Lithium-ion battery supply chain technology development and investment opportunities

Carnegie Mellon University – Battery Seminar
June 2020

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Benchmark Mineral Intelligence

Due to policy statements and strong public opinion trends, major automakers have committed over USD$300B towards actively developing battery electric vehicles

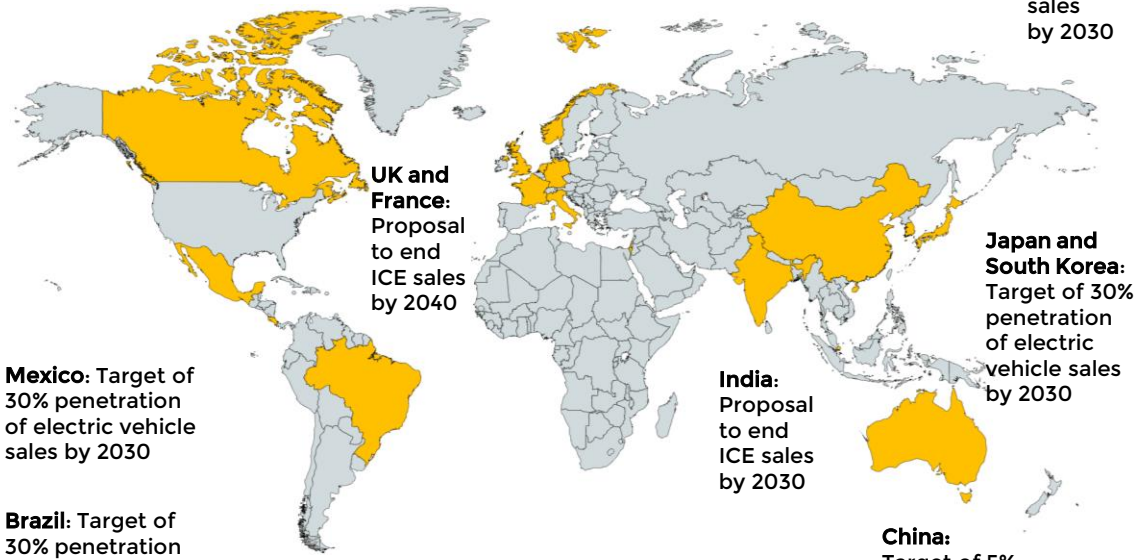
Global policy statements by governments supporting EV adoption

Canada: Target of 30% penetration of electric vehicle sales by 2030 Quebec targeting 100% zero emissions by 2050

Norway and Netherlands: Proposal to end ICE sales by 2035, **Germany** by 2030. Considerations for EU wide ban by 2030

Italy: Target of 30% penetration of electric vehicle sales by 2030

Israel: Proposal to end ICE sales by 2030



UK and France: Proposal to end ICE sales by 2040

Japan and South Korea: Target of 30% penetration of electric vehicle sales by 2030

Mexico: Target of 30% penetration of electric vehicle sales by 2030

India: Proposal to end ICE sales by 2030

Brazil: Target of 30% penetration of electric vehicle sales by 2030

China: Target of 5% penetration of electric vehicle sales by 2020, 20% by 2025

Examples of major passenger car and light duty vehicle OEM EV strategy announcements

Total annual vehicle production

10-12mn

Launching 12 EV models by 2022

RENAULT NISSAN MITSUBISHI

Planning at least 20 EVs by 2023

GENERAL MOTORS

Chinese OEMs expected to comply with 20% EV penetration rate by 2025

JAC MOTORS, CHERY, SAIC, Great Wall, FAW, 萬向集團, 北汽重卡, GEELY, 东风汽车公司

VW group plans to invest more than $24bn in zero-emission vehicles by 2030. Will develop 80 EV models by 2025.

VOLKSWAGEN GROUP

Toyota has set a sales target of ~1m EVs and FCVs by 2030, investing >$13 billion to develop and make batteries

TOYOTA

5-9mn

Planning to invest $11bn in EVs by 2022, and will have 40 hybrid and full EV models

