The Lithium-Ion (EV) battery market and supply chain

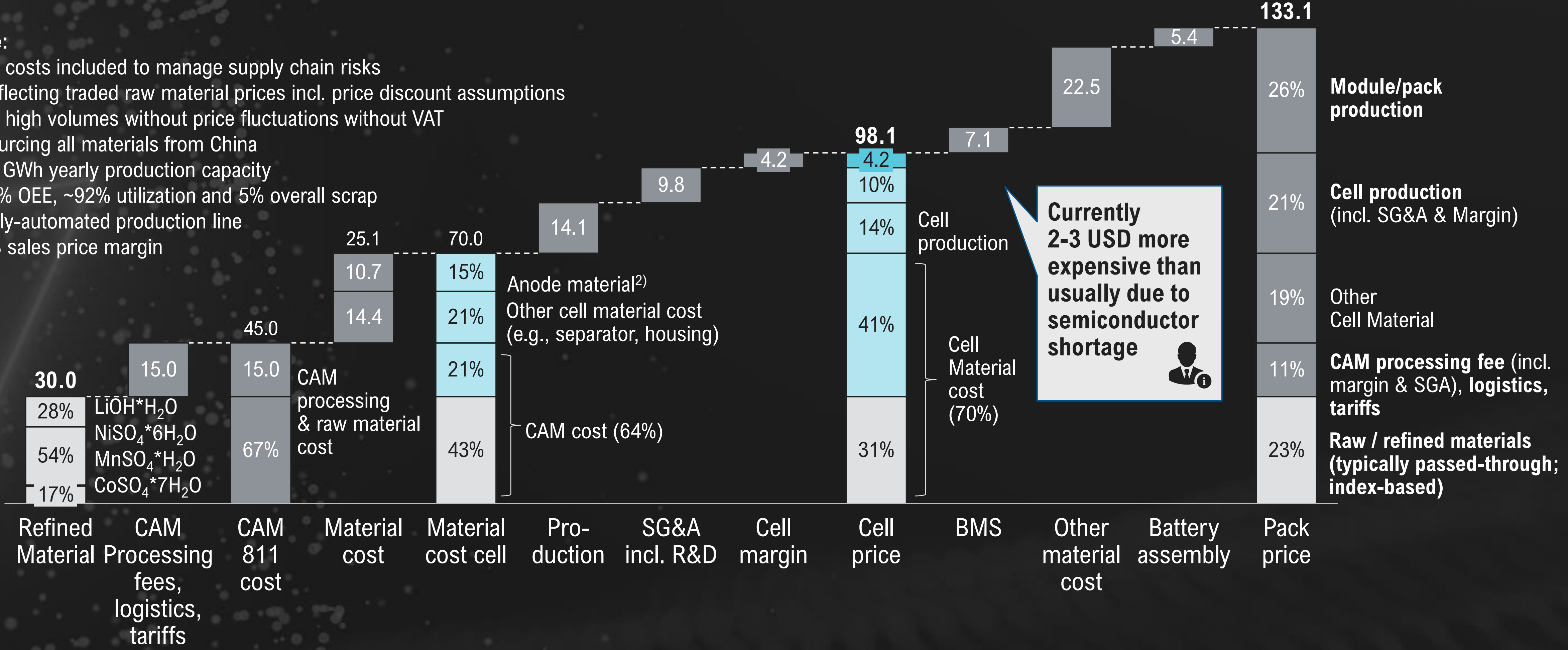
Market drivers and emerging supply chain risks

April, 2022

Batteries are key for electrification – EV battery pack cost ca. 130 USD/kWh, depending on technology/design, location, and material prices [Jul 2021 figures]

Cost breakdown of pack – Prismatic NCM 811[1)] [USD/kWh]

Note:
- No costs included to manage supply chain risks
- Reflecting traded raw material prices incl. price discount assumptions for high volumes without price fluctuations without VAT
- Sourcing all materials from China
- 36 GWh yearly production capacity
- 90% OEE, ~92% utilization and 5% overall scrap
- Fully-automated production line
- 5% sales price margin

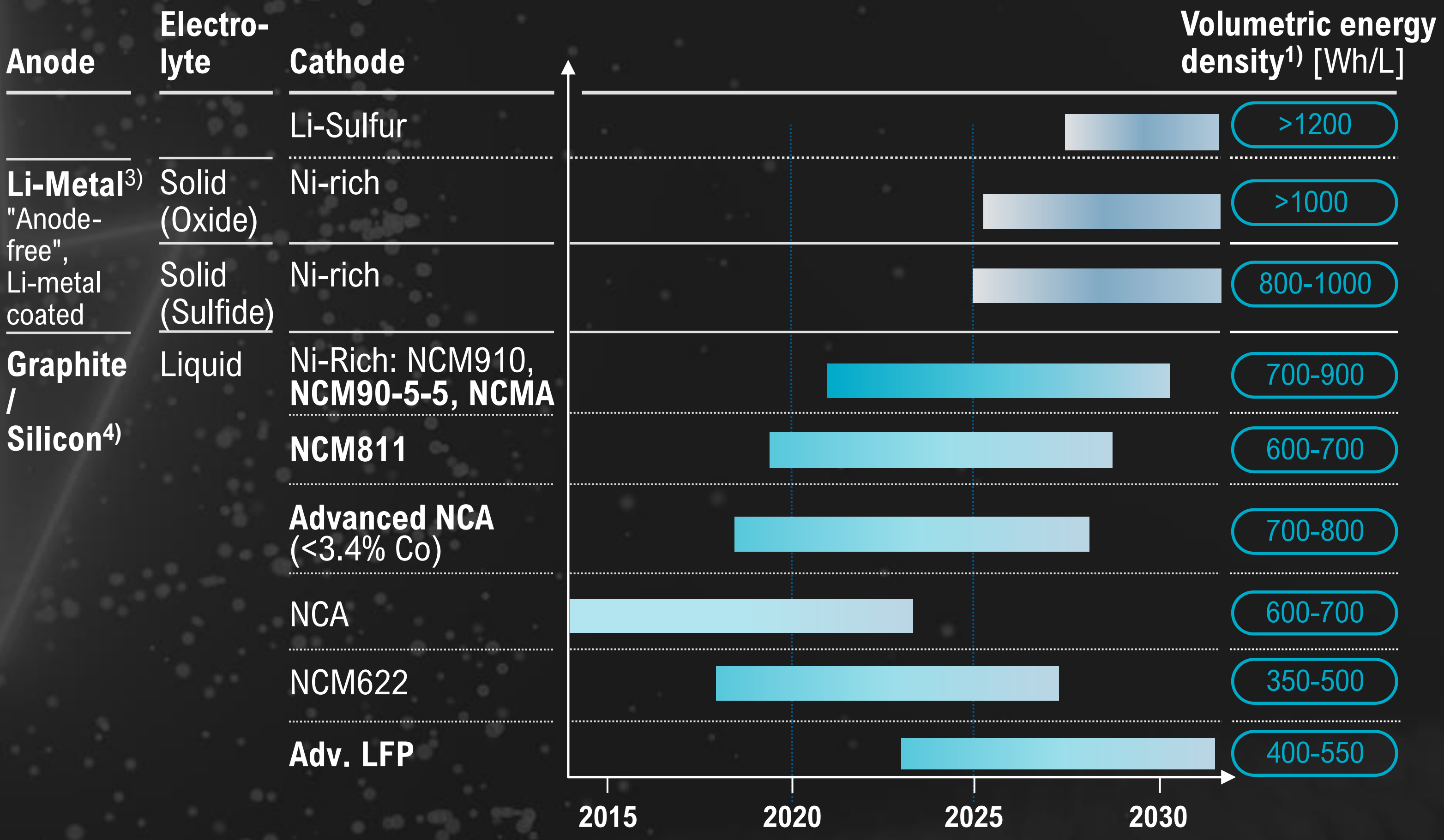


1) Prismatic cell (69 Ah; 3,7 V; 253 Wh), production in China

Source: Roland Berger Integrated Battery Cost model C³

Technology progress in batteries goes along with a broader proliferation of cell chemistries used, and expectations for further cost decreases

LiB technology roadmap – LFP and Ni-based CAM (First serial application in vehicles)



Next-Gen Technology (~ 2025)

- **Solid state**: Introduction of oxide and sulfite-based, anode-free[2] and with Li-metal-coated anodes
- **Hi-Si anodes** even before
- **LFP** for lower range/A-/B-segment-, selected CV use cases, and as option
- **Ni-rich** tech. for high energy use cases
- **NMx** "in-between" NCM and LFP from cost and energy density perspective
- **Mn-rich** technologies as cheaper alternative for volume vehicles
- **Cell-to-Pack**-technologies to in-crease energy density on system level
- **Post-LiB starting before 2030**

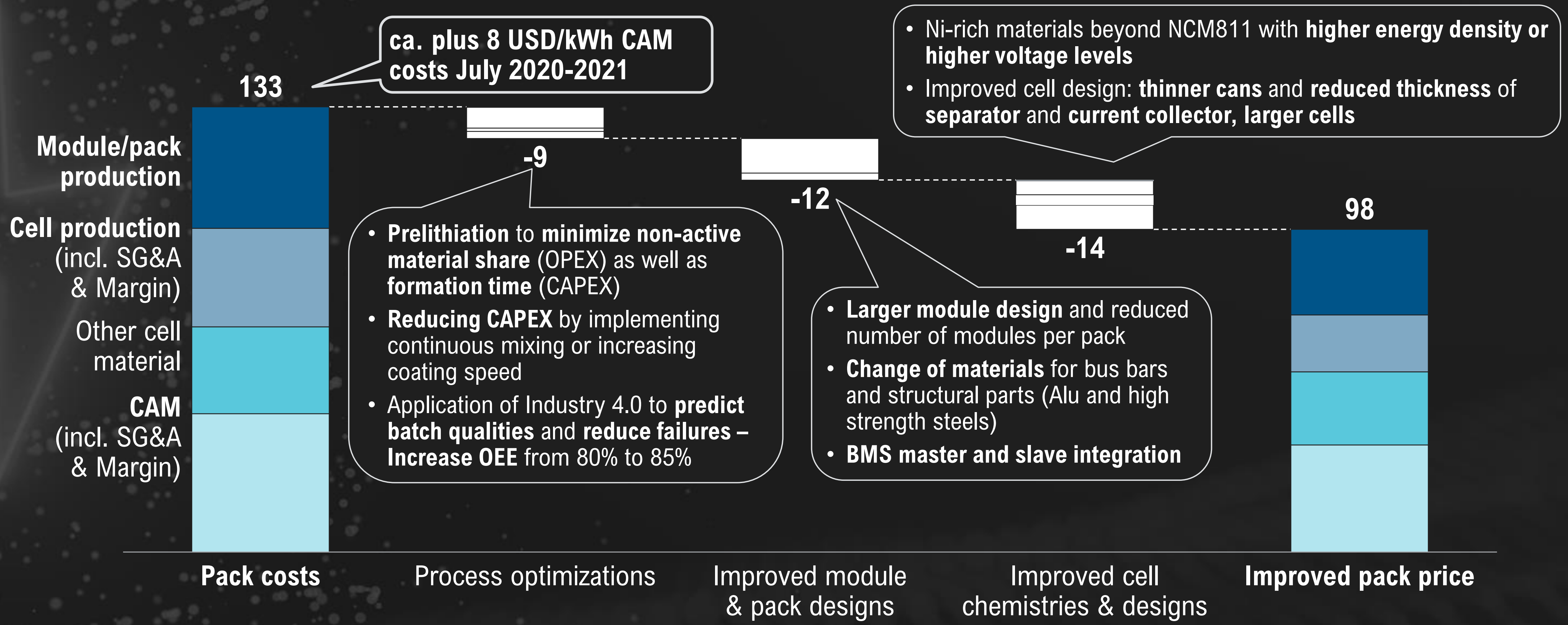
1) Stacked electrodes; 2) First prototypes; 3) Foil or deposited; 4) Typically blends of different cathode chemistries and specifically adapted anode chemistries

