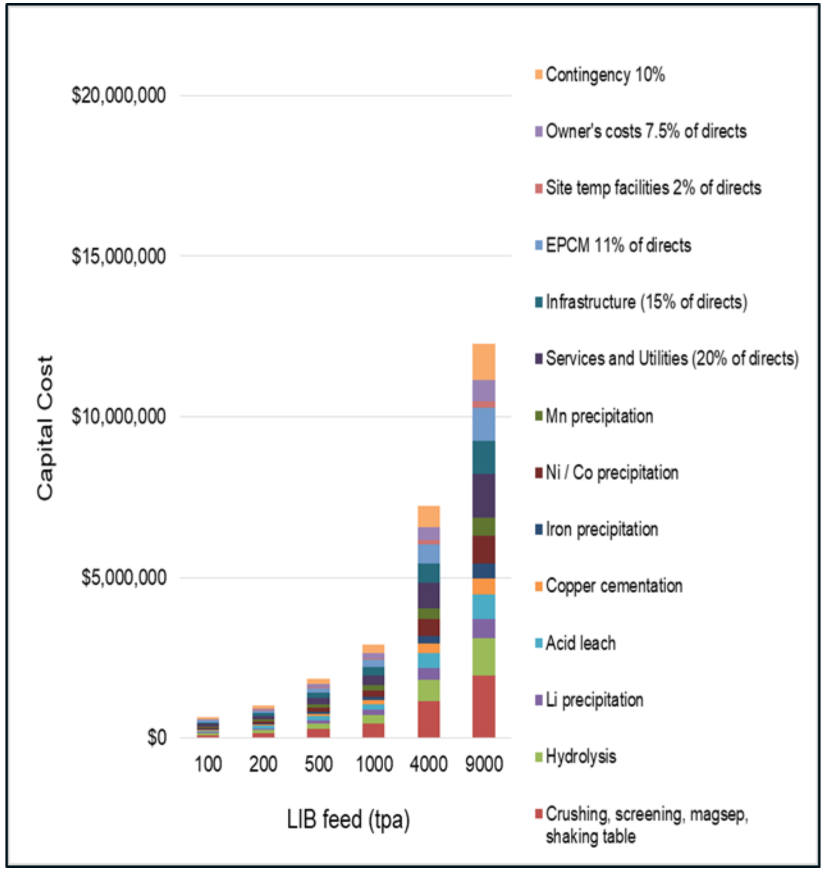
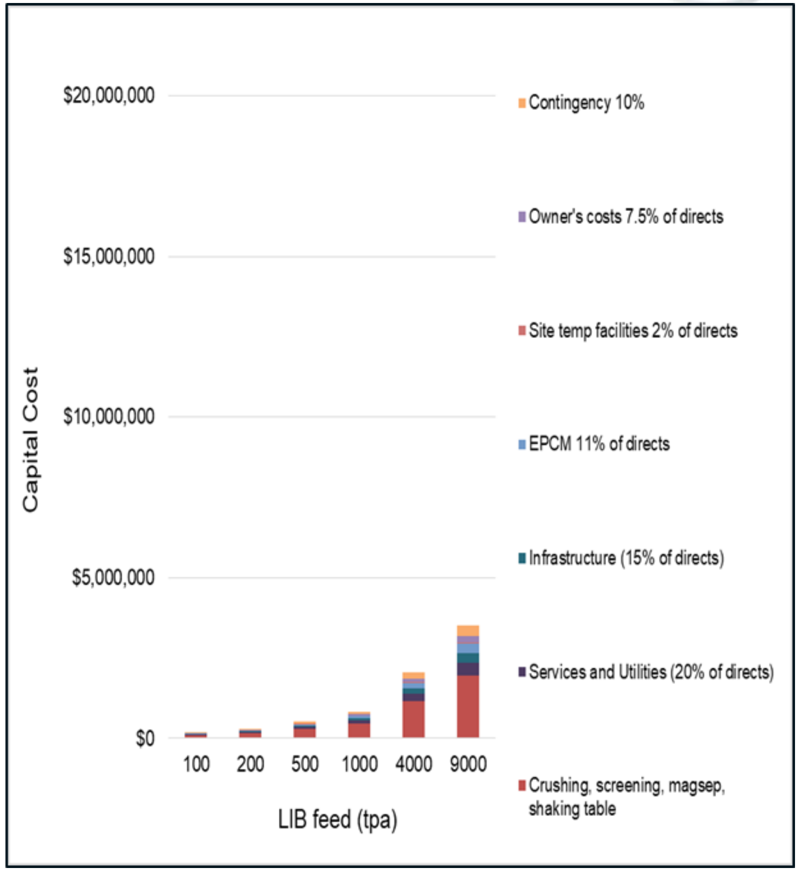
Techno-economic study: Capex breakdown



