Economic viability of repurposed batteries and recycled battery materials

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EXTENDING RANGE

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Roland Berger

Your presenter today

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Check out our website for more insights from RB's Battery team!

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We have a dedicated team of international battery experts supporting clients along the entire value chain on strategic topics

Introduction to Roland Berger's global "Battery Team"

Our experience

Mining/refining | Cell & pack | OEMs | ESS | EoL & aftermarket

Unmatched experience of **200+ projects** with key players along battery value chain

Our offerings

Investor Support
- M&A target search
- Commercial & Technical Due Diligence (sell & buy side)
- SPAC merger & IPO support (e.g., prospectus)

Strategic Advisory
- Business modelling & planning, Product portfolio, Got-to-market strategy, Supply chain strategy, Vertical integration, Strategic partner search, JV negotiations

Operational Support
- Product cost reduction incl. should cost analysis & benchmark
- Manufacturing footprint and ramp-up support
- R&D and organizational efficiency

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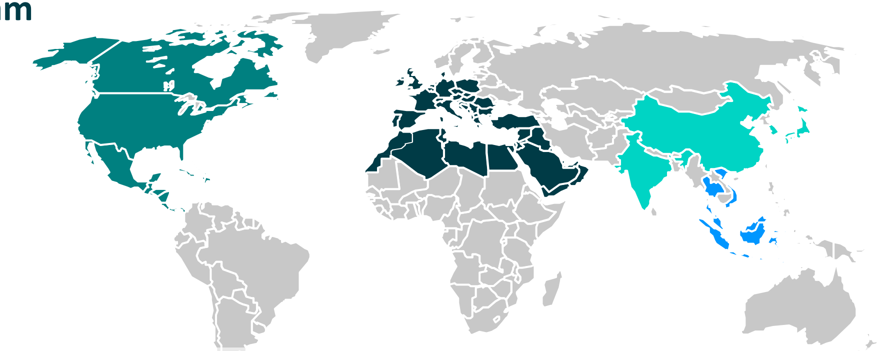
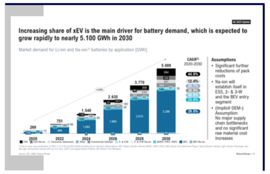
Our team



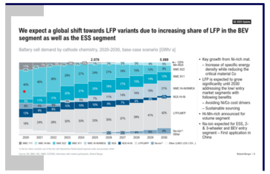
Global team of **50+ battery** technology and market experts with hubs in North America, Europe and Asia

Our tools & models

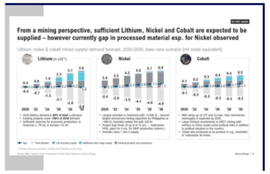
LiB & NaB demand forecast per application & market



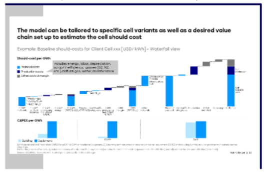
Battery technology roadmaps and market share forecast



Battery materials supply vs. demand forecast



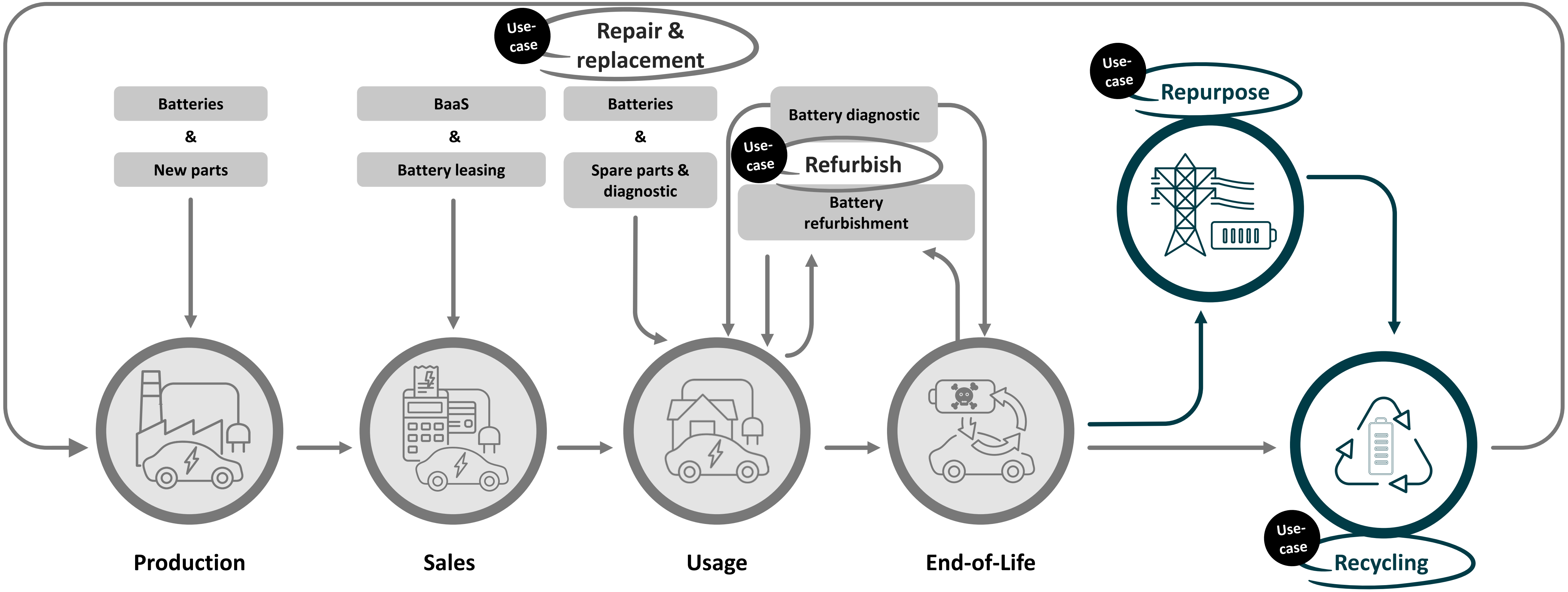
Integrated cell should cost model (PCAM/CAM/Cell)