Source: Expert interviews, Roland Berger Integrated Battery Cost model C^3

Indicative, Jul. '21 cell costs

Costs can likely be reduced by USD 30-40 / kWh focusing on pack design, processes and cell chemistry – further progress requires holistic approach

Cost reduction levers [USD/kWh, prismatic NCM811 pack]

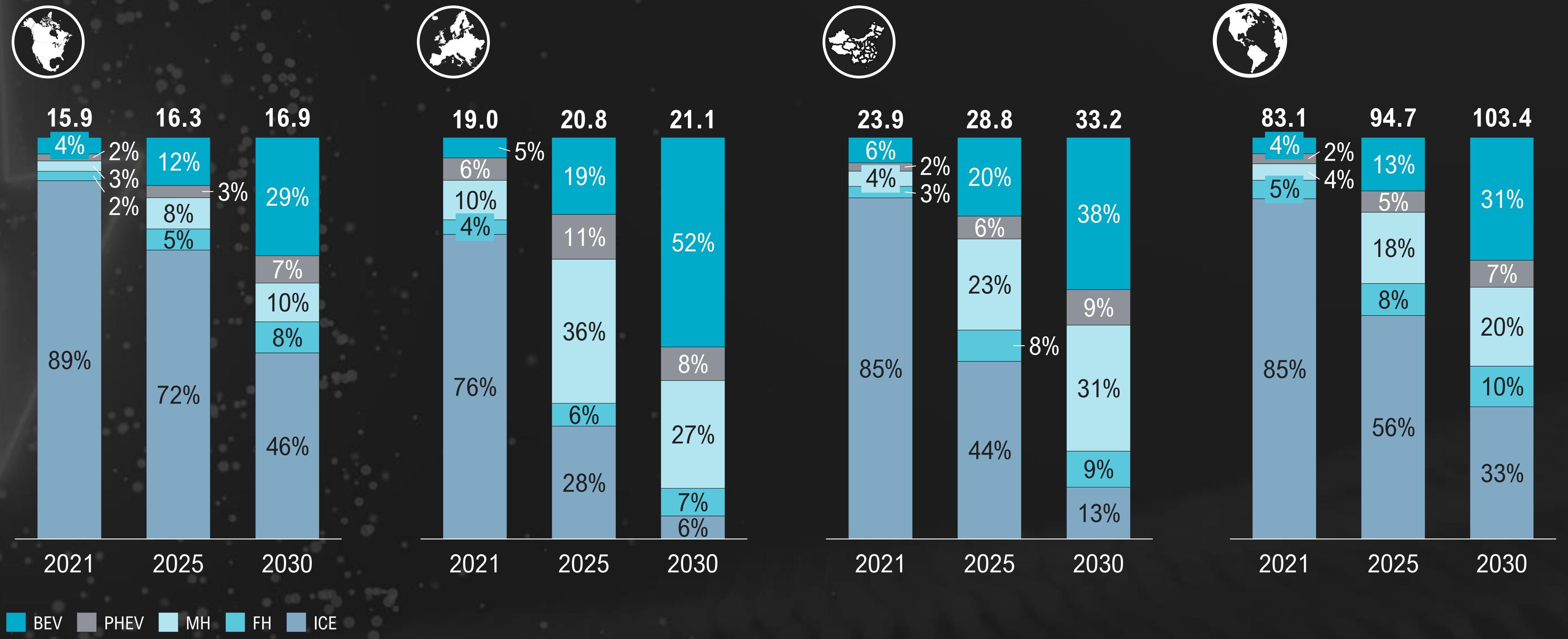


Source: Roland Berger Integrated Battery Cost model C³

As of Oct 2021, based on OEM communication

Assuming communicated electrification targets, BEV/PHEV passenger car sales would reach close to 31 mio vehicles in 2030, with ~30% BEV

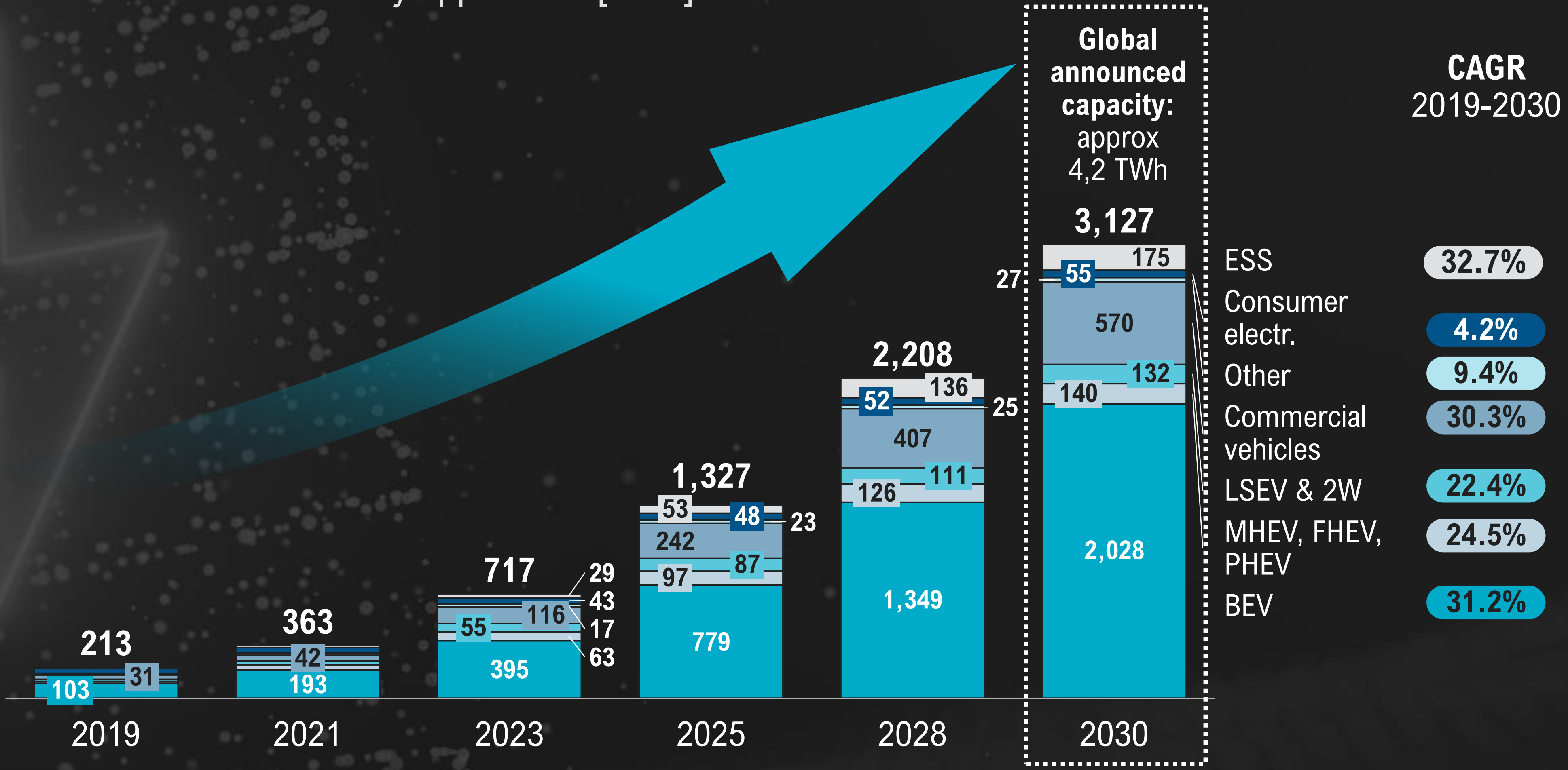
Light vehicle powertrain shares by region [m vehicles; %]



Source: Roland Berger

This level of electrification (31 million BEV) would correspond to global LiB demand of over 3,100 GWh in 2030 – announced capacity significantly higher already

Market demand for LiB by application [GWh]



- Significant further reductions of pack costs
- (Implicit OEM-) Assumption: No significant raw material cost increases
- BEV and ESS with over 30% CAGR

Abbreviations: ESS – Stationary Energy Storage Systems; LSEV – Low Speed Electric Vehicle; 2W – Electric Two Wheelers; MHEV, FHEV, PHEV – Mild Hybrid, Full Hybrid and Plug-in Hybrid Electric Vehicle; BEV – Battery Electric Vehicle

Source: Avicenne, Fraunhofer, IHS Interviews, Roland Berger

The dependency of the industry on LiB cells and critical battery materials creates significant supply chain risks along the full value chain

Overview LiB Cell Supply Chain (CAM/AAM only, example NCM chemistry)

Mining → **Refining** → **Precursor** → **Cathode/anode** → **Cell/Module** → **…**





Mining / Refining:
- Production and processing of natural resources
- Long-term investment cycles, high required investment
- Not automotive-specific (esp. for Nickel**)**

Precursor / Cathode/anode:
- Chemical process industry
- Highly R&D driven for top-tier products
- Automotive-specific and potentially customer specific

Cell/Module:
- Highly automated chemical (mixing, coating) and mechanical assembly process

CAM
Cathode Active Material

Mining	Refining	Precursor	Cathode/anode	Cell/Module
Ni (ore/refined)	Ni-SO_4	NMC precursor	NMC cathode	Battery cell
Co (ore/refined)	Co-SO_4			
Mn Ore	Mn-SO_4			
Li-Brine	Li_2CO_3			
Li-Spodumene	$LiOHxH_2O$			
Li-Lepidolite				

Other materials:
(not shown)
- Electrolytes
- Separator
- …

AAM
Anode Active Material

Mining	Cathode/anode
Natural graphite	Gr anode
Artificial graphite	

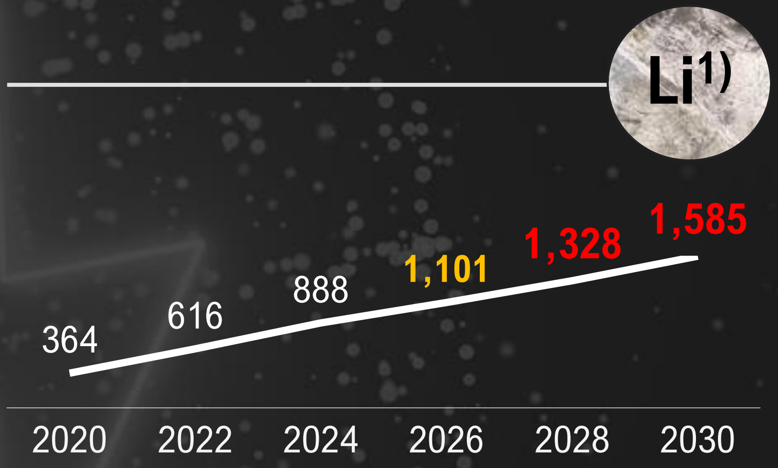
CAM and AAM:
> 50% of cell value!