Pyrometallurgical route: Capital cost breakdown [Blend]



Hydrometallurgical route: Capital cost breakdown [Blend]



Black mass route: Capital cost breakdown [Blend]

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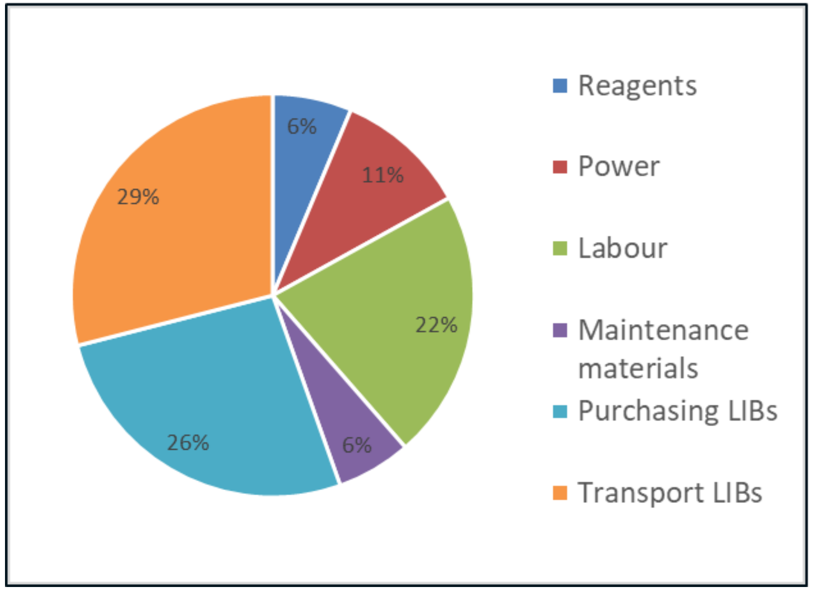
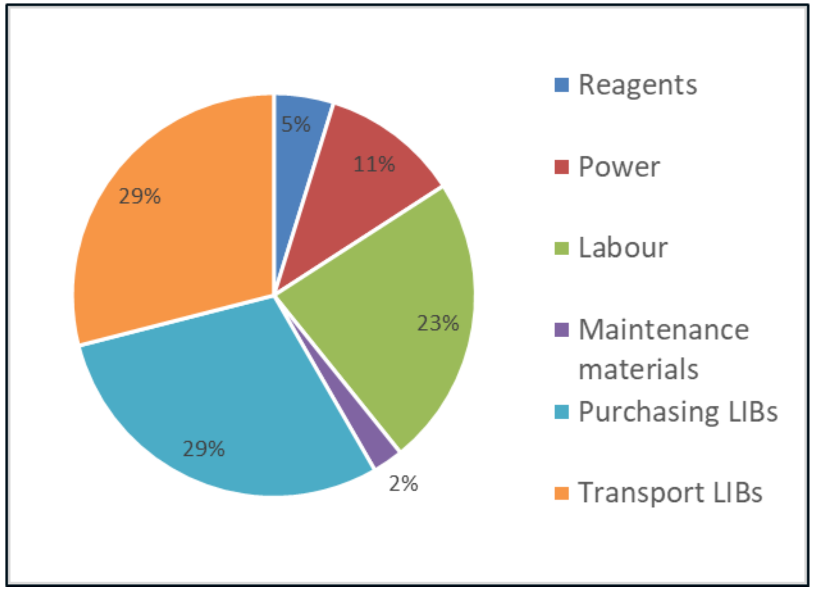
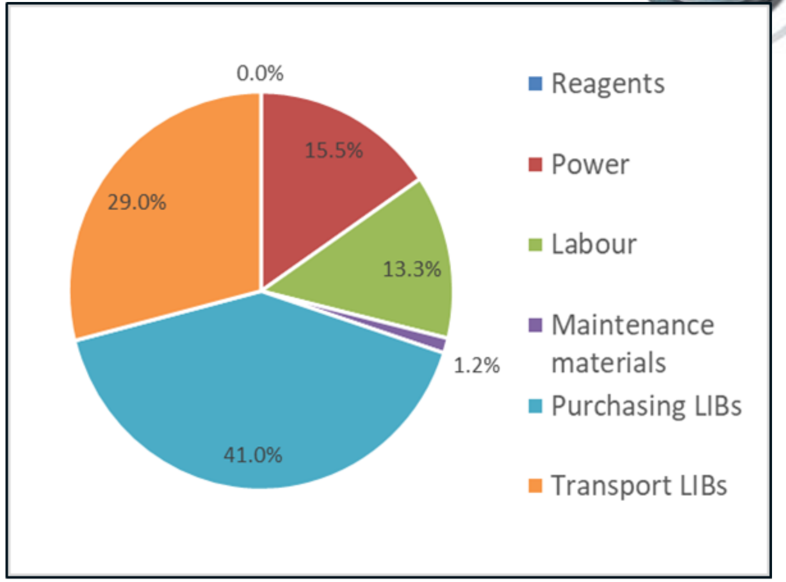
Techno-economic study: Operating cost breakdown