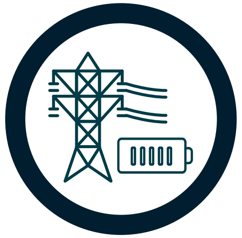
Set of proprietary **tools & databases** that can be leveraged during projects

We see 4 primary use-cases for end-of-life batteries – Today, we'll focus on repurposing EV batteries in stationary applications (second life) and recycling

New world: EV/ battery lifecycle economy



Key questions to be addressed



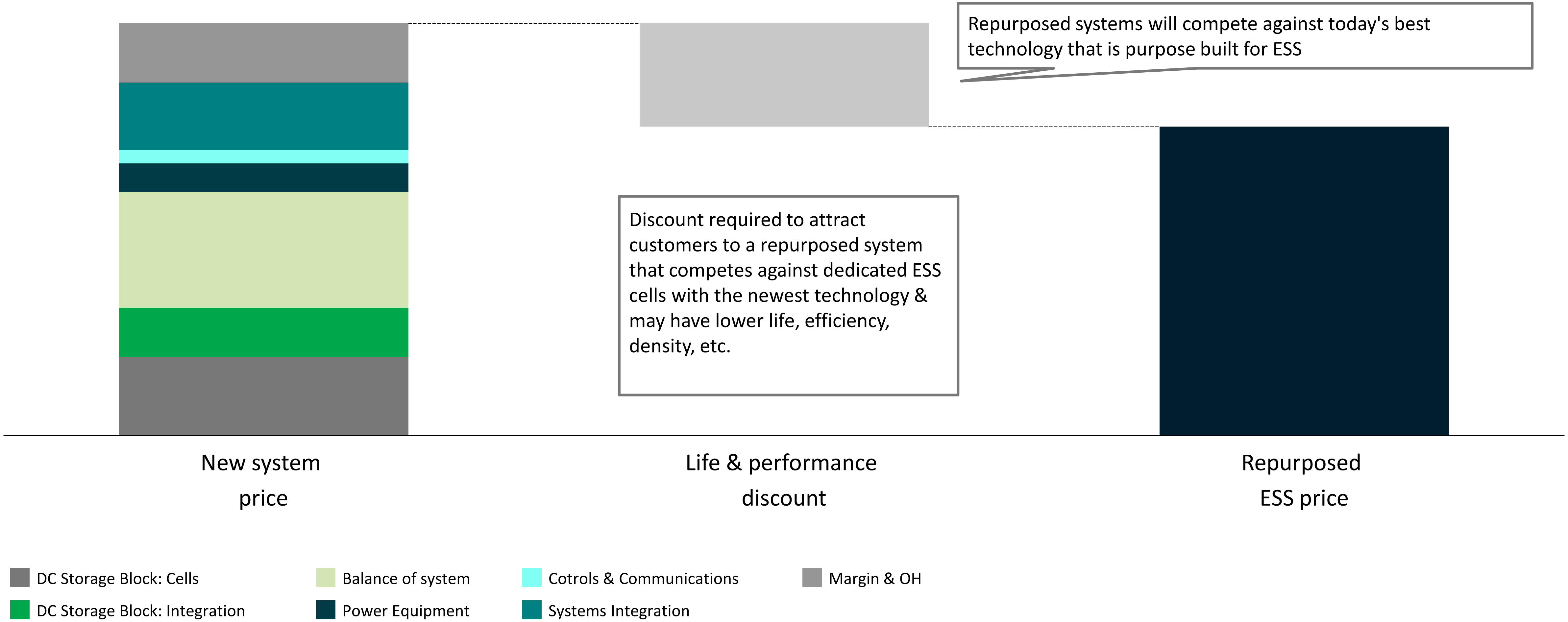
Is **battery repurposing economically viable?**

Can **recycled battery materials be cost competitive** to virgin battery materials?

Indicative

To analyze the economic viability of a repurposed ESS system, we start by determining the discount factor that would be required based on remaining SoH

Step one: Estimate price of repurposed ESS (1/2) – Concept



Source: Roland Berger Battery Repurposing Economics Model

Indicative

Based on the Roland Berger levelized cost of storage model, a ~25% discount would be required for repurposed ESS (based solely on cycle life differences)

Step one: Estimate price of repurposed ESS (2/2) – Results of levelized cost of storage analysis

Reference case

Customer application:
Commercial & Industrial

Application:
Peak shaving & ancillary (bill management)

Power:
1 MW

Energy capacity:
2 MWh[2)] (2-hr duration)

Optimistic assumption[2)]

Location:
United States

Optimistic assumption[3)]

Cycles per year:
350

	Project inputs[1)]	New system	Repurposed system	
Parameters[1)]	Cycle life [#]	**7,000**	**3,600**	Lower cycle life
Parameters[1)]	Round trip efficiency [%]	91%	91%	Optimistic assumption
Financials	O&M [EUR/kWh]	4.94 (2.5% escalation per annum)	4.94 (2.5% escalation per annum)	
Financials	Charging costs [EUR/MWh]	115.8 (2.0% escalation per annum)	115.8 (2.0% escalation per annum)	
Financials	EPC & install costs [EUR/kWh]	53.1	53.1	Optimistic assumption
Financials	ESS equipment cost [EUR/kWh]	**235.8**	**171.7**	**Discount required: 27%**
Financials	Levelized cost of storage [EUR/MWh]	**323.6**	**323.6**	ESS equip. cost adjusted to achieve like LCOS