Main risk areas (red boxes): Ni (ore/refined), Co (ore/refined), Li-Brine, Li-Spodumene, Li-Lepidolite, Ni-SO_4, Co-SO_4, Li_2CO_3, $LiOHxH_2O$, NMC precursor, NMC cathode, Natural graphite, Artificial graphite, Gr anode

Source: Roland Berger

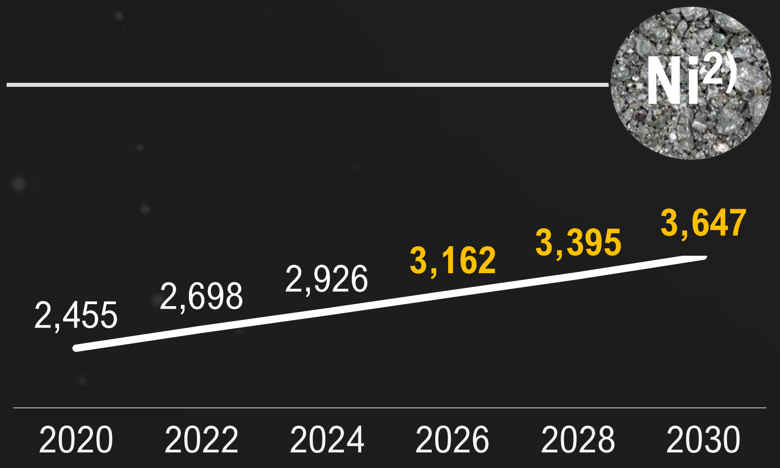
Supply availability and price risks for Lithium, Nickel and the refined salts stem from a potential demand-supply imbalance driven by long lead times…

Global supply and supply characteristics for battery raw materials [kt LCE/metal eq. p.a.]



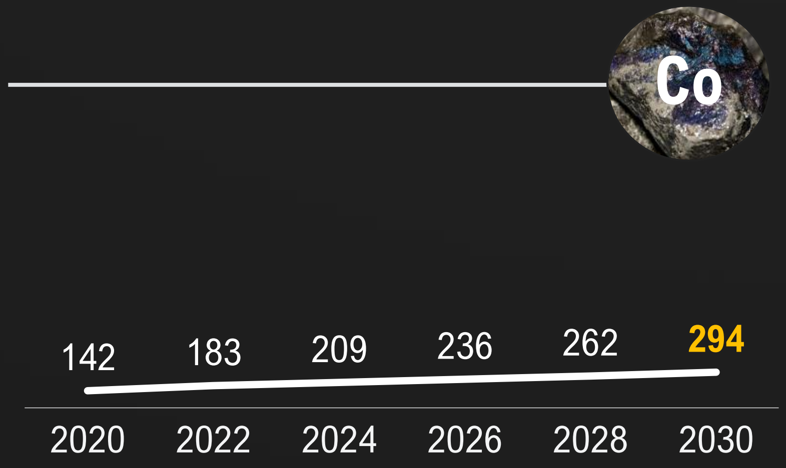
Potential for **long-term production capacities** well **over 1,500 kt LCE**, but with **higher cash costs** that are likely to result in **higher costs for balanced supply**

Production lead time[3]:
3 yrs – 7 yrs



Higher **cash-costs of new projects** likely to result in **higher costs for balanced supply,** high CO2 footprint and costs for pig iron nickel conversion[4] might lead to criticalities

Production lead time[3]:
6 yrs – 13 yrs



Main resources in **Congo** (70%), **Russia** (4%), and **Australia** (4%)

Cobalt powder

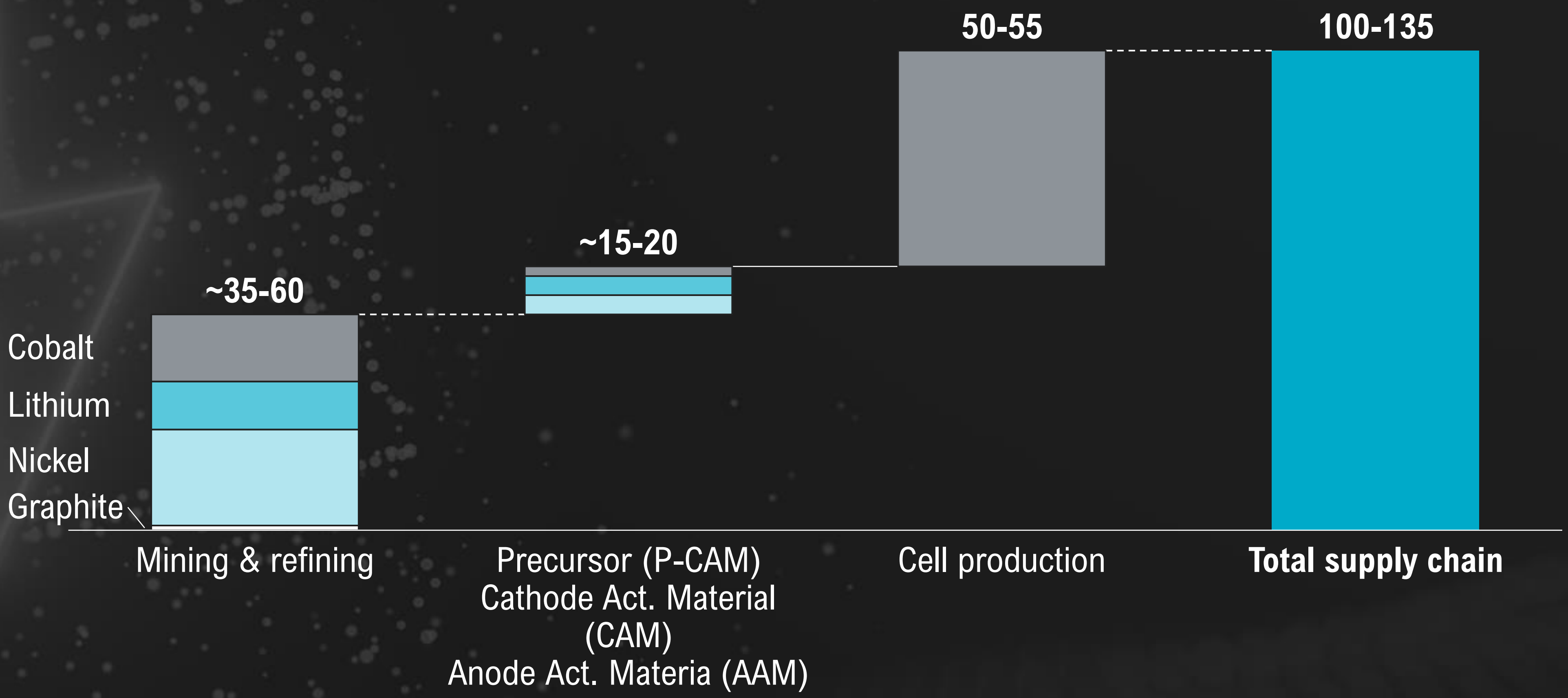
Production lead time[3]:
4 yrs – 10 yrs (Cu-by product)

Note: Incl. recycling. 1) LCE 99.5% ; 2) Spodumene has higher purity with less iron, magnesium & other deleterious metals 3) Start of exploration to metal delivery, "best case" – "average lead time"
4) Might become cheaper via Mixed Sulphate precipitation by Tsingshan

Source: Roland Berger "LiB Supply-Demand Model"

… and significant investments along the supply chain – more than EUR 100 bn for Europe, EUR 250 bn – EUR 300 bn globally until 2030

CAPEX[1)] estimate for cell production and NMC CAM & AAM supply chain [EUR bn for 1,000 GWh equivalent]



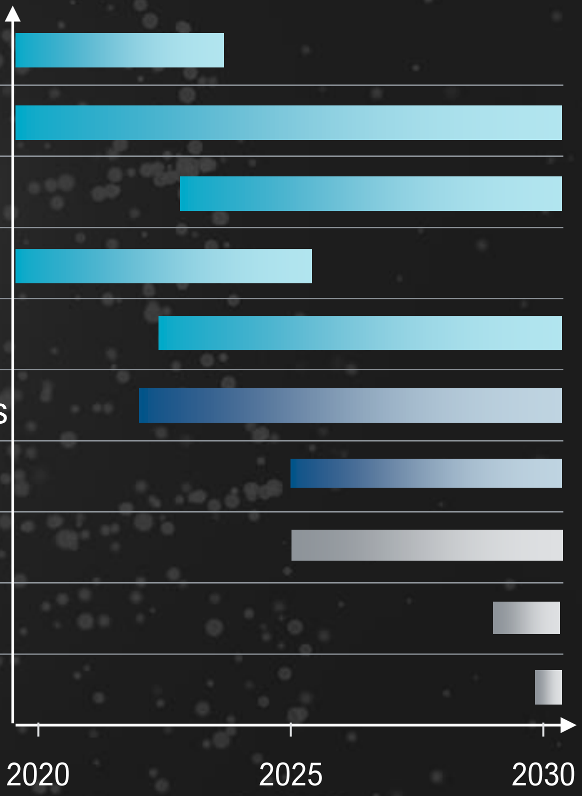
1) CAPEX based on natural graphite, similar for artificial graphite; Note: Excluding manganese upstream value chain

Source: Roland Berger – Integrated Cell-CAM-Cost-Model [C3], 2021

Illustrative & non-exhaustive

Ni-rich cell technology is driving the Li demand, especially for LiOH, $LiCO_3$ is still required for LFP. Despite alternative technologies, limited demand ease for Lithium

Cell chemistry roadmap 2030 and its implications on Li precursor demand



Technology/material	Energy density[1]	Maturity	Li precursor
NMC622	350-500	●	$LiCO_3$
Ni-rich (NMC)	700-900	●	LiOH
Mn-rich (NMO)	500-600	●	$LiCO_3$
NCA	700-800	●	LiOH
Advanced LFP	400-550	●	$LiCO_3$
Si/C composites	800-900	◕	Add. pre-lithiation
Pure Si	>1000	◑	Add. pre-lithiation
Na-ion	250-400	◑	Substitution of Li
Solid State	>1000	◔	Li metal (predominantly)
Li-Air	>1000	○	Li metal

○ Low maturity level ● High maturity level

1) per Wh/L

Key Takeaways

- **Today´s** lithium-ion technology is **dominated** by **NMC/ NCA** in combination w/ graphite anode
- To increase energy density and lower cobalt content and BOM cost **Ni-shares** are constantly **increasing** which shifts the demand from $LiCO_3$ precursor towards **LiOH**
- Co-free alternatives as **LFP** are **entering** the market to decrease Co dependency and lower cost
- On anode side a **shift** from pure graphite towards Si/C composites and pure **Si** anodes can be observed, significantly increasing the energy density and leading to **additional Li demand for pre-lithiation**
- Mass market entry for **solid state** technology, which requires Li metal anode material, **not** expected **before the end of the decade**
- **Substitution risk by sodium-ion** technology expected **in ESS** storage application w/ lower energy density requirements and possible later in the automotive segment

Source: Expert interviews, Roland Berger Integrated Battery Cost model C^3

For Lithium, spodumene sources become much more important due to shorter lead times and higher purity that is needed to produce Ni-rich CAM, using LiOH