Pyrometallurgical route:
Operating cost breakdown
[blend, 1 000 tpa]



Hydrometallurgical route:
Operating cost breakdown
[blend, 1 000 tpa]

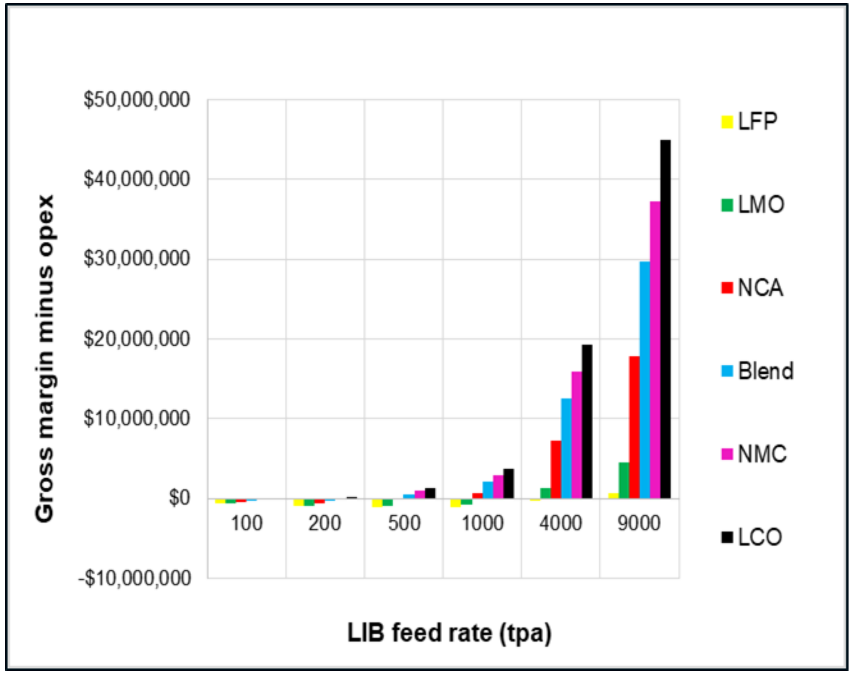


Black mass route:
Operating cost breakdown
[blend, 1 000 tpa]