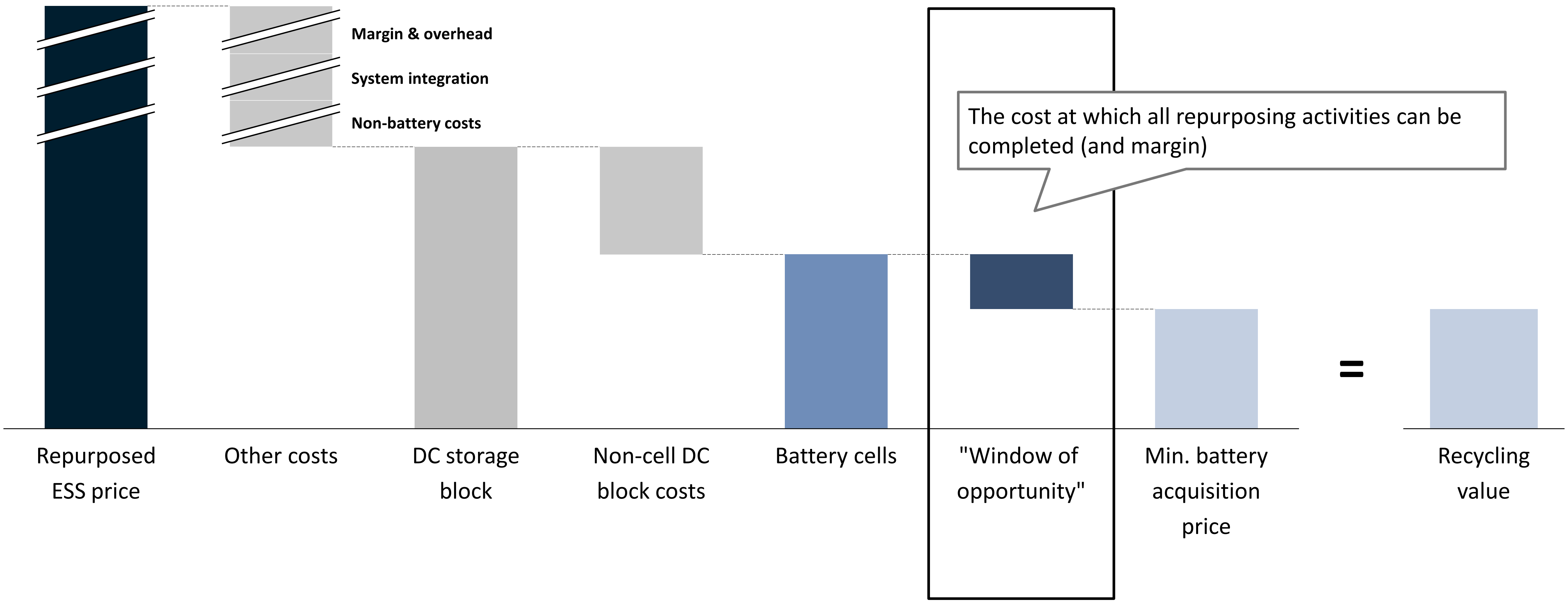
1) Other inputs remain that constant across comparison include: 0.5% extended warranty starting in year 3; No salvage value; Financed with 20% debt (8% rate) and 80% equity (12% cost of capital); 27% tax rate with 5-year MACRS depreciation; 2) Larger than approx. communicated range for C&I – Larger system optimistic as non-battery costs are a smaller share of total; 3) US considered optimistic given incentive environment (IRA invest. tax credit) & more flexible electricity tariff structure (e.g., demand response incentives)

Source: Roland Berger Levelized Cost of Storage Model, Lazard

Illustrative

With the repurposed ESS price, we then identify the "window of opportunity" to repurpose battery cells – Acquisition cost is driven by battery recycling value

Step two: Determine window of opportunity (1/2) – Concept



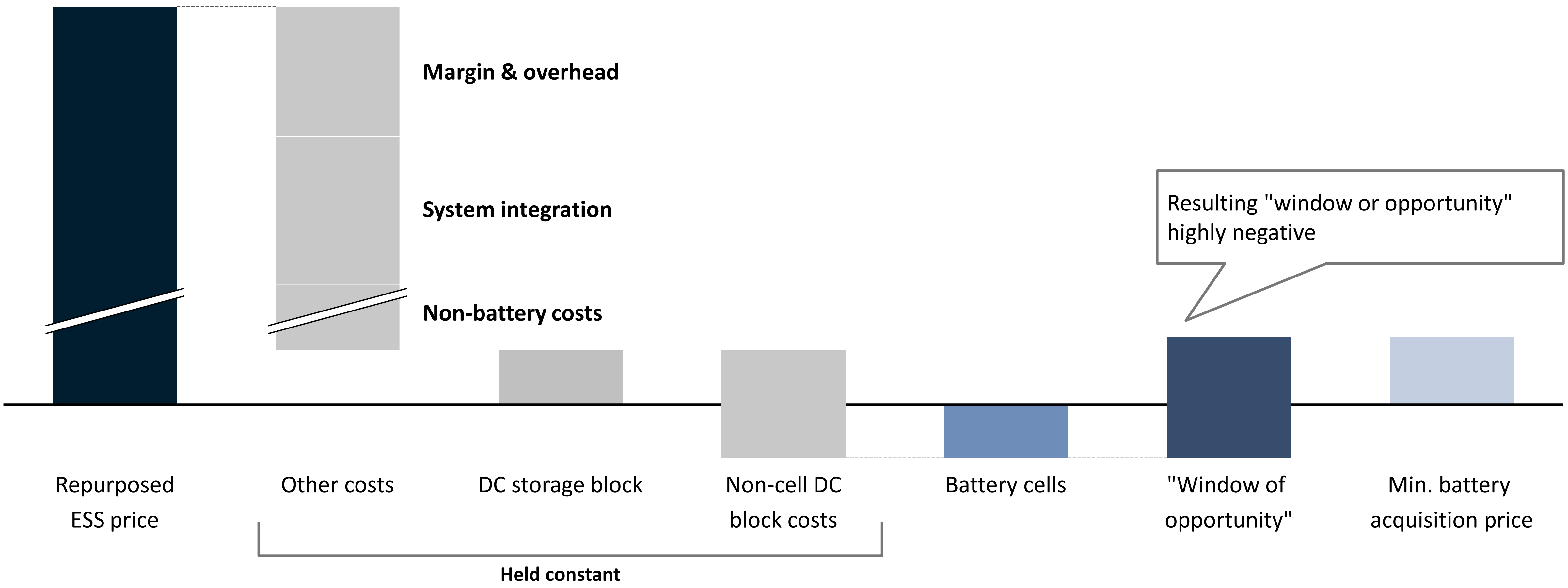
1) Such as margin and overhead, system integration, non-battery costs (e.g., PCS, C&C, DC block BOS), and non-cell DC block costs

Source: Roland Berger Battery Repurposing Economics Model

Indicative

Based on estimated repurposed ESS price, battery cell prices would have to be negative – Ensuring there is no viable "window of opportunity"