Ford

Aiming to develop 8 EV models by 2025, with 30 panned by 2030

HYUNDAI

KIA MOTORS

Set target of two thirds of vehicle sales EV by 2030

HONDA

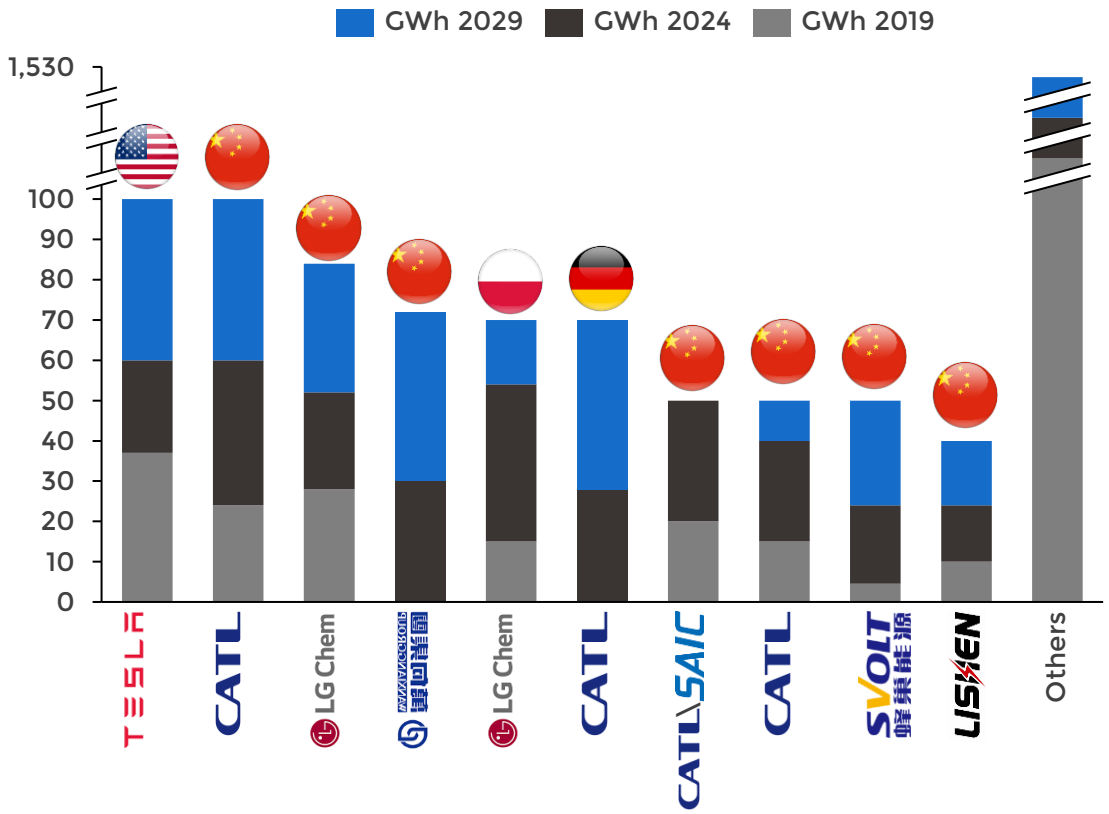
2022 — 2025 — 2030

EV strategy timeline

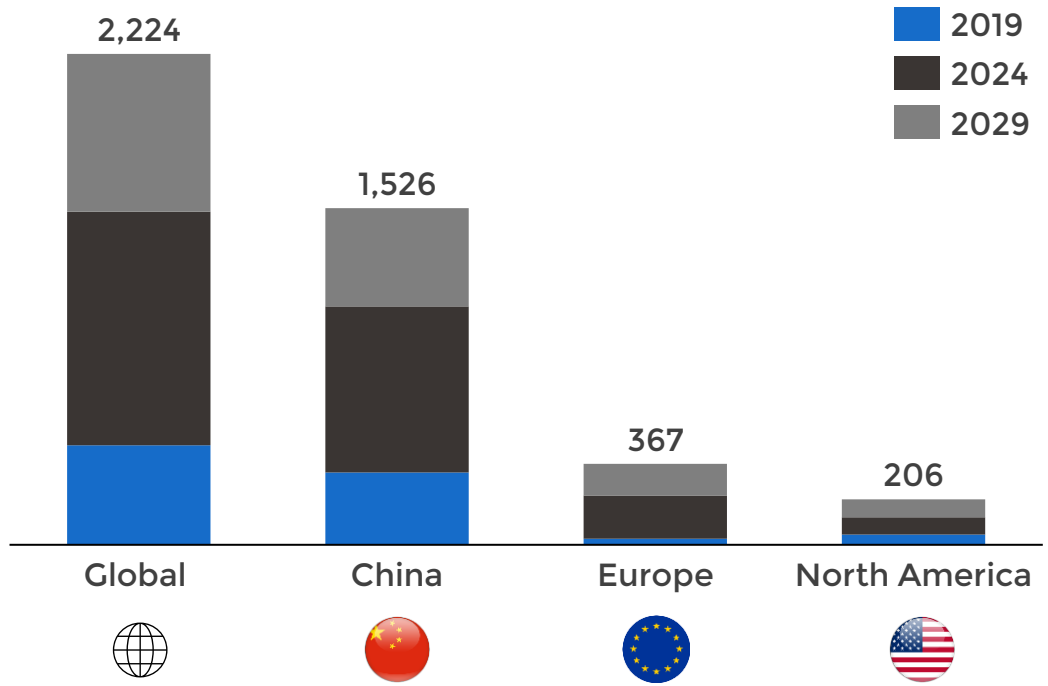
Note: ICE - Internal Combustion Engine

As a result, lithium-ion manufacturers are ramping up >2TWh capacity from 121 battery “megafactories”, the majority of which are expected in China

Expected GWh battery cell manufacturing production through 2029 – major producers



Total lithium ion battery megafactory capacity by region, 2029 (GWh)