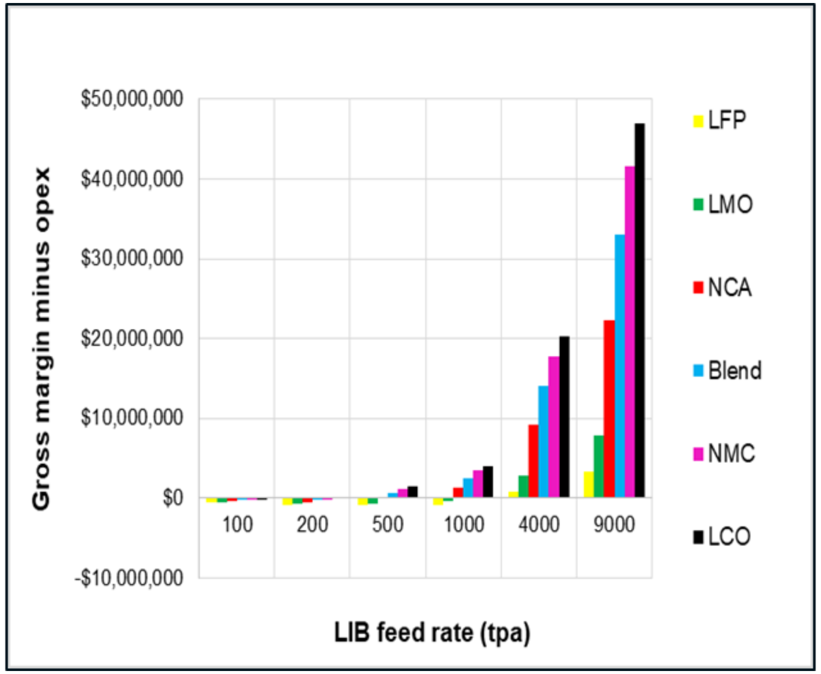
<u>Assumptions:</u>

- Cost of purchasing LIBs = 15% of metal value
- Transport cost of LIBs = 29% of Operating cost
- Hydrometallurgy flowsheet: Assume 80% of value paid out for Ni and Co hydroxides
- Black mass flowsheet: Assume 40% of value paid out for Ni, Co and Li, including transport

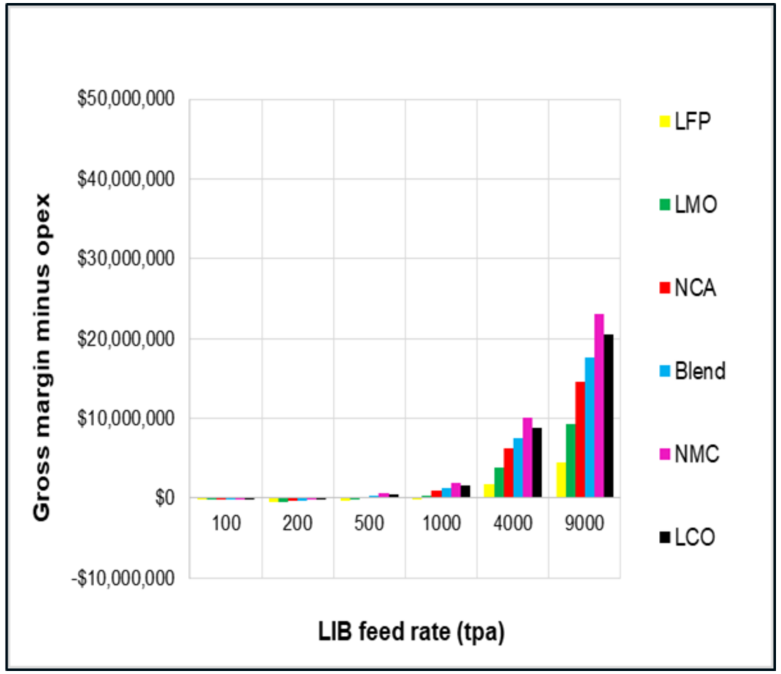
Techno-economic study: Gross margin minus opex