Step two: Determine window of opportunity (2/2) – Results



1) Such as margin and overhead, system integration, non-battery costs (e.g., PCS, C&C, DC block BOS), and non-cell DC block costs

Source: Roland Berger Battery Repurposing Economics Model

There are opportunities that could increase the viability of repurposed systems, but the quantity and severity of threats appear to outweigh them

Opportunities & threats to economic feasibility of a repurposed ESS integrator

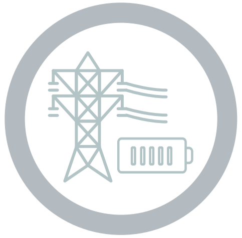
Opportunities

- **CO_2 tax on ESS systems** in EU making ESS with new cells relatively more expensive
- **Import duty on cells or ESS systems containing cells from China**, blocking out cheap LFP cells
- **Future gen. battery cell chemistries have a cycle life substantially beyond vehicle life** & therefore surplus used auto batteries are available in the market

Threats

- **Lower cost, high tech., dedicated battery cells for ESS** further reducing window of opportunity, e.g., optimized LFP, Sodium-ion
- **Innovation in battery recycling** allowing higher EOL battery acquisition cost of a recycler, increasing the repurposing battery acquisition cost, e.g., via direct recycling
- **A price premium develops for recycled material, increasing the repurposing battery acquisition cost**
- **Higher than expected repurposing cost**
- **Customer uneasiness or early, public failures** hampers adoption of repurposed systems

Key questions to be addressed

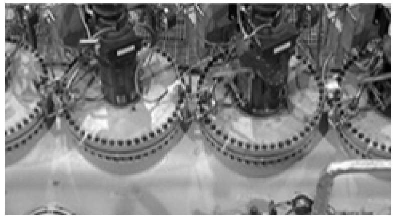
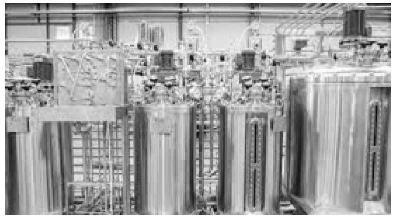


Is **battery repurposing economically viable?**

Can **recycled battery materials be cost competitive** to virgin battery materials?

The recycling value chain spans collection, pre-processing and refinement – Today's discussion will focus on the profitability of hydrometallurgical recycling

Overview of lithium-ion battery recycling value chain

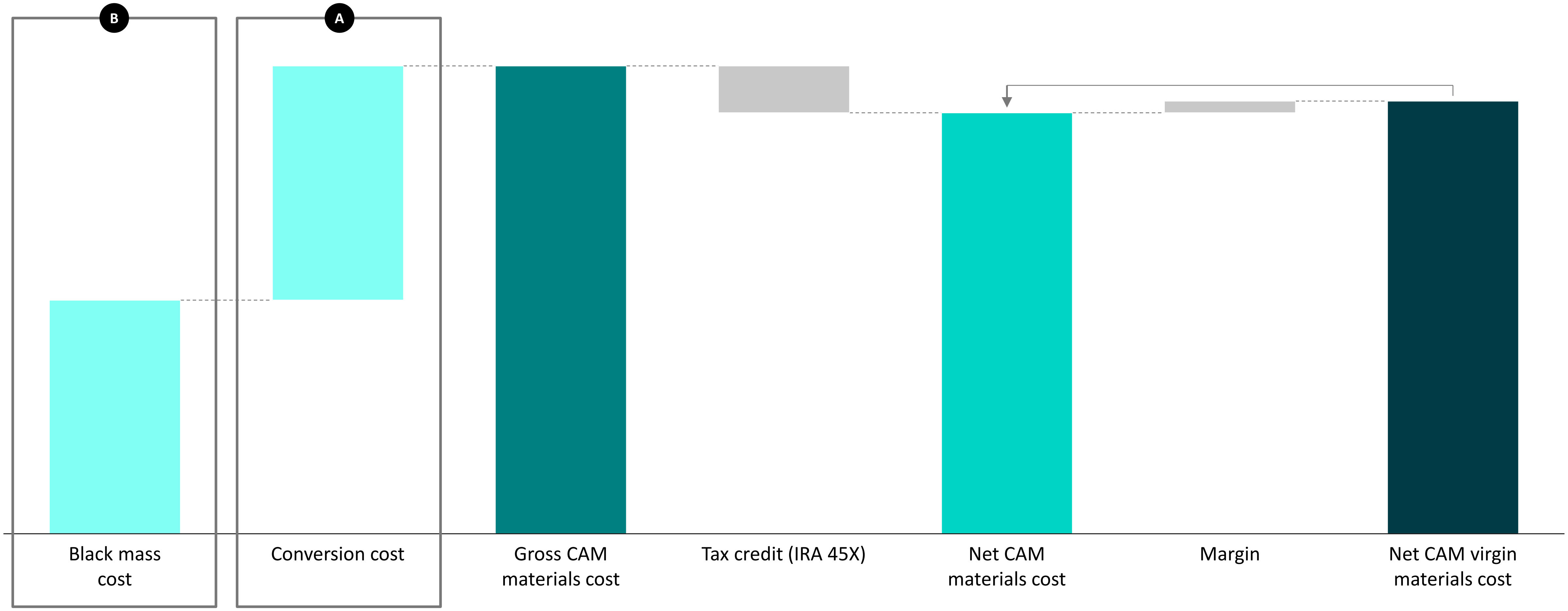
	Recycling			Battery materials	
	Collection (& sortation)	**Pre-processing** (pyro. or mech.)	**Refinement** (hydro.)	**Precursor**	**Cathode active material (CAM)**
					
Process description	• Collection of batteries, production waste • Sortations	• Discharging/ dismantling • Mechanical shredding • Heat treatment	• Acid leaching of constituent metals • Solvent extraction, precipitation to refine to battery-grade	• Precipitation of metal hydroxide • Ammonia recovery, effluent treatment	• Mixing of precursor and lithium source • Calcination/lithiation • Post treatment (coating)
Primary outputs[1)]	• Sorted battery material (scrap, EoL)	• **Black mass** • Copper, plastics, etc.	• Metal sulfates • Lithium carbonate	• Ternary precursor	• Ternary cathode active material
			Focus		