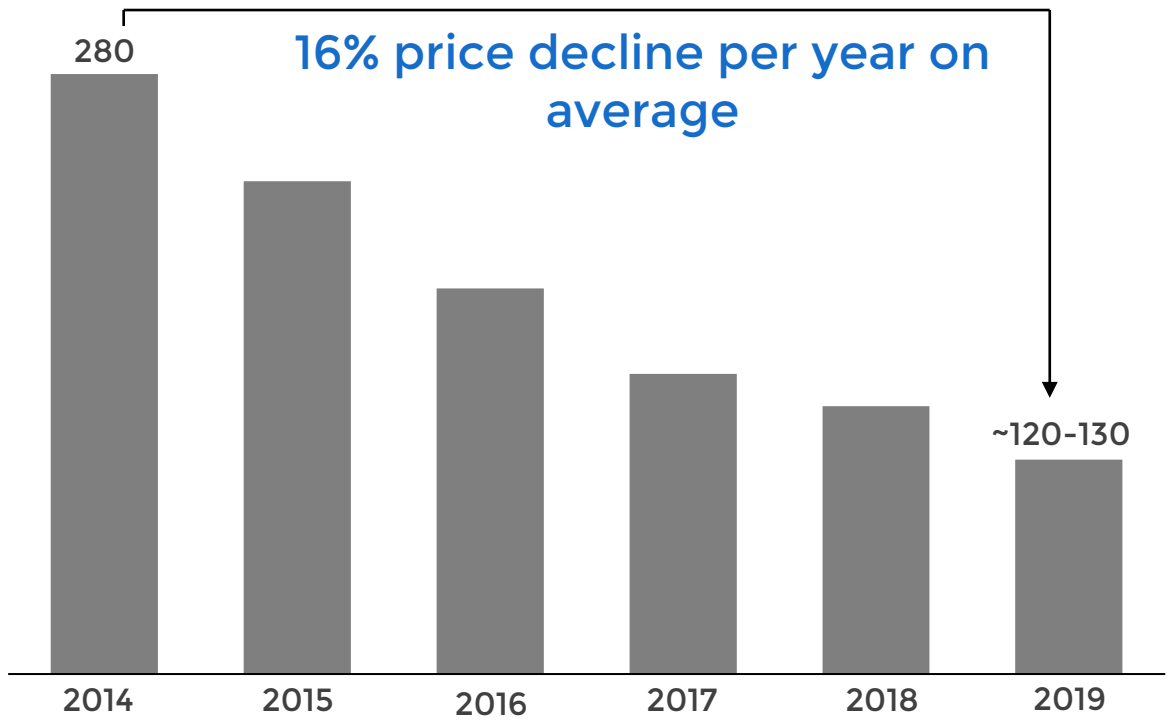


China will continue to dominate cell manufacturing with demand for European and US made cells out-stripping supply. This is especially the case for Tier 1 producers who may only have limited volumes available outside the large OEMs

Note: Not all stated capacity is available in a given year as commissioning dates fall throughout the year and facilities take time to ramp up

This significant global battery cell capacity ramp-up will compound the continuing decline of $/kWh battery cost of production

Best-in-class $/kWh for battery cell manufacturing (2014-2019)



2014 is the year when meticulous cell price tracking across the industry was instituted

Cell-level cost reductions mostly concentrated on:

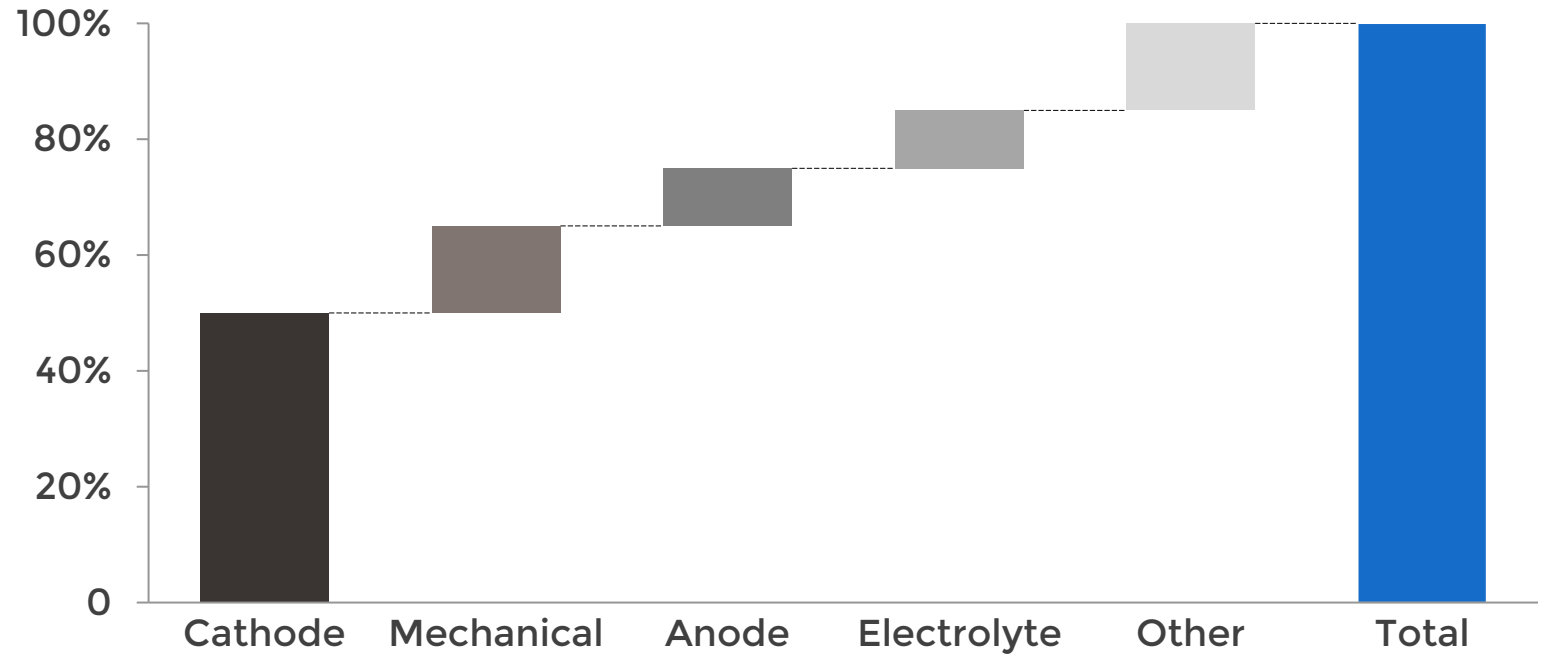
- Cost management along materials supply chain (largest opportunity)
- Manufacturing efficiency improvements and large-scale production
  - Yield loss improvements during manufacturing process

Pack-level cost reductions result from:

- Improved energy density of individual cells from chemistry evolution
- Improved cell density within packs from less volumetric intensity of interstitial materials