Different sources for battery grade lithium

	Brine	Spodumene	Recycling
	• Brine is pumped to the surface and concentrated by evaporation in a succession of artificial ponds, each one in the chain having a greater lithium concentration • After a few months to about a year, depending on climate, a concentrate of 1 to 2% Li is further processed in a chemical plant	• Li found in hard rock forms in crystals that are hosted in Pegmatites which form when mineral-rich magma intrudes into fissures in continental plates • These pegmatites host a mineral called spodumene which contains the lithium • Li is extracted from spodumene by fusing in acid	• Up to 95% of lithium and other critical materials are recovered from spent li-ion batteries and treated before reintroduction into the supply chain • Increasingly considered as it reduces constraints imposed by materials scarcity and enhances environmental sustainability (lower energy consumption, lower water use, lower SOx emissions)
Global lithium supply	45%	55%	
Tonnes required for 1 t of battery-grade Li	750 tons	250 tons	28 tons of spent lithium-ion batteries
Purity	Low - Higher amounts of Fe, Mg or other deleterious materials within the 0.5% remaining in refined Li	**High – requisite for usage in Ni-rich materials**	High
Time to move into prod.	Long	**Short – Esp. for pegmatite-based projects**	Short
High-techn. required	Yes	**No**	No
Processing time	Long	**Short**	Short
Weather dependent	Yes	**No**	No
Capital intensity	High	**Low**	Low
Operating costs	**Low**	High	Low

Source: Benchmark Mineral Intelligence, Argone National Laboratory's ReCell Center, Secondary research, Roland Berger

Lithium production is highly concentrated – Three operations concentrated more than half of the current production (2020)

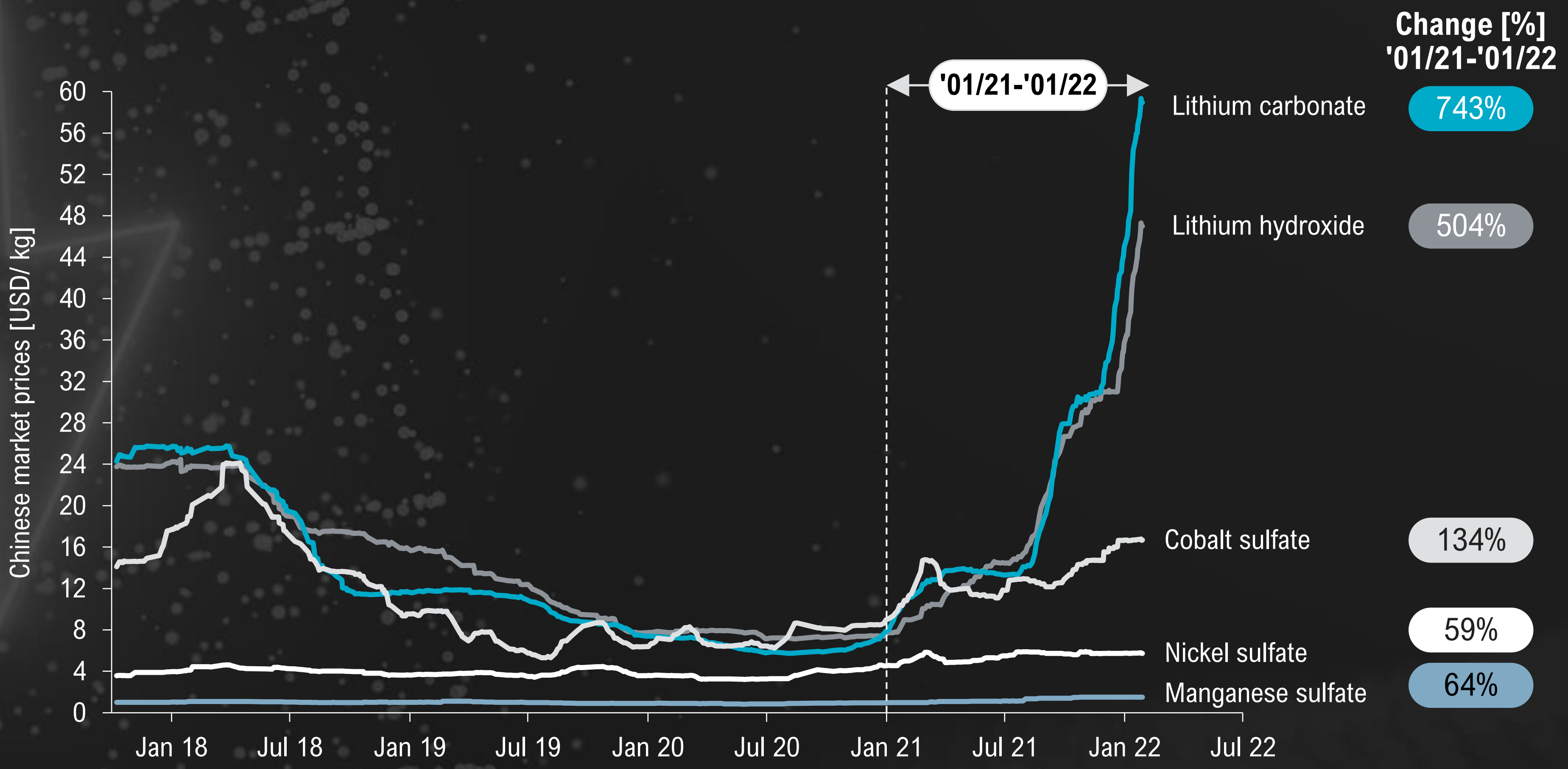
Lithium production breakdown by operation [kt LCE; 2020]

Operation	kt LCE	Mine type	Share of total
Greenbushes	88.0	Spodumene	21%
Salar de Atacama	70.0	Brine	17%
Mount Marion	59.8	Spodumene	14%
Salar de Atacama	42.0	Brine	10%
Bald Hill	35.6	Spodumene	8.6%
Pilgangoora	26.8	Spodumene	6.5%
Salar de Hombre Muerto	19.8	Brine	4.8%
Mt Cattlin	16.0	Spodumene	3.9%
Altura	14.1	Spodumene	3.4%
Cauchari-Olaroz	14.0	Brine	3.4%
Chaerhan Lake	13.5	Brine	3.3%
Others	14.8		3.6%

Source: S&P Global, Desk research, Roland Berger

Battery raw material prices have been subject to strong fluctuation – Substantial upwards pressure especially after COVID-19 recovery due to supply imbalance

Spot prices for battery raw materials in China, 2017-2022 (Feb.) [USD/kg][1)]



- Battery material market prices reached **all-time high in 2022**, due to
  - Recovery from COVID-19 drives demand, especially in China
  - **Announced capacity expansions fell short** while supplying countries still suffer from COVID-19
- Price increases **affect all market participants**, and the production costs (incl. tariffs and logistics) are decisive to be competitive

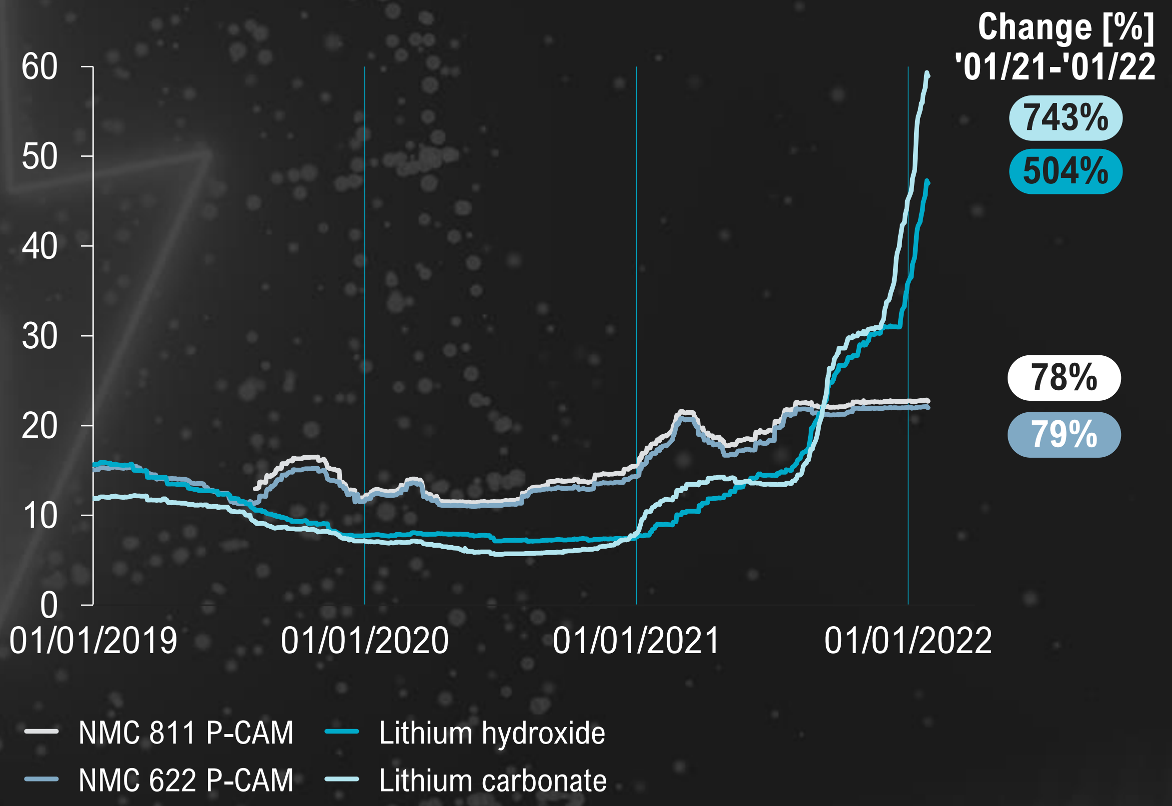
1) Battery grade materials

Source: Interviews with market participants, ICCSINO, iFind, Roland Berger

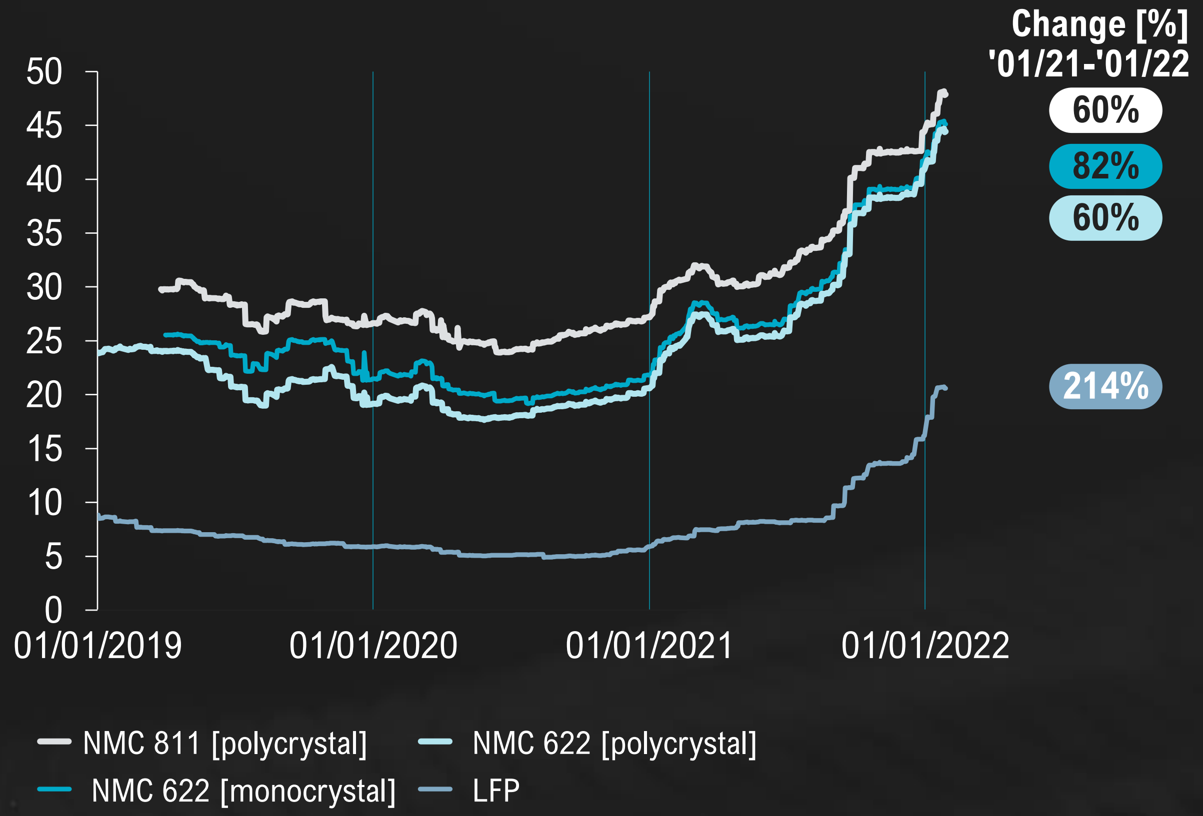
Consequently, also Chinese P-CAM and CAM spot prices increased significantly within the last year