Pyrometallurgical route:
Gross margin minus operating costs



Hydrometallurgical route:
Gross margin minus operating costs



Black powder route:
Gross margin minus operating costs

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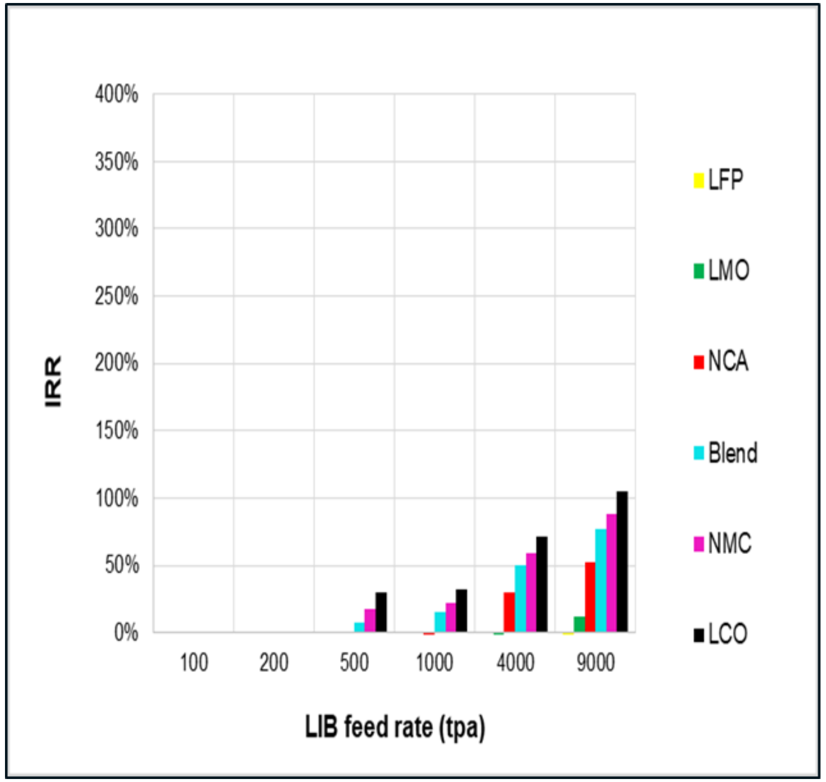
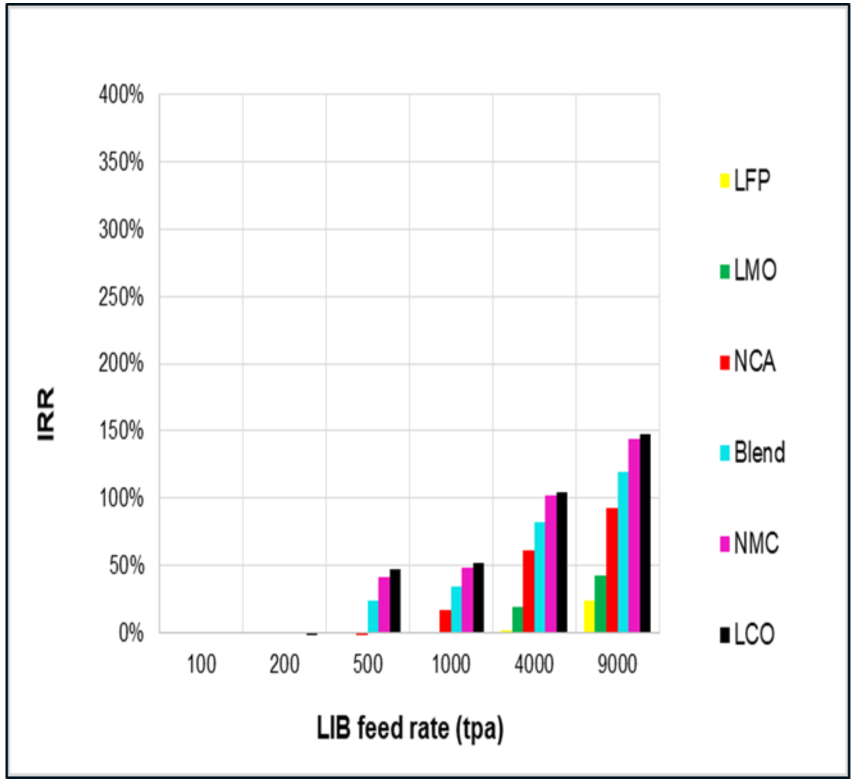
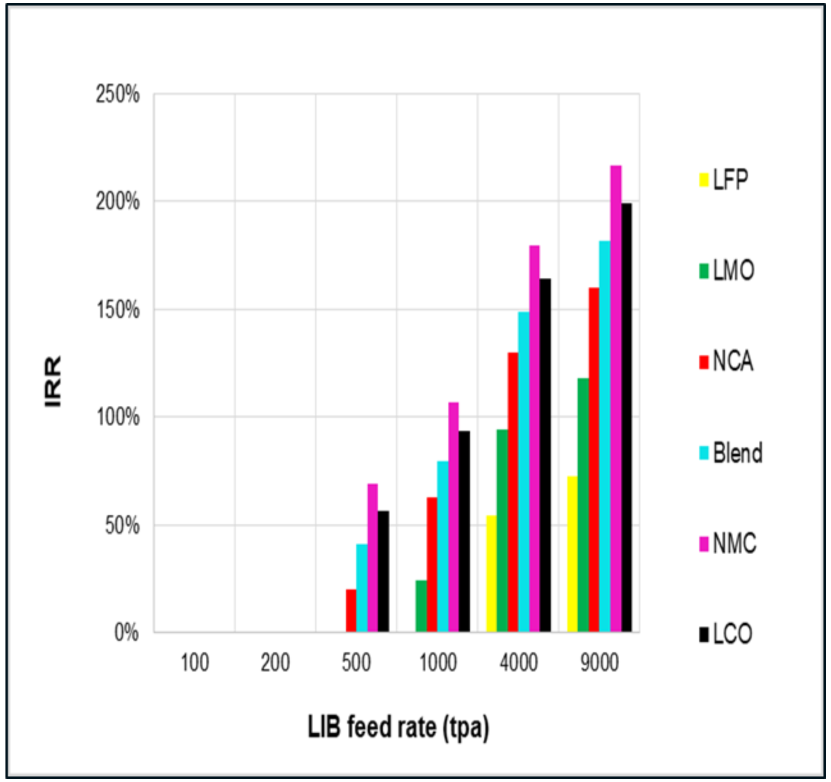
Techno-economic study: IRR