Cathode materials are the largest $/kWh cost, and is the focus of cost reduction through materials management and manufacturing efficiency improvements

Major contributors to $/kWh cell cost (%)



- Cathode is >50% of the total cost of producing battery cells
- Cost control is pushing innovation and push to new chemistries
- Depending on raw materials prices, 3 key metals contribute ~50-65% of cathode manufacturing cost
  - Lithium
  - Nickel
  - Cobalt
- Short of vertical integration, supply chain optionality and security is key to realizing cost-downs in these materials

6 key trends shaping the lithium-ion battery cell industry

1. Western automotive push towards higher quality
2. Nickel-rich cathode chemistries
3. Cathode chemistry differentiation by application
4. Chinese control of global materials supply chain
5. Opportunities for supply chain co-location
6. Pending supply/demand imbalances

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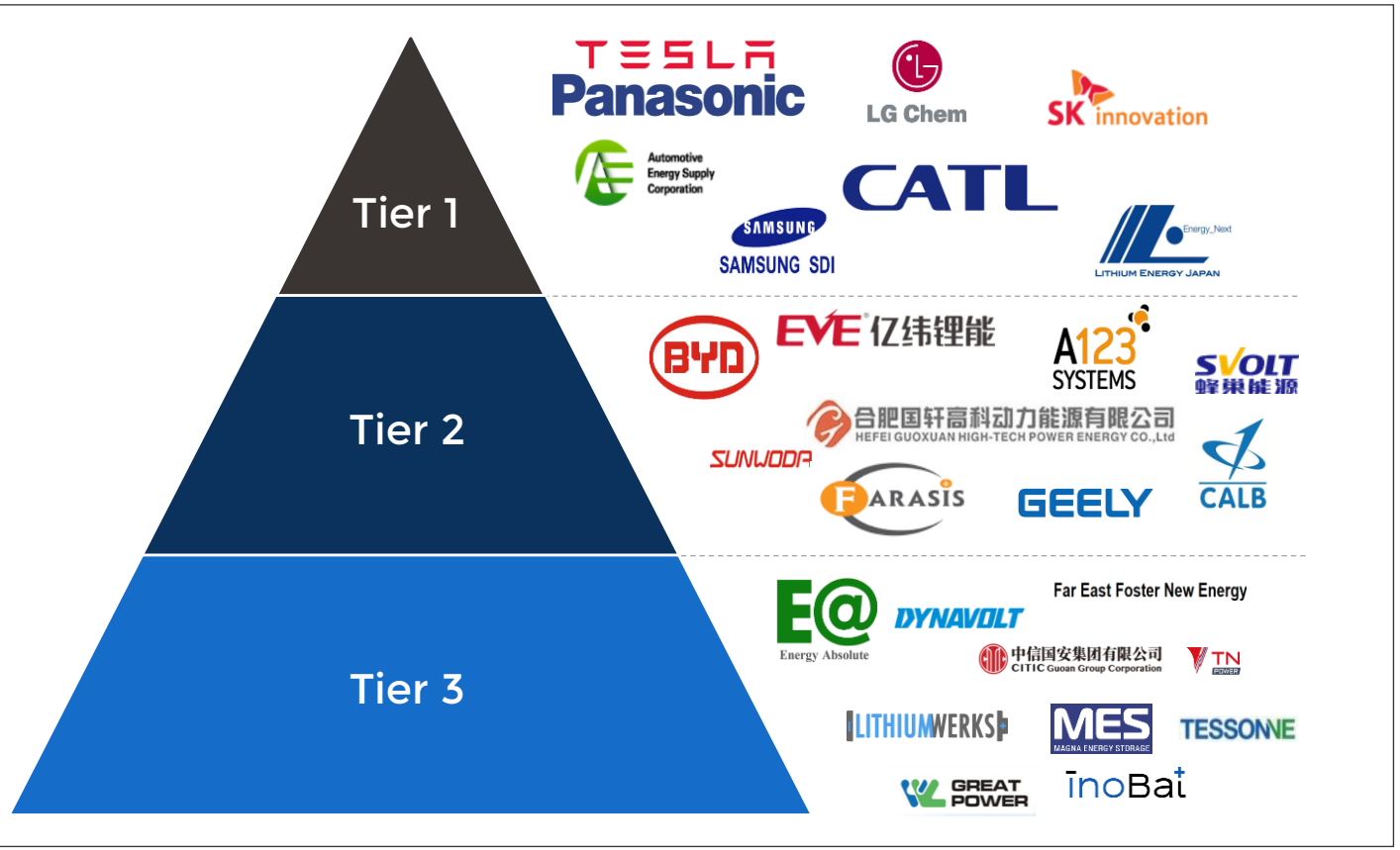
Market Trend #1 – While higher tier battery producers are preferred by Western automotive, lower tier battery suppliers will try to "level up"



- Higher likelihood of being used in Western automotive
- Longer supplier qualification timelines
- Higher material quality requirements
- More stringent spec tolerances
- Larger qualification sample requirements