Chinese material market prices for P-CAM ands CAM

Chinese P-CAM material market prices [USD/ kg]



Chinese CAM material market prices [USD/ kg]



Source: Interviews with markets participants, iFind, ICCSINO, Roland Berger

The Lithium-Ion (EV) battery market and supply chain

Part 2: Risk mitigation and stakeholder strategies

Part 2:

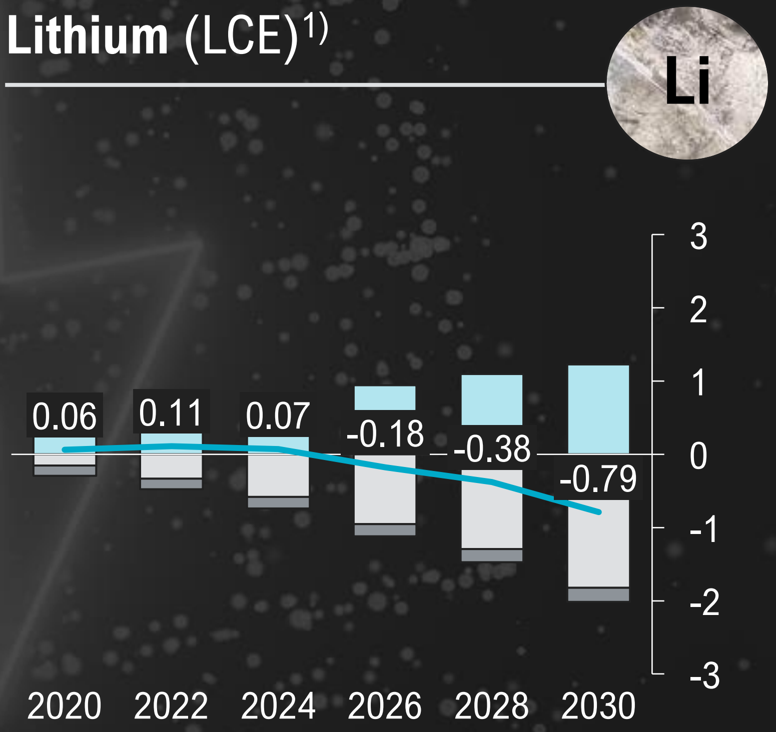
- Recognize the **impact of EoL recycling on** critical materials **supply**
- Comprehend the impact of vertical integration, regionalization and co-location of pCAM-, CAM- and cell production on costs and CO2 emissions
- Gain insight into vertical integration strategies of leading players
- Understand strategic implications for OEMs, cell- and CAM suppliers, mining companies and legislators

Indicative estimates as of Nov '21

Not taking into account supply from LiB-EoL recycling, demand-supply situation would be even tighter – especially also in Cobalt and Nickel

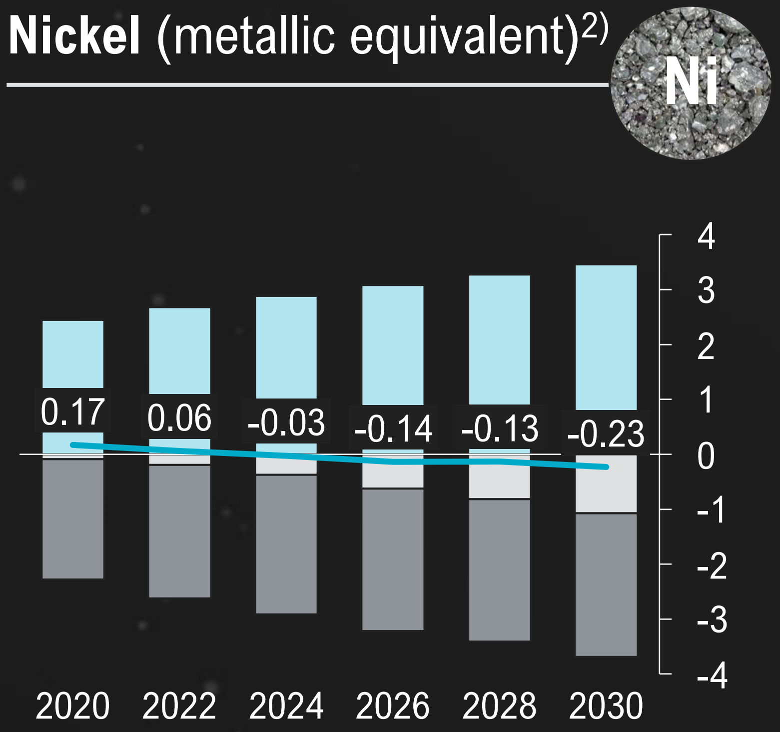
Roland Berger supply – demand forecast (excl. EoL recycling of LiB's) [mill. metric tons]

Lithium (LCE)[1]



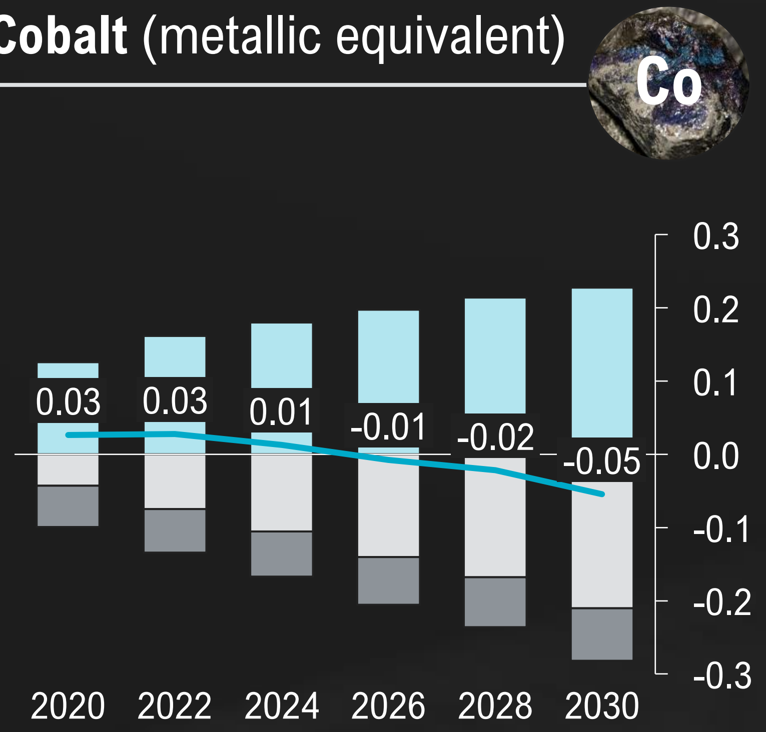
Demand > Supply

Nickel (metallic equivalent)[2]



Demand > Supply

Cobalt (metallic equivalent)



Demand > Supply

Supply vs. demand (total) | Gross Demand (LiB) | Demand (rest) | Potential virgin material supply (incl. LiB scrap recycling)

1) Supply until 2025 based on planned/announced mining and refining capacities. New processed volume after 2025 increases by the average (absolute) increase for the 2019-2025 period as new mining projects are launched to keep up with demand; 2) Includes intermediate and battery grade

Source: Roland Berger Integrated LiB Supply-Demand-Database

Governments are aiming for circular economy and battery recycling regulations, that also ask for minimum recycled material shares

Proposed new EU battery directive[1)]

EUROPEAN COMMISSION

Mandatory recycling content in new batteries

Article 8 proposes the **mandatory recycled content** in industrial batteries, electric vehicle batteries and automotive batteries

- From **January 2027** EV batteries that contain cobalt, lithium or nickel in active materials shall be accompanied by technical **documentation on recycled material content**
- From **January 2030** EV batteries shall contain the following **minimum recycled material shares** in each model and batch:
  - **Cobalt: 12%**
  - **Nickel: 4%**
  - **Lithium: 4%**
- From **January 2035** EV batteries shall contain the following **minimum recycled material shares** in each model and batch:
  - **Cobalt: 20%**
  - **Nickel: 12%**
  - **Lithium: 10%**

Extended Producer Responsibility

Article 47 proposes the **Extended Producer Responsibility** for producers of batteries which include obligation to organize and finance activities for:

- **Collection of waste batteries**
- **Subsequent transportation**
- **Treatment and recycling of waste batteries**

Article 49 proposes rules for **collection of waste EV batteries** which include obligation to:

- Take back waste batteries **free of charge and without any obligation** from end user to buy new batteries
- **Take back all batteries** of the respective type that they have made available on the market

Article 55 sets **collection rates** of waste portable batteries but currently **excluding waste EV batteries** (no targets set yet).