1) Outputs at each process will vary depending on recycling technology deployed

Illustrative

Economic viability of recycled battery materials is driven by conversion costs and black mass costs

Economics for recycled materials – Concept



Source: Roland Berger Battery Recycling Economic Model

Profitability and cost competitiveness at hydrometallurgical refineries is driven by a number of factors – Operating scale among the most important drivers

Key determinants of hydrometallurgical refinement conversion costs

Determinant	Key considerations	CapEx impact	OpEx impact
Operating scale "What size do I build?"	• Effective operating scale	◕ 1)	◑ 1)
Plant operating parameters "How well can I do it?"	• Capacity utilization (incl. black mass quality) • Operating excellence	◔	◕
Plant location "Where do I put the plant?"	• Local labor and utility rates • Subsidies and incentives • Wastewater restrictions	◑	◑
Network setup "Where do I extract vs. refine?"	• Proximity to Gigafactories, consumables, etc. • Transportation costs	◔	◑
Technology & design choices "What do I choose to do?"	• Value chain setup (incl. integration level) • Flow sheet design choices • Treatment of waste streams	◔	◕

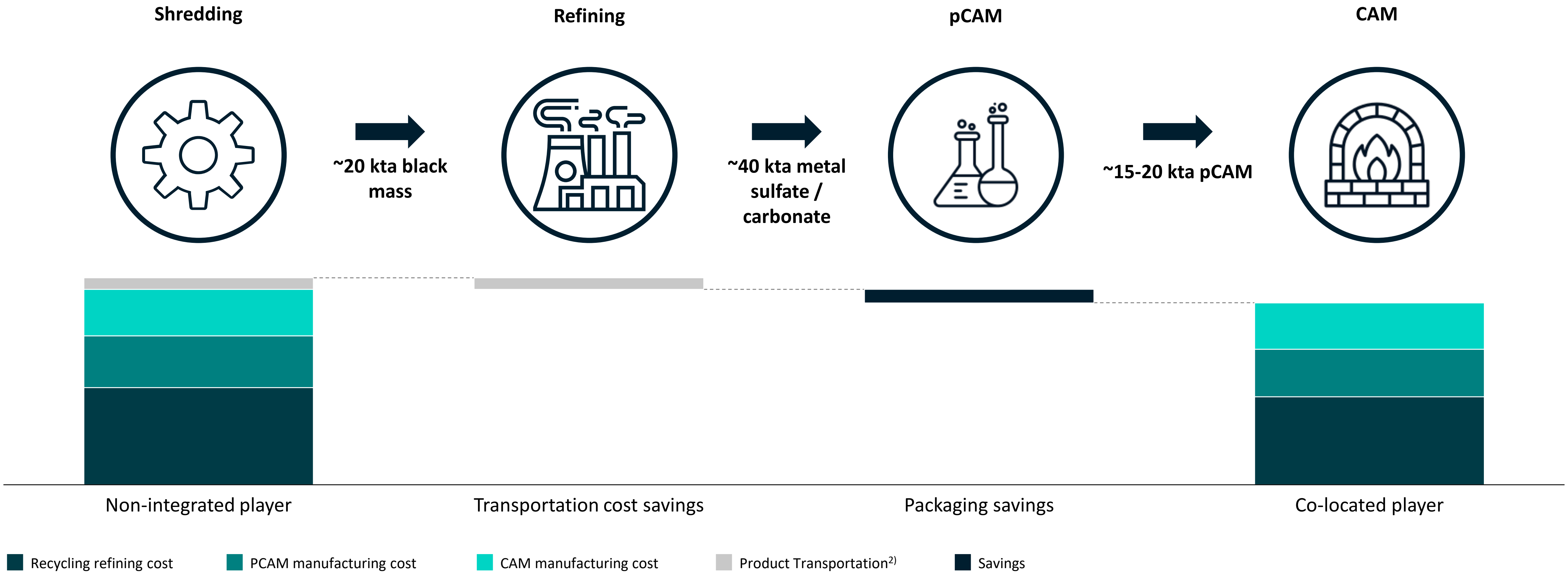
● High impact ○ Low impact ■ Deep dive

1) Assumes greater than 50 kta

Indicative

Co-location of battery recycling and CAM manufacturing can give a cost advantage of to USD 1-2/kg of CAM

Savings potential from co-locating shredding to CAM manufacturing – Concept

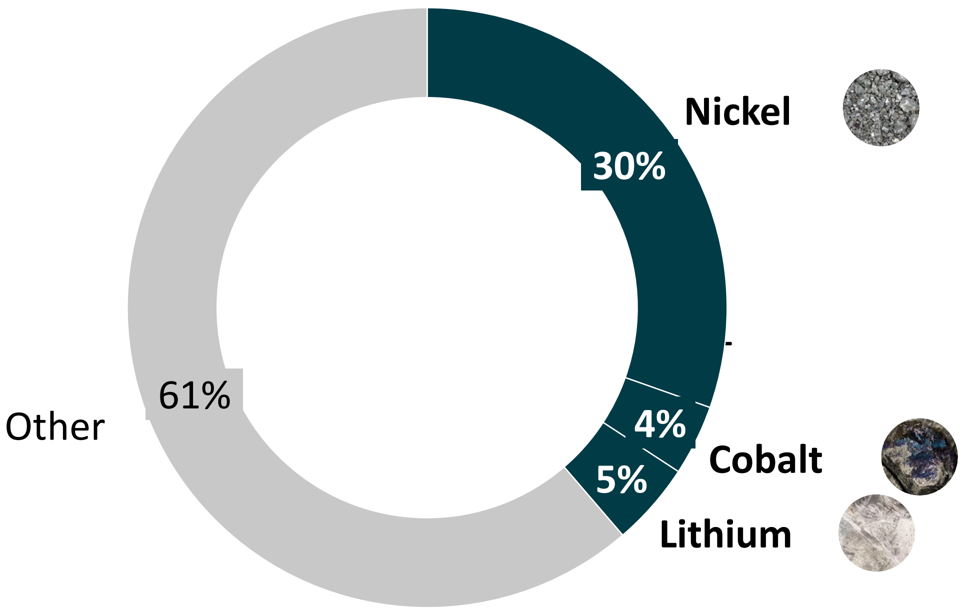


Source: Roland Berger Battery Recycling Economics Model

Black mass is priced based on the metal value of the nickel, cobalt and sometimes) lithium included in the material - Key to the price is the payable

Black mass pricing mechanism

Black mass composition
(NMC811)



Black mass pricing

Metal content

Spot market price

Discount factor "Payable"

FOCUS

Black mass comes from two major supply sources: Manufacturing scrap and end-of-life, each with different market dynamics and key drivers

LiB recycling supply sources

Production scrap

Source	Cell manufacturers, CAM manufacturers
Composition	Homogenous (same chemistry and format)
Potential risk for supply	Vertical integration/ in-house recycling by (p)CAM manufacturers and cell manufacturers due to low capital required and high suitability/ purity of materials recovered

End-of-life (EoL)

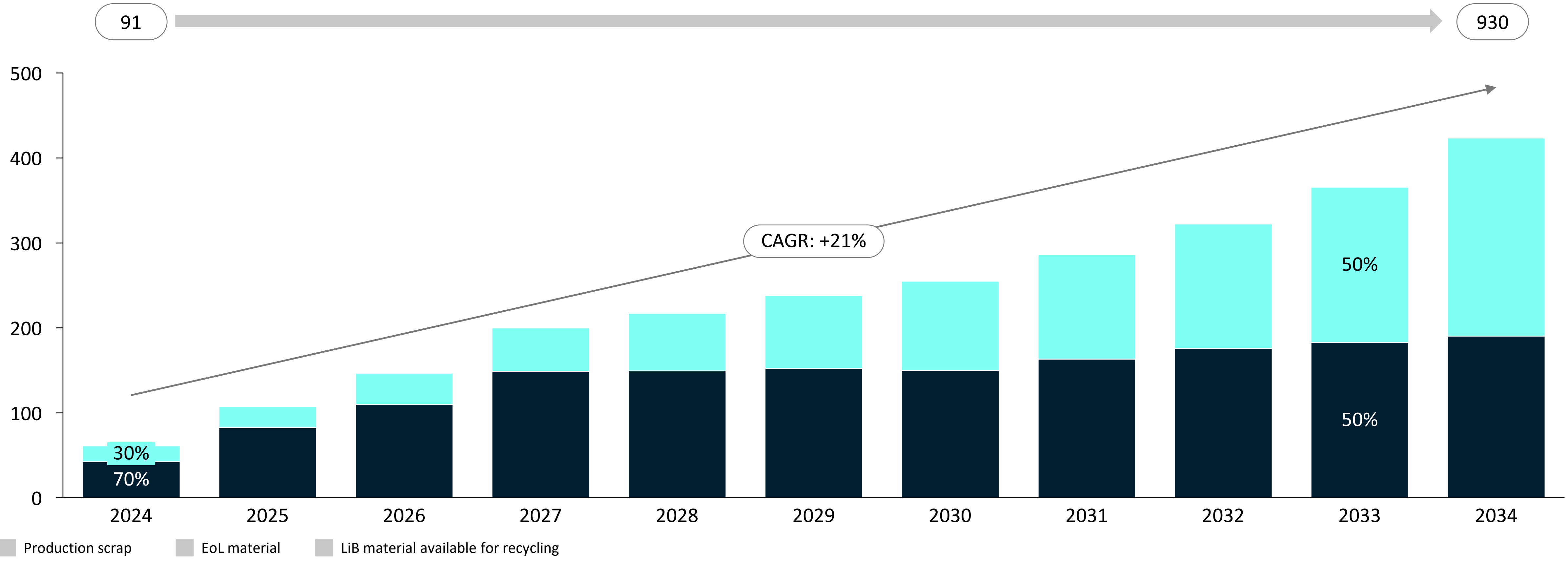
Source	OEMs, collectors, end users
Composition	Heterogenous (different chemistries and formats)
Potential risk for supply	• Access to collection networks • High amount of 2nd life/reuse of batteries after damage/defect/recall or at EoL (prolongation of lead-time)

LiB supply for recycling

Indicative | As of Q3 2024

The challenge for recyclers is to secure enough feedstock to profitably run operations until the wave of end-of-life (EoL) batteries hits in ~10 years

Total addressable black mass[1)] market by stream in North America, 2024-2034 [kt black mass]



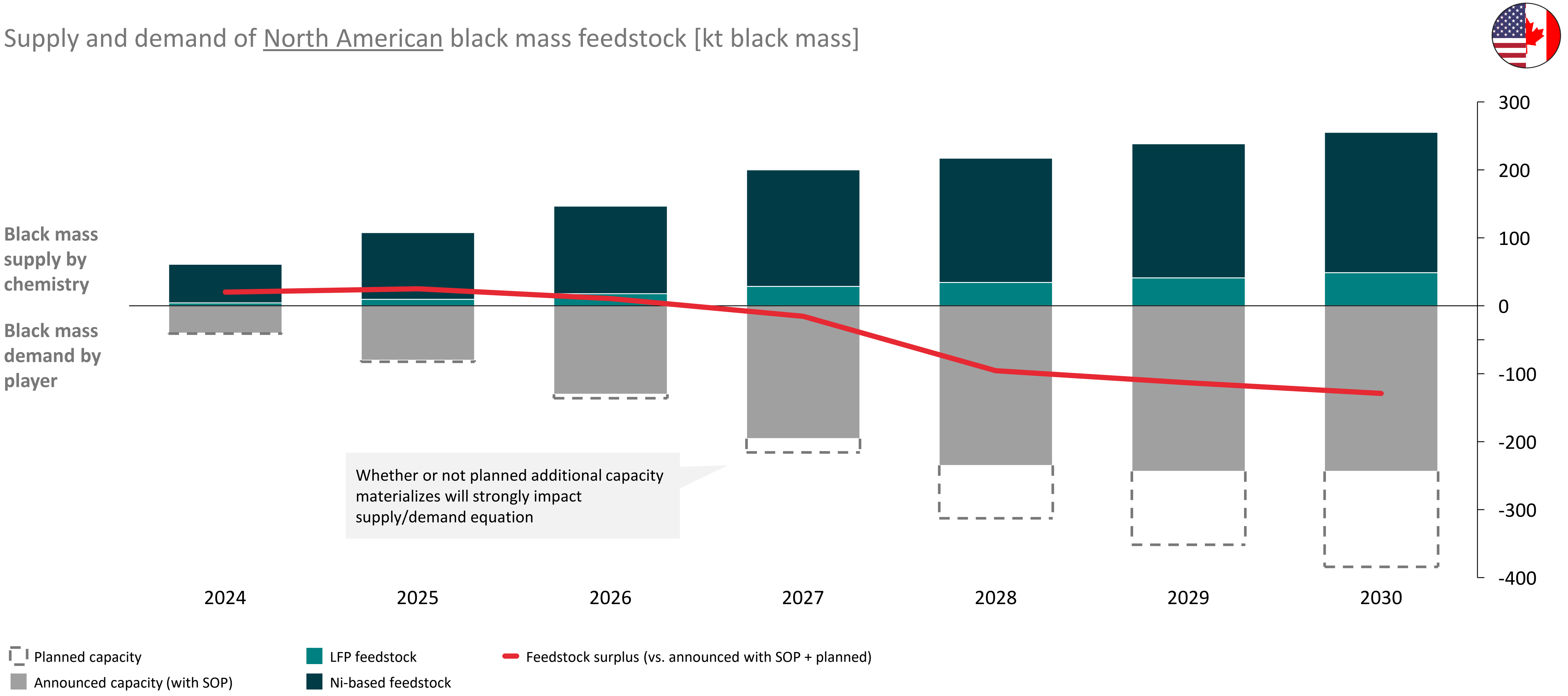
1) Black mass market assessed only considers the combination of cathode and anode active materials (CAM and AAM)

Source: Roland Berger Battery Recycling Volume Model

Indicative | As of Q3 2024

With demand from domestic recyclers projected to surpass NA supply, the competition for feedstock will increase

Supply and demand of North American black mass feedstock [kt black mass]

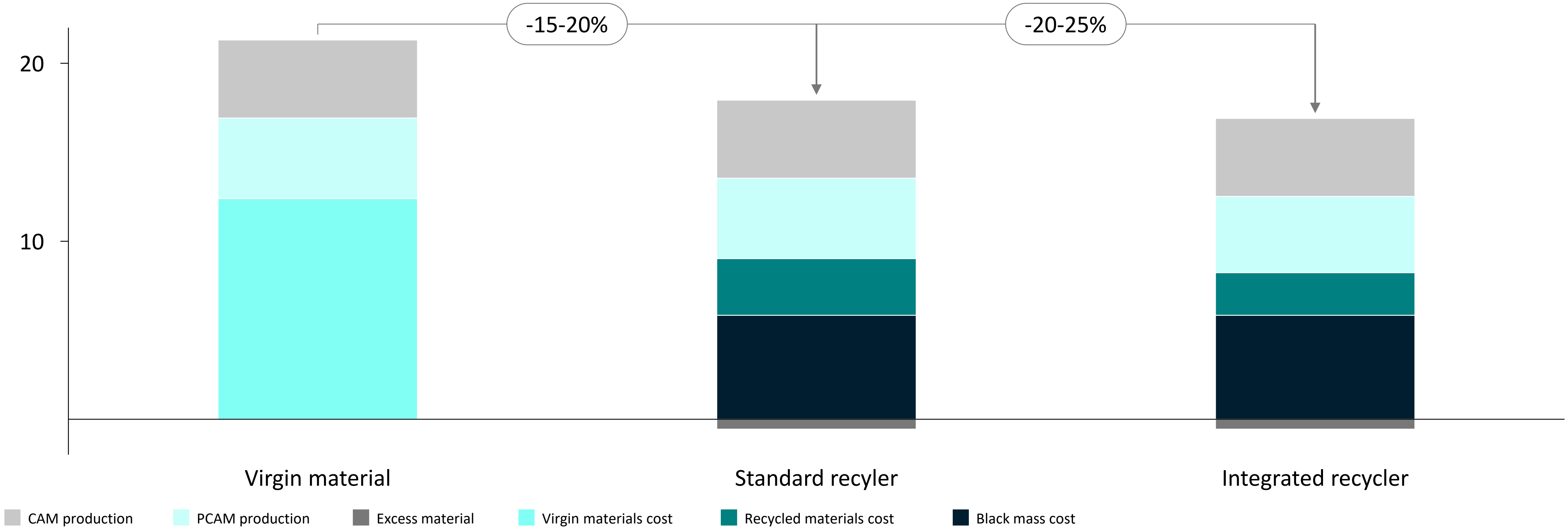


Source: Roland Berger Battery Recycling Volume Model

Indicative | As of Q3 2024

Putting this together, recycled materials can be cost competitive vs. virgin materials, especially at the current level of payables in the US…

Cost competitiveness in NA market[1)] **(60% payables on Ni/Co/Li)** [USD/kg of NMC 811 CAM]



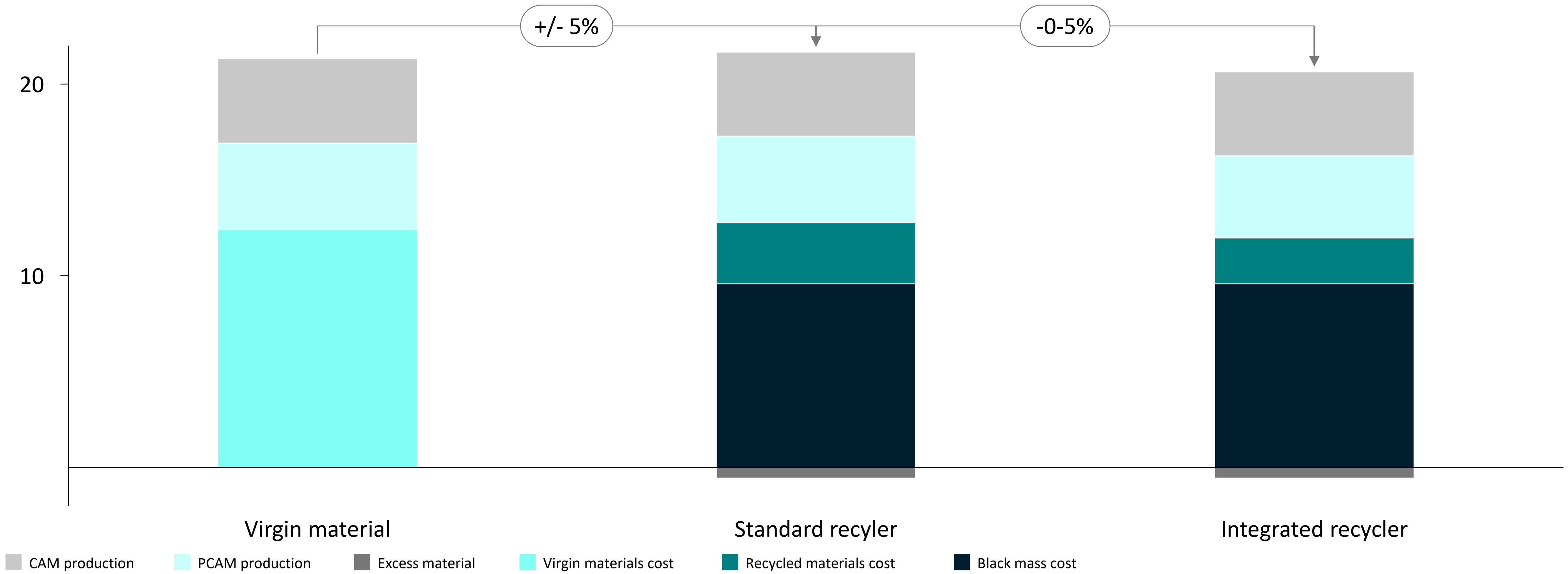
1) Assume 60% payables, black mass specs for NMC 811 batteries with (4.5% lithium content, 30.4% nickel content, 3.6% manganese content and 3.8% cobalt content), costs of production for 30 kta hydrometallurgical refining facilities and pCAM/CAM production costs from a scaled facility (~40 kta); 2) No sulfation/conversion costs included

Source: Roland Berger Battery Recycling Economics Model, Roland Berger pCAM/CAM Economics Model

Indicative | As of Q3 2024

…however, at higher payables the economic viability of recycled battery materials is less certain, increasing importance of other key cost drivers

Cost competitiveness in NA market[1)] **(70% payables on Ni/Co/Li)** [USD/kg of NMC 811 CAM]



1) Assume 70% payables, black mass specs for NMC 811 batteries with (4.5% lithium content, 30.4% nickel content, 3.6% manganese content and 3.8% cobalt content), costs of production for 30 kta hydrometallurgical refining facilities and pCAM/CAM production costs from a scaled facility (~40 kta); 2) No sulfation/conversion costs included

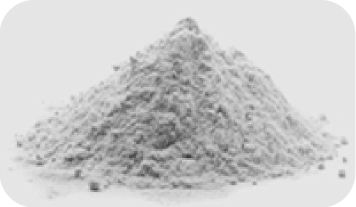
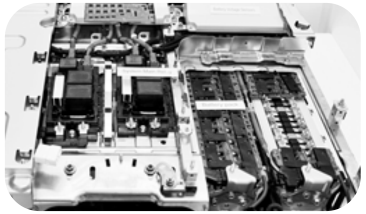
Source: Roland Berger Battery Recycling Economics Model, Roland Berger pCAM/CAM Economics Model

Key takeaways

- Battery end-of-life has potential to reshape the automotive aftermarket into an EV & battery lifecycle economy creating opportunities for new players – **Each 4R use-case represents a different solution to capture value from EoL batteries**
- The viability of a repurposed ESS system requires **a 25% discount on new ESS prices** –The required battery cell price to achieve this discount is negative resulting in **no viable "window of opportunity" for battery repurposing**
- There are opportunities that could increase the viability of repurposed systems, but the **quantity and severity of threats appear to outweigh** them – Limiting repurposing to niche applications
- **Black mass payables and the efficiency of recyclers operations & set up** are the key drivers to cost competitiveness of recycled battery materials vs. virgin materials
- **At current payables levels, recycled materials can be cost competitive to virgin materials** although at higher payables levels, the economic viability becomes less certain
- As more recycling facilities come online in the US, **access to feedstock is expected to become increasingly challenging** increasing the importance of key success factors:
  - Partnerships to secure feedstock (including cell makers, OEMs and scrapyards)
  - Optimized flow sheets (including strategic co-location)
  - Efficient plant operations

Our offerings cover all major functional topics along the battery value chain, including investor support, strategy definition and operational improvements

Value chain focus

	1 Mining & Refining	2 Battery Materials	3 Battery Cells	4 Module, Pack & Integration	5 Appl., Markets & Regulation	6 After market & Recycling
						
Investor support	• Commercial DD for strategic and financial investors	• VDD, CDD, TDD & SPAC merger for strategic and financial investors	• VDD, CDD, TDD & IPO support for strategic and financial investors	• VDD, CDD, TDD & SPAC merger for strategic and financial investors	• Market assessments of all mayor markets for battery value chain players	• VDD, CDD, TDD & SPAC merger for strategic and financial investors
Strategy	• Supply chain strategy for downstream players • Partnering and GTM-stra-tegy for mining companies • Cluster strategies	• Cluster strategy, vertical integration, market entry for material producers • Pricing strategy	• Vertical integration, cluster strategy, regulations for cell manufacturers • Business planning and market entry EU & US • Equipment go2market	• Strategy reset, vertical integration for pack producers and automotive OEMs	• Market strategy and regulatory impact assessment for all players within the battery and e-mobility space	• Market entry & partnering for OEMs, Tier 1 suppliers, recycling players, cell producers and chemical companies • Aftermarket strategies
Operations	• Target costing for refineries • TCO optimization BEV mining trucks • Industrialization progress tracking and monitoring	• Footprint/site-selection for material producers • Target costing for pCAM/ CAM/AAM production facilities • Industrialization progress tracking and monitoring	• Footprint, site selection, sourcing strategies for cell producers • Cell-cost benchmarking and "should-cost" evaluation of cell production • Industrialization progress tracking and monitoring • Task.-force management	• Cost benchmarking • Cost optimization, supplier selection/sourcing strategies for OEMs, pack manufacturers and other battery users	• R&D collaboration model for shared OEM EV platform	• Cost benchmarking • Industrialization progress tracking and monitoring

Functional topics covered

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