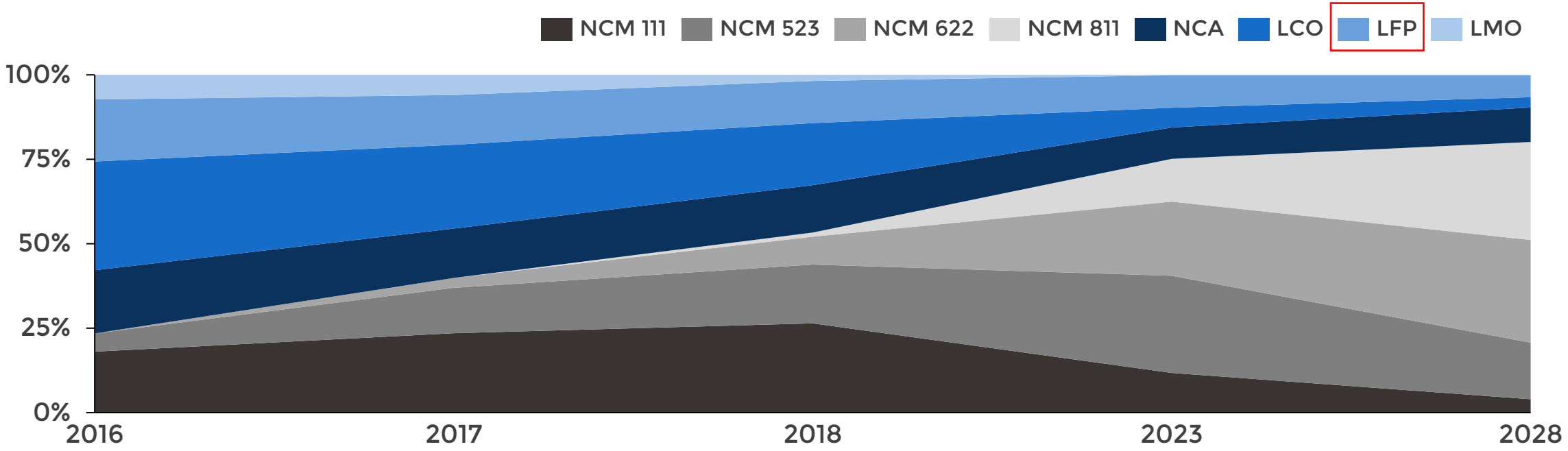
But, does not necessarily mean:

- Trends in China are the same
- More innovative
- Better position to raise capital
- First choice for Western automotive in perpetuity

Product quality differentiation is the main reason that battery cells will not become "commoditized" like solar panels

Market Trend #2 - Nickel-rich cathode chemistries expected to capture larger market share as customers push for higher energy density, but LFP is a “dark horse”

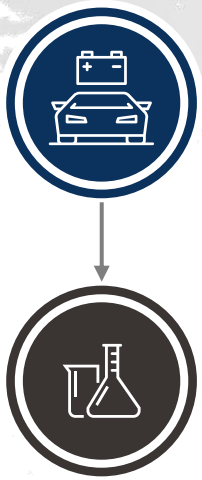
NCA holds while NCM varieties take the majority of the market



Lithium is the only element common to all of these chemistries

Market Trend #3 - Long-term, as industry shifts towards autonomous driving and EVs penetrate new geographies, cathode chemistries will differentiate by application

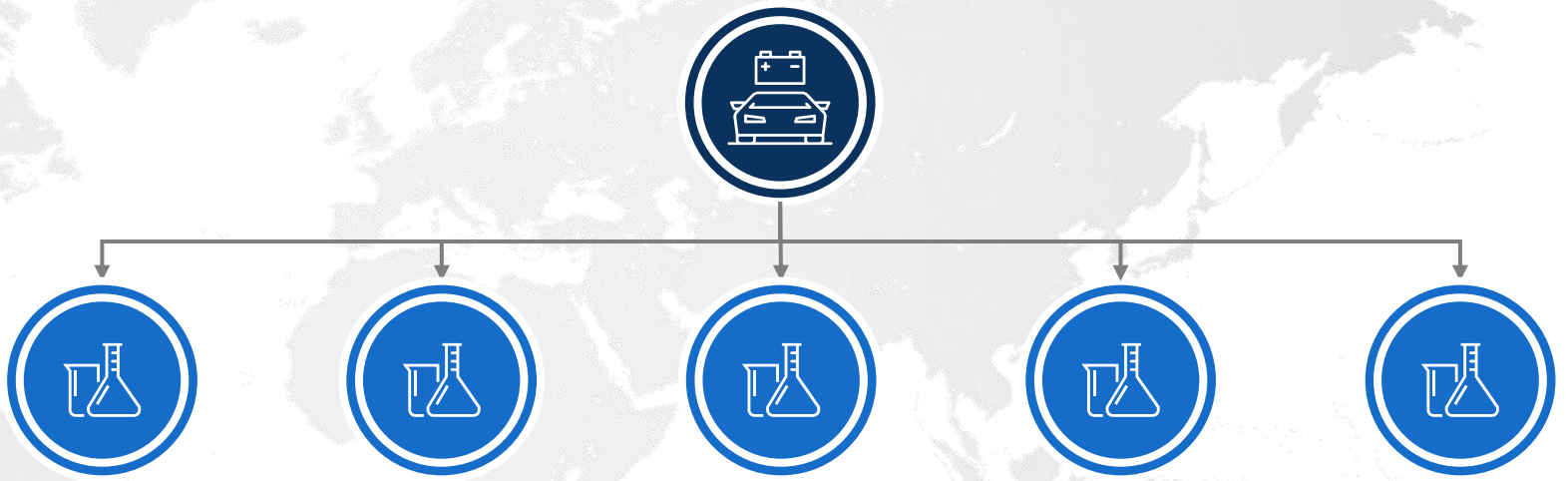
Present



NCM

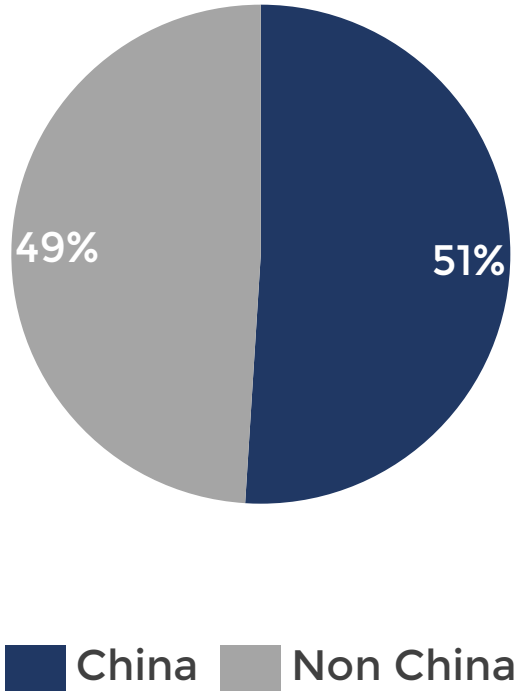
Standard battery chemistry across all vehicles

Future – custom chemistries by application

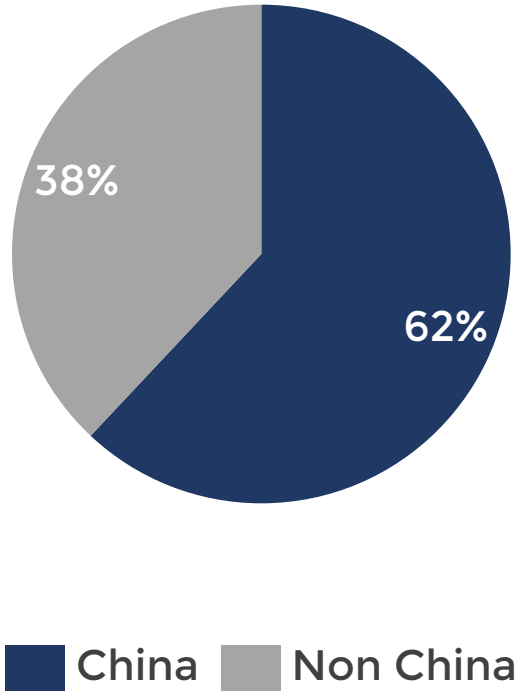


Market Trend #4 – China dominates capacity in the upstream cathode and materials supply chain, and expected to continue to do so at least for the next decade

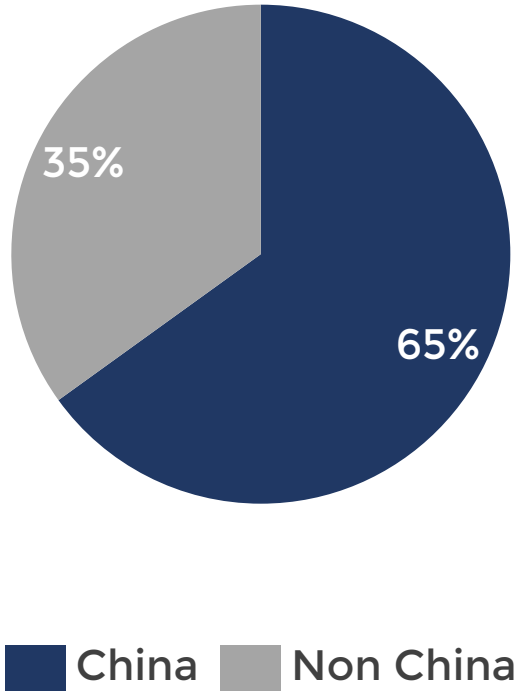
Current lithium chemicals supply



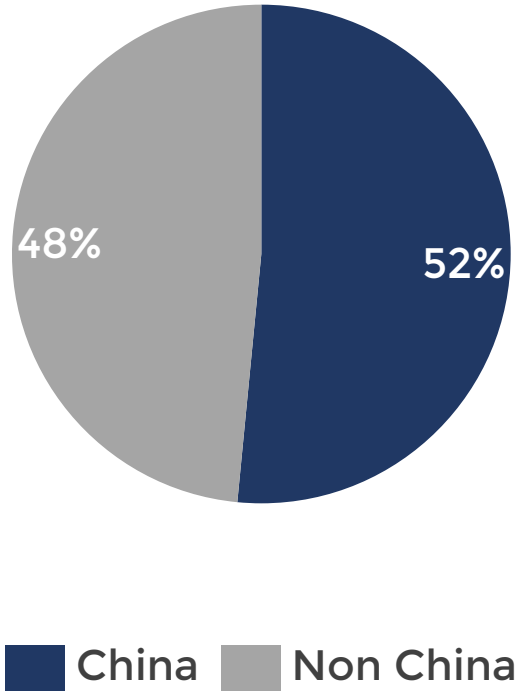
Current cobalt chemicals supply



Current cathode supply

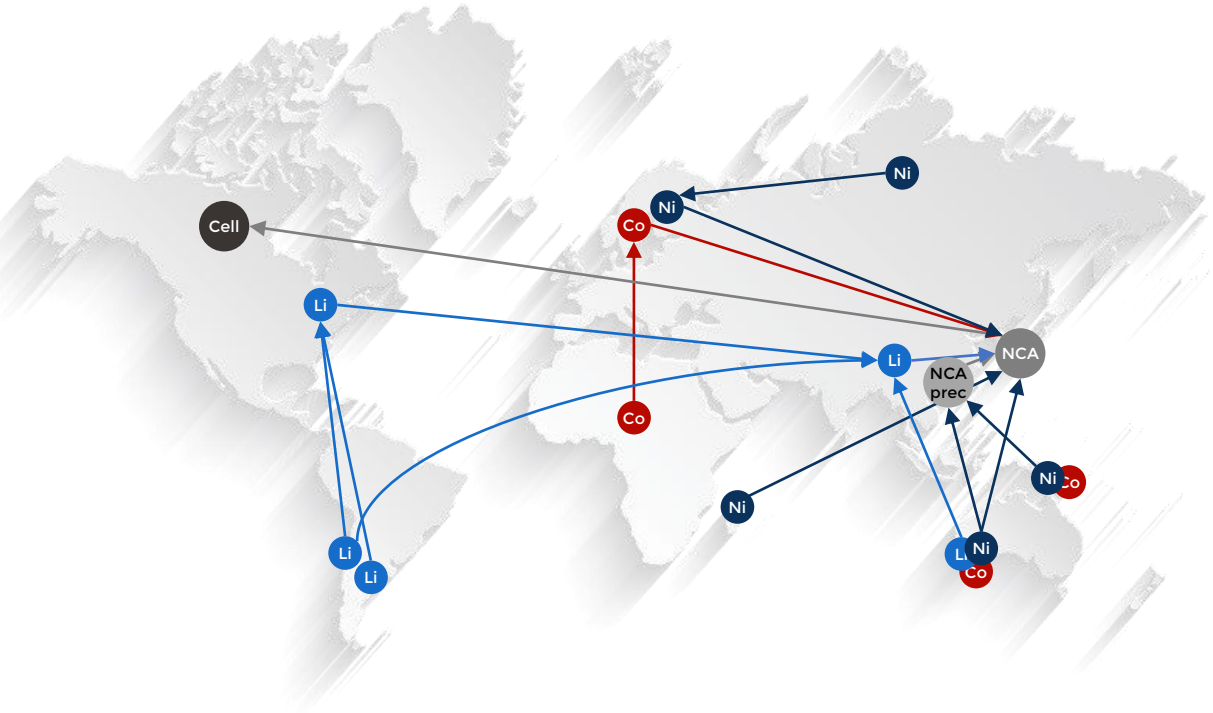


Current nickel supply



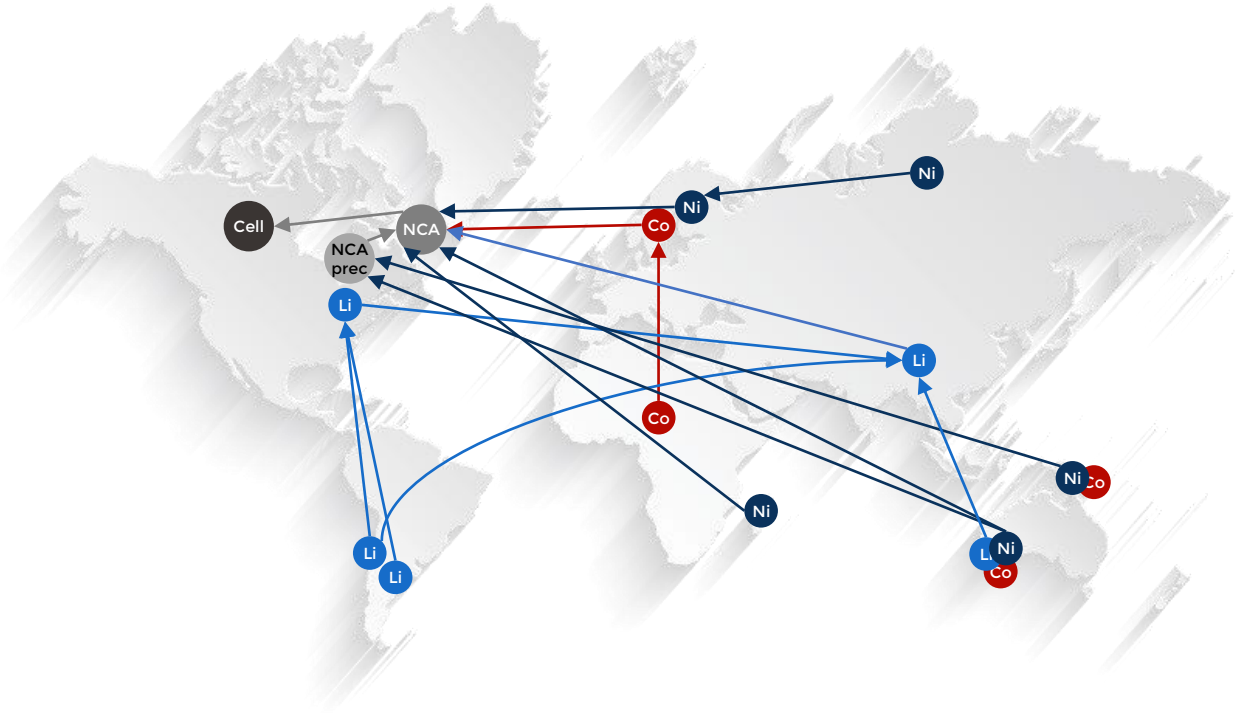
Market Trend #5 – Western markets' EV demand and governments' push towards new job creation in advanced industries creates capacity co-location opportunities

From – Globally Distributed Supply Chain



General product flow towards Asia

To – Vertically Integrated For Cost Optimization



General product flow towards end markets

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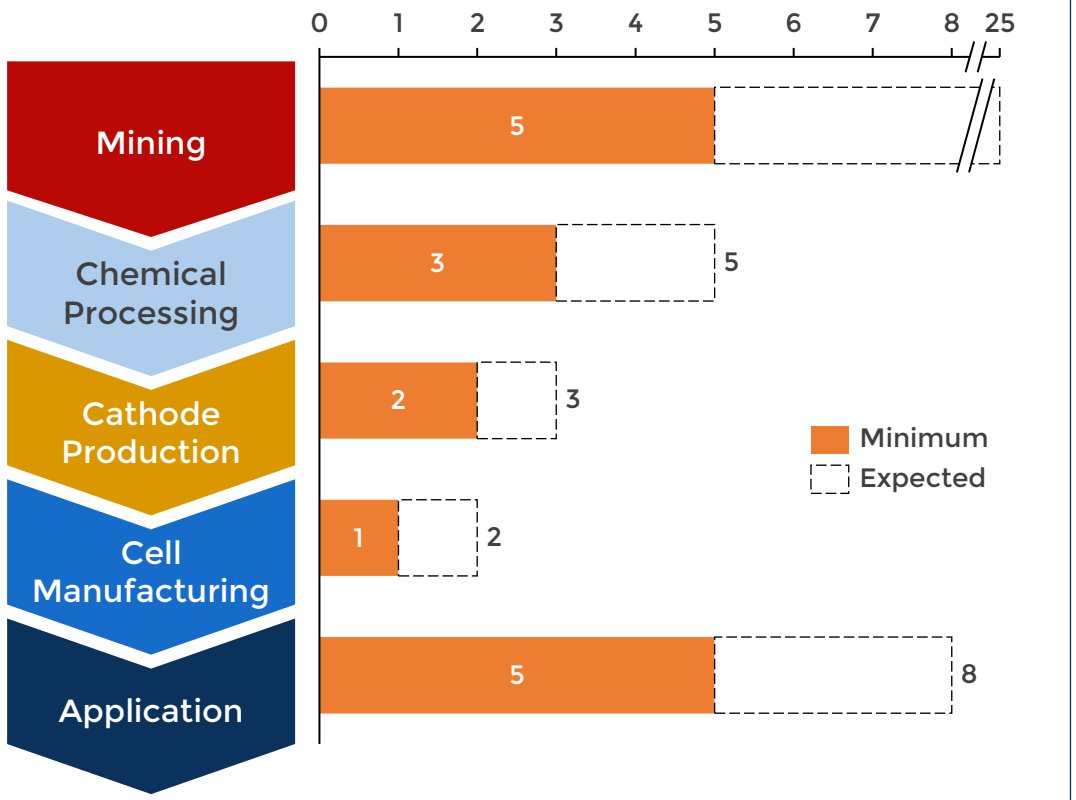
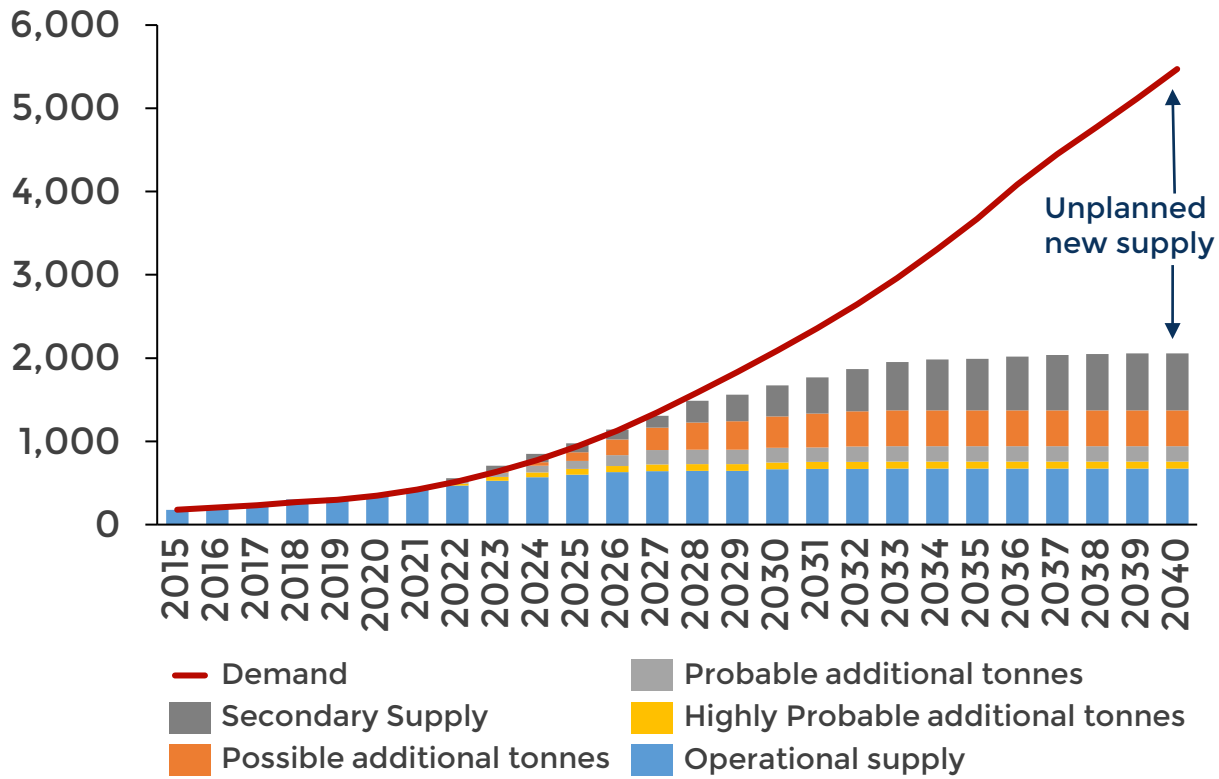
Market Trend #6 – The dislocation in timeline to build each portion of the supply chain could lead to multiple battery material shortages

Approximate timeline to progress supply step



Example–Lithium chemicals demand/supply tonnes ('000)



6 key trends shaping the lithium-ion battery cell industry

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