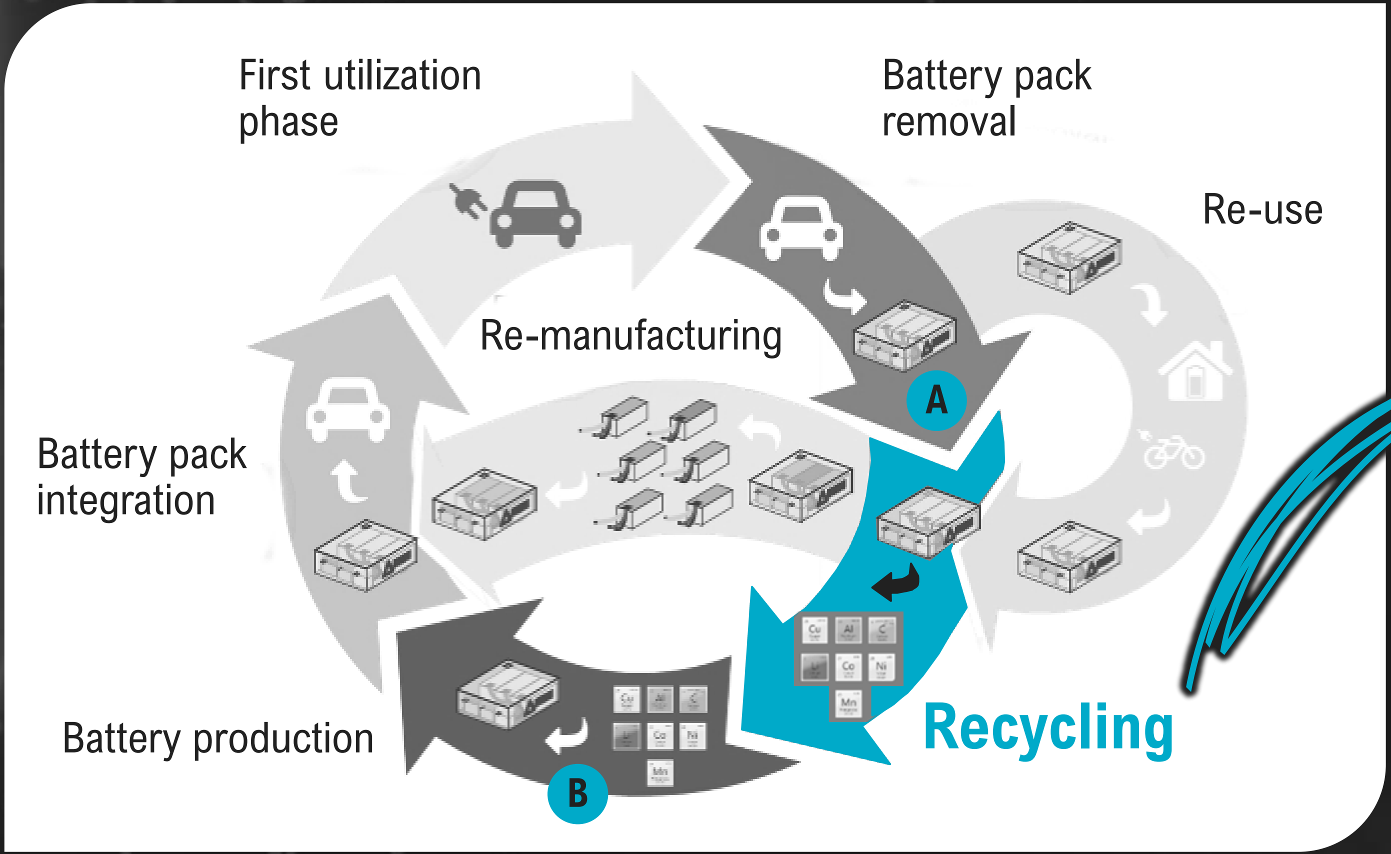
1) Final regulation not defined yet – Dates and values subject to change

Source: European Commission

Illustrative example for passenger cars

Battery recycling in the regulation refers to the recovery of materials such as Nickel, Cobalt and Lithium from end-of-life batteries – recycling from scrap important earlier

Circular concepts for batteries: Re-Use, re-manufacturing and re-cycling



Recycling

Recycling is required to recover raw materials from the battery through a safe process.

Closed loop recycling refers to the recycling of batteries and the use of those recycled metals as input for battery production

Main sources are

- **A** EoL batteries
- **B** Production scrap

Re-use

Lithium-ion batteries that have residual capacity at the end of their service life in BEVs can possibly be used in other applications, e.g., stationary energy storage

Re-manufacturing

Remanufacturing enables the extension of the first life cycle by preparing used batteries for reuse in BEVs by replacing or exchanging damaged components of the battery

Source: RWTH Aachen, Roland Berger

Illustrative & Exemplary

Players along the value chain have different incentives to be involved in recycling of scrap or EoL LiB – OEMs and cell manufacturer with highest control over feedstock

LiB recycling value chain

	Mining / refining	Battery materials	Cell	OEM	Recycling
	Mining → Refining	Pre-cursor → CAM	Electr. man./cell assembly	Module/Pack/ Vehicle	Collection & sortation → Extraction → Metallurgical refinement
Motivation to recycle	• Diversify sourcing streams and improve negotiating power by capturing market share	• Secure access to scarce raw material feedstock and to diversify supply • Leverage chemical process know how	• Meet legal obligations for recycling cont. • Participate in recycling value	• Meet legal obligations of EPR[3] • Participate in recycling value	• Increase utilization of existing assets (collection networks, mechanical / chemical processes and facilities) and relationships • Diversify revenue streams
A Scrap[1] focus	✓	✓	✓ (circled)		✓
B EoL[2] focus	✓	✓		✓ (circled)	✓

(circled) Major control over feedstock & regulatory obligation for LiB recycling

1) LiB manufacturing scrap; 2) End of life; 3) Extended Producer Responsibility

Indicative & Not exhaustive

Hydrometallurgy potentially offers financial and environmental benefits over pyrometallurgy – Direct recycling with high potential for manufacturing scrap

Key recycling technology high-level evaluation and exemplary players

	Pyrometallurgy + Hydrometallurgy	Mechanical + Hydrometallurgy	Direct recycling ("Cathode-to-cathode" recycling)
Description	• Whole or shredded batteries are smelted to yield a Nickel, Cobalt, and Copper alloy • Alloy further refined through hydrometallurgical processes to isolate metals	• Batteries are shredded with separation of black mass (cathode materials) from other materials • Acids are used to leach the constituent metals out of black mass	• Cathode active material is recovered from black mass (as opposed to precursors) • No smelting or leaching is required • Would follow mechanical processing
Pros	• High recovery rates for Nickel and Cobalt • Proven industrial scale processes with hydro process robust against chemistry changes • Higher input flexibility, e.g., for e-waste	• High recovery rates for all metals, incl. cost-effective recovery of lithium possible • Lower capex on metal extraction step • Lower environmental impact (except calcination)	• Results in high value cathode active material (CAM) that can be sold to a battery cell manufacturer
Cons	• Lithium and manganese are lost in slag; recovery currently often not economically viable – Pot. conflict with proposed EU regulatory framework[1)] • Energy and emissions intensive	• More expensive hydro. process required than after pyro. (i.e., alloy more homogenous input) • Significant use of hot water, acids, and solvents; in hydro. profitability dependent on scale	• Not yet proven to be an effective solution on a commercial scale or for mixed chemistry recovery • For EoL recovery, obsolescence a critical issue due to cathode chemistry evolution

Pyro + hydro process is currently the dominant for LiB recycling in NA and the EU, and may be well-suited for supply-constrained markets, where input flexibility is key to manage utilization – Mechanical + hydro process, which is the dominant process in China, offers higher material recovery rates and lower CAPEX requirements – Direct recycling still in R&D phase but very promising for manufacturing scrap recycling

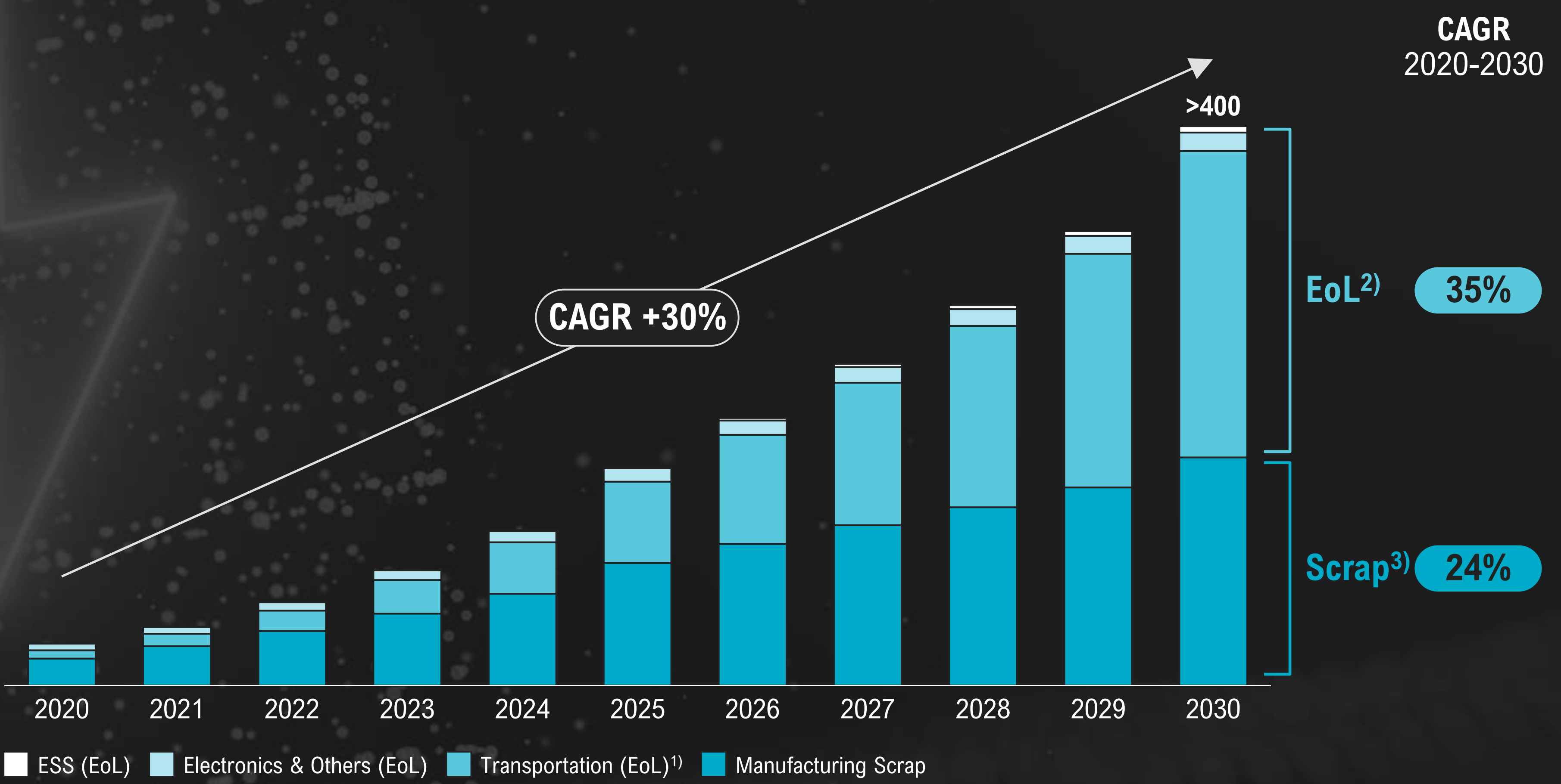
1) Current proposal for regulation would mandate 35% recovery rate of lithium in 2025 or 70% in 2030 in the high ambition scenario

Source: Company information, Interviews with market participants, European Commission, Roland Berger

Indicative estimates as of Nov '21

LiB(-material) feedstock for recycling is expected to reach >400 GWh equivalent globally by 2030 – Scrap expected to remain leading source until 2027

Available LiB(-material) for recycling globally by application [GWh equivalent, EoL + scrap]



- LiB recycling supply grows at CAGR of 30% in line with demand growth
- Share of EoL expected to grow from 35% to ca 60% between 2020-30
- Transportation applications EoL nearly triples its share of LiB recycling supply supported by rapid demand growth and high collection rates
- Scrap availability slows down its growth in the second half of the decade as declining scrap rates, resulting from improving LiB production process, decouple it from demand expansion

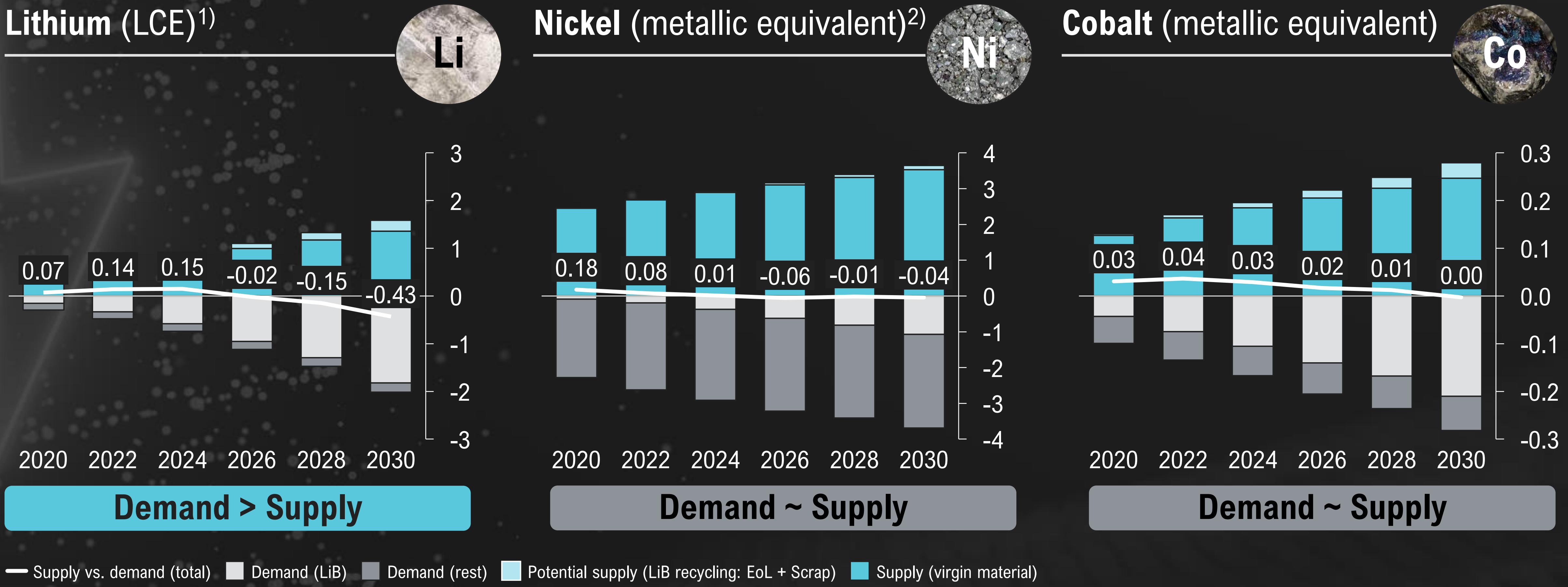
1) Transportation includes passenger and commercial vehicles, ePBV, LSEV, 2-wheeler, eShip, eVTOL; 2) Assuming different lifetimes/ramp-down curves, collection rates and recycling rates per application type (e.g., due to second life or land fill); 3) Assuming 5-10% average scrap rate (status quo at steady state without ramp-up) with slight decrease over time until 2030

Source: Roland Berger

Indicative estimates as of Nov '21

Potentially recoverable materials from LiB recycling play only a minor role compared to overall supply but could be tipping the scales of the supply vs. demand balance

Roland Berger supply and demand forecast – Cobalt, Nickel, Lithium, 2020-2030 [million metric tons]



1) Supply until 2025 based on planned/announced mining and refining capacities. New processed volume after 2025 increases by the average (absolute) increase for the 2019-2025 period as new mining projects are launched to keep up with demand; 2) Includes intermediate and battery grade

Source: Roland Berger Integrated LiB Supply-Demand-Database

Key-Take-Aways

✓ **Impact of EoL recycling on critical materials supply:**
Potentially recoverable materials from LiB recycling play only a minor role compared to overall supply, but could be tipping the scales of the supply vs. demand balance and are needed to comply with regulatory requirements

Focus Next Chapter

- **Impact of vertical integration**, regionalization and co-location of **pCAM-, CAM-** and **cell production** on **costs** and **CO2 emissions**

We use our integrated cost model for pCAM-/CAMand cell production and logistics to understand and compare different levels of vertical integration and co-location

Overview of cost elements varied by cell design and cell manufacturing strategy alternatives[1)]

	Raw Material	Tariff	Shipping	Energy	Labor	Building CAPEX[2)]	Equipment CAPEX[3)]
Location Normal, IL; Phoenix, AZ; Fort Worth, TX; Cottbus, Germany; Somerset, UK; Shenzhen, China; South Korea, Ulsan	○	●	●	●	●	●	●
Cell variant Prismatic LFP (wound), Prismatic NMC 811 (wound), Cylindrical 2170 NCA, Cylindrical 2170 NMC 811, Prismatic NMC 811 (stacked), Future LFP Cell	○	●	●	●	●	●	●
Country of origin of inputs[4)] China, EU, Japan, South Korea, USA, …	●	●	●	○	○	○	○
Level of vertical integration Cells only, Cells+CAM, Cells+CAM+P-CAM, …	○	●	●	○	○	○	○
Scale effects	○	●	○	○	●	○	●

● Cost Highly affected by lever ○ Cost marginally affected by lever /Not varied in model yet

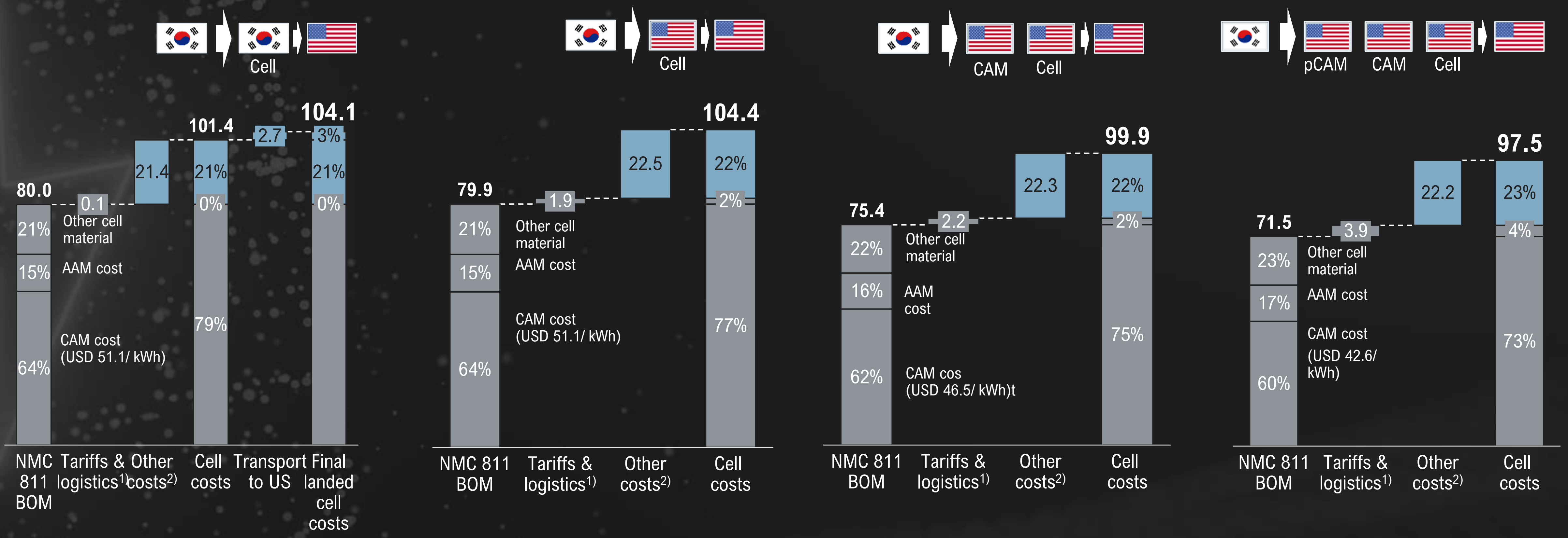
1) Considers cell manufacturing costs only; costs associated with CAM/ P-CAM manufacturing included in material; 2) Incl. respective depreciation; 3) Incl. respective depreciation and variable maintenance; 4) Incl. raw materials (e.g., lithium hydroxide/ carbonate, nickel sulfate), battery materials (e.g., CAM, AAM) and equipment

Source: Roland Berger

Material prices as of Jul. '21

Regionalization of supply chain can reduce political and logistics risk, vertical integration can reduce costs – supply chain set-up to be evaluated case-by-case

Vertical integration scenarios – Prismatic NMC 811 (wound) South Korea vs. US [USD/ kWh]



Material refining → pCAM production → CAM production → Cell production → Cell usage

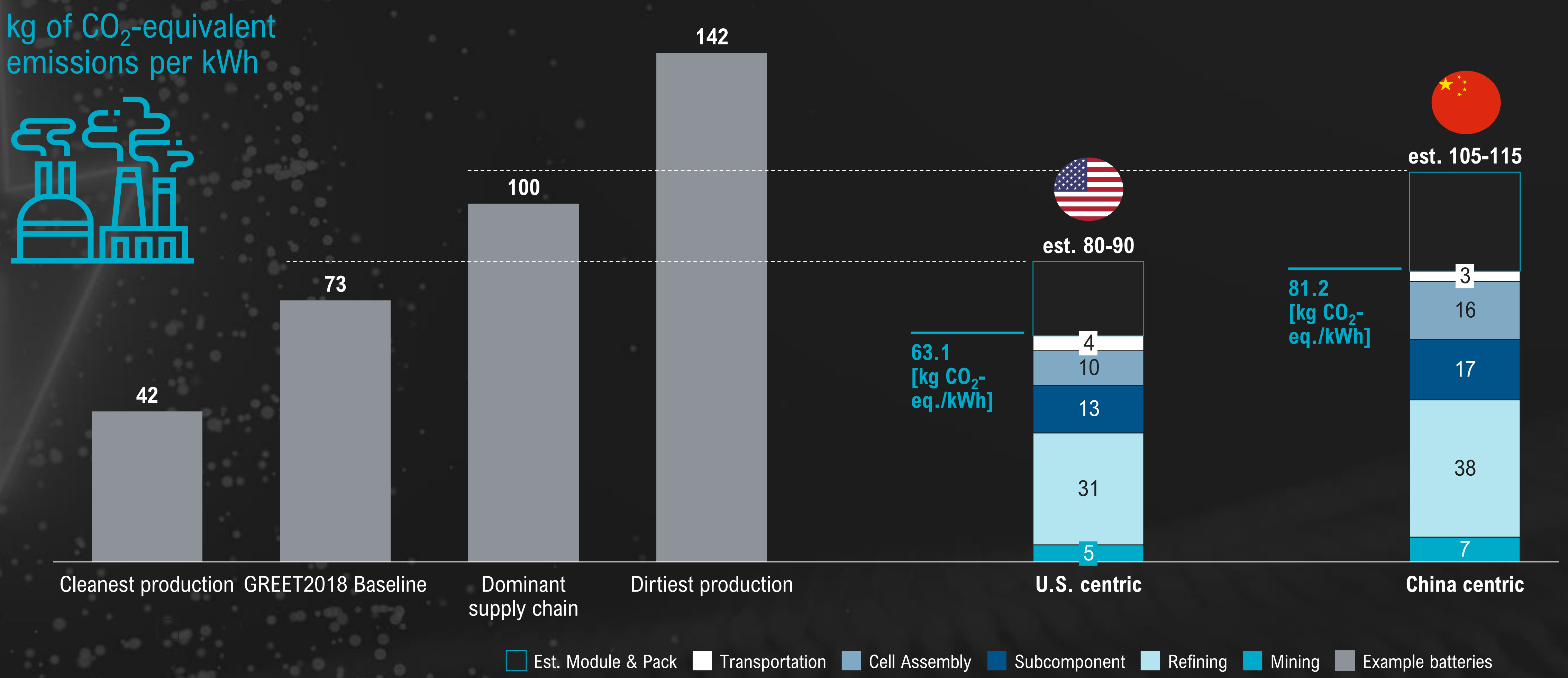
→ "Sourced from"

1 All materials sourced from South Korea assuming Chinese sport market prices from Jul. 2021; 2) Assumes 40 GWh annual production capacity, 90% OEE & utilization, 6.5% scrap and includes cost due to energy, labor, maintenance, scrap, warranty & depreciation

Source: ICCSINO, Roland Berger Integrated Cost Model C3

Bottom-up analysis of CO_2 emissions in cell production and production of necessary material shows impact of production locations, supply chain design and technology

Comparison of bottom-up analysis to published estimates, 2020 [kg CO_2-eq./kWh]



Source: ANL, Roland Berger

Full localization including refinery not always better from a CO2 perspective – depends largely on Scope 2 and Scope 3 emissions of upstream operations

Range of CO_2 emissions depending on supply chain set-up and technologies used – Example "Cells produced for US"

Battery production input		Avg. CO_2-eq. emission [% of total]	Avg. CO_2-eq. emission [tCO_2-eq/t]	MIN	Range of emissions [tCO_2-eq/t]	MAX	Comments
Cathode active material	Lithium carbonate/hydroxide	17.7	18.00	2.80	1 2 D 3 C B A	21.79	High Scenario values due to dirty electricity
	Nickel sulfate	23.4	6.43	1.70	1 2 D B A C 3	12.40	Values in line with published emissions
	Cobalt sulfate	5.6	5.94	3.25	1 C D B 2 3	20.60	Varies depending on allocation method to cobalt
	Manganese sulfate	1.8	3.35	3.31	D B A C	3.46	Minimal published research on emissions
	Aluminum sulfate	0.0	0.04				Negligible emissions/ Bauxite dissolved in acid
	Iron Phosphate	0.0	0.00				No emissions (Waste product of Steel making)
Anode active material	Natural graphite	1.2	3.83	3.52	C D B A 1	4.00	Academic study challenged with industry expert
	Artificial graphite	11.3	23.33	4.30	1 2 D A	23.89	Recent study shows significantly higher emissions
	Silicon	0.1	8.46	5.80	1 C D B A 2 3	17.20	Negligible emissions
	Electrolyte	1.7	2.10	2.20	C D A B 1	6.52	Emissions varies based on electrolyte composition
Cell production	CAM/AAM processing	20.2	9.64	8.58	C D A B	10.70	Emissions using industry data
	Production process	11.5	2.08	0.88	1 D C B 2 A	3.06	Emissions using industry data

Scenario A: "China centric"
Scenario B: "Localized cell Production"
Scenario C: "Localized Active materials"
Scenario D: "US Centtric"
Validation data point #1
Validation data point #2
Validation data point #3

1) Not including additional battery materials

Source: Roland Berger for SAFE

Lithium extraction technologies differ greatly in economic and environmental cost

Economic and environmental cost by source/ extraction technique – Examples, figures vary depending supply chain set-up

Li sources/ extraction tech.	Stage of Development	Sample countries	Emission of CO_2 [MT/ MT LiOH]	Use of water [m^3/ MT LiOH]	Use of land [m^2/ MT LiOH]	Production cost[1)] [k USD/ MT LiOH]
Spodumene – Hard rock	In use	Australia, Brazil, China, Canada, Czech Republic	15	170	464	6.9
Brine – Evaporation ponds	In use	Chile, Argentina, China	5	469	3,124	5.9
Brine – Geothermal[2)]	In development	Germany, UK, US	0	80	6	3.1
Sedimentary/ clay	In development	US, Serbia	*Data not yet available*			

Note: CO2 missions based o examples: Chilenian brine vs Australian spodulene with Chinese conversion

1) Estimated based on CY 2021; 2) Information based on Vulcan Energy Zero Carbon lithium project in Germany

Source: Fitch, Roland Berger

Also the flow sheet of refinery processes has significant impact on carbon footprint – Example $NiSO_4$:Difference of c.110 t CO_2 per t of refined Nickel possible

Raw material carbon footprint (deep dive) – Production processes for nickel refining

Manufacturing processes

Process

Mine	Mine	Mine	Mine
↓	↓	↓ Saprolite ore – Ni ~2%	↓
Concentrator	HPAL	Rotary kiln	Bioleaching
↓	↓	↓	↓
Smelter	Metals extraction	Electric furnace	Metals extraction
↓	↓	↓ NPI – Ni ~12-14%	↓
Refinery	Hydr. Nickel / Nickel Sulphide	Converter	Nickel Sulphide
Briquettes / Powder		↓ Nickel matte – Ni ~70-80%	
↓	↓	Autoclave dissolution Solvent extraction	↓
Refinery	Refinery	Battery-grade $NiSO_4$	Refinery

Carbon footprint

Avg. 10.2 $t\text{-}CO_2/t\text{-}Ni$	Avg. 21.8 $t\text{-}CO_2/t\text{-}Ni$	Avg. 114.8 $t\text{-}CO_2/t\text{-}Ni$	4.6 $t\text{-}CO_2/t\text{-}Ni$

Potential difference in carbon footprint [t CO_2e/t of Ni] **110**

Source: Terrafame, Skarn Associates, Roland Berger

To realize a step-change in cost reduction, and to avoid significant pollution and CO_2 emissions, an integrated perspective of metallurgy and chemistry is needed

CAM value chain: Optimization potential through integrated perspective "Metallurgy AND Chemistry"

"Metallurgy“

Convert ore to battery grade Ni

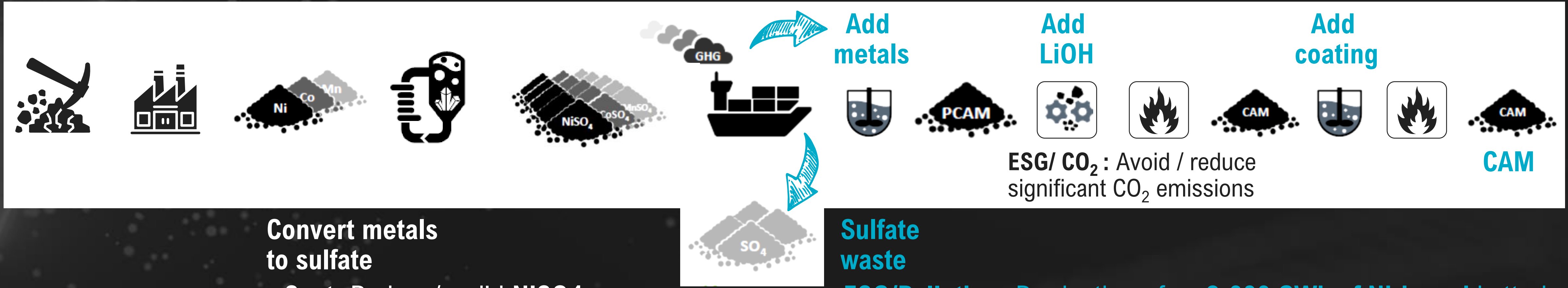
- **Cost:** Reduce/avoid **conversion premium** from NPI to battery-grade Ni
- **ESG/CO_2:** NPI conversion: ca. **45 to** of additional direct CO_2 emissions **per ton** of refined nickel

&

"Chemistry “

P-CAM **CAM production**

Cost: Change flowsheet and **significantly upscale** line capacity to **decrease** current **processing cost**



Convert metals to sulfate

- **Cost:** Reduce/avoild **NiSO4 premium**
- **ESG/CO_2:** Avoid significant **CO_2** emissions and sulfate waste

Sulfate waste

ESG/Pollution: Production of ca **2,000 GWh of Ni-based** batteries in **2030** would result in 1.5 mio tons Ni and approx. **3 mio tons of sodium sulfate p.a.** in 2030, that cannot be recycled but mostly would be disposed to the sea

Source: Roland Berger

Key-Take-Aways

✓ **Impact of EoL recycling on critical materials supply:**
Potentially recoverable materials from LiB recycling play only a minor role compared to overall supply, but could be tipping the scales of the supply vs. demand balance and are needed to comply with regulatory requirements

✓ **Impact of vertical integration, regionalization and co-location of pCAM-, CAM- and cell production on costs and CO2 emissions:**
Vertical integration and co-location reduce landed cell costs, in addition, regionalization of th esupply chain can further decrease overall emissions – to realize a real step-change, an integrated perspective of metallurgy and chemistry is needed

Focus Next Chapter

- **Vertical integration strategies** of leading players

OEMs and cell manufacturer can choose different levels of involvement to reduce supply chain risks – Lower risk associated with higher control over value chain

Common operational risk mitigation levers

	Regular sourcing contract	Long-term agreement	Investment
Description	Supply agreement without volume guarantees	Long-term offtake agreement with volume and/or price guarantees	Co-investment with strategic partner to address raw material need
Advantages & disadvantages	(+) Low commitment, high volume flexibility	(+) No upfront CAPEX required (+) More flexibility on volume increments	(+) High influence on product/R&D (speed) (+) Higher operational control (quality, cost, raw material mgmt., plant location) (+) Participation in profit
	(–) Supply availability risk (–) Price risk (–) No/very limited influence on product/R&D	(–) Medium influence on product/R&D (–) Less ability to select plant location, i.e., EU localization	(–) High upfront CAPEX required (–) Risk of obsolescence of industrial asset
Assessment	Price risk mitigation only	Better risk mitigation, mid-/long-term commitment	Strongest risk mitigation, requires upfront CAPEX

Source: Interviews with market participants, desk research, Roland Berger

Key-Take-Aways

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✓ **Vertical integration strategies of leading players:**
Aiming for an integrated battery value chain to mitigate supply chain risks and occupy critical control points

Focus Next Chapter

- **Strategic implications for OEMs, cell- and CAM suppliers, mining companies and legislators**

Strategic implications

- **Not securing the supply** of raw/refined (battery) materials could **jeopardize the business model around EVs**
- **Mandatory recycling** will help to **ease supply situation** especially for **Cobalt** and to some extend for **Lithium** and **Nickel**
- **Occupying the critical control points** along the supply chain can provide **strong competitive advantages**
- **Localization of the supply chain** can reduce **cost, risk, political exposure**, and reduce **CO_2 footprint**
- **Upstream partnerships** are needed to **secure supply** – but to **secure and optimize costs**, combining metallurgy-, cell chemistry-, and cell-design- competences, **integration down to mining level** is needed

Our support related to the LiB value chain

Project experience, proven frameworks and tools for a variety of topics

- ✓ **Supplier / partner selection** and **negotiation** support
- ✓ **Supply chain risk analysis** for OEMs and cell players
- ✓ **Due diligence** (Commercial, Technical, Vendor) on all levels of the value chain
- ✓ **Vertical integration** / depth-of-engagement strategy for OEMs and cell players
- ✓ **Go-to-market-** and **pricing-strategy** for active materials
- ✓ **Market entry strategies** for mining, refining, active materials and cell companies
- ✓ **Joint venture management**: partner search, MoU-/Term-sheet-definition, …

…

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Disclaimer

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