Pyrometallurgical route:
IRR 10 years



Hydrometallurgical route:
IRR 10 years



Black powder route:
IRR 10 years

Techno-economic study

- The LIB-recycling process becomes economical at feed rates of about 500 tpa for the more valuable battery types.
- Profitability sensitive to the battery feed composition, specifically the Co, Ni and Cu content.
- Based on our analysis, the most profitable recycling route is the production and sale of black mass, followed by the hydrometallurgical and pyrometallurgical routes.
- Production of black mass presents the lowest risk, but depends on finding a suitable buyer and subject to refining charges (estimate 40% of contained metal value is paid out).
- There is scope for further process development, especially in the face of ongoing battery development, such as battery chemistry and varied types each with its own distinct design and component features. This makes it difficult to establish robust and versatile recycling processes.

Recommendations

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Recommendations

At the current low collection rates of batteries, there is not a business case for establishing a LIB recycling plant in South Africa. Strategies to increase the collection of LIBs are required in the following areas:

- Improvement of collection infrastructure
- Increased consumer awareness of the importance of recycling batteries
- Disincentivising or banning of disposal to landfill

There needs to be political will to encourage the uptake of EVs in South Africa. These could include:

- Acceleration of the implementation of South Africa's Green Transport Strategy
- Adoption of green public transport
- Implementation of fiscal incentives to make EVs more cost-competitive and stimulate market penetration.
- Addressing issues related to the availability of charging stations, reliable electricity supply and possibly setting manufacturing and sales targets as is being done elsewhere.

Recommendations

- Globally, EV revolution anticipated to happen over the next 10 years
- South Africa lagging behind - impact of large volumes of end-of-life batteries entering the waste stream will probably only be experienced in the next 10 to 20 years.

- Until local volumes increase sufficiently to merit a local recycling facility, it is recommended that processes be implemented to treat LIBs to a stable state, after which it can be exported to international recycling facilities.

Longer-term recommendations

- Once collection rates ~ 500 tpa are reached, a small-scale mechanical plant for the pre-processing of the LIB waste to produce black mass could be implemented. The black mass can be treated locally through partnerships with metallurgical operations or exported to international refineries for metal recovery.

- Once a reliable supply, of large enough LIB waste volumes, is collected a hydrometallurgical plant can be considered for the treatment of LIBs to produce either metal precipitates or high purity battery materials.

- The LIB waste volumes available for local treatment can be increased by accepting regional or international LIB waste by creating a favorable economic and regulatory environment for battery recycling. It is, however, questionable if we could be competitive in a market currently dominated by China.

Acknowledgements

The authors acknowledge the funding received from the Department of Science and Innovation under the Waste RDI Roadmap.

https://wasteroadmap.co.za/research/grant-030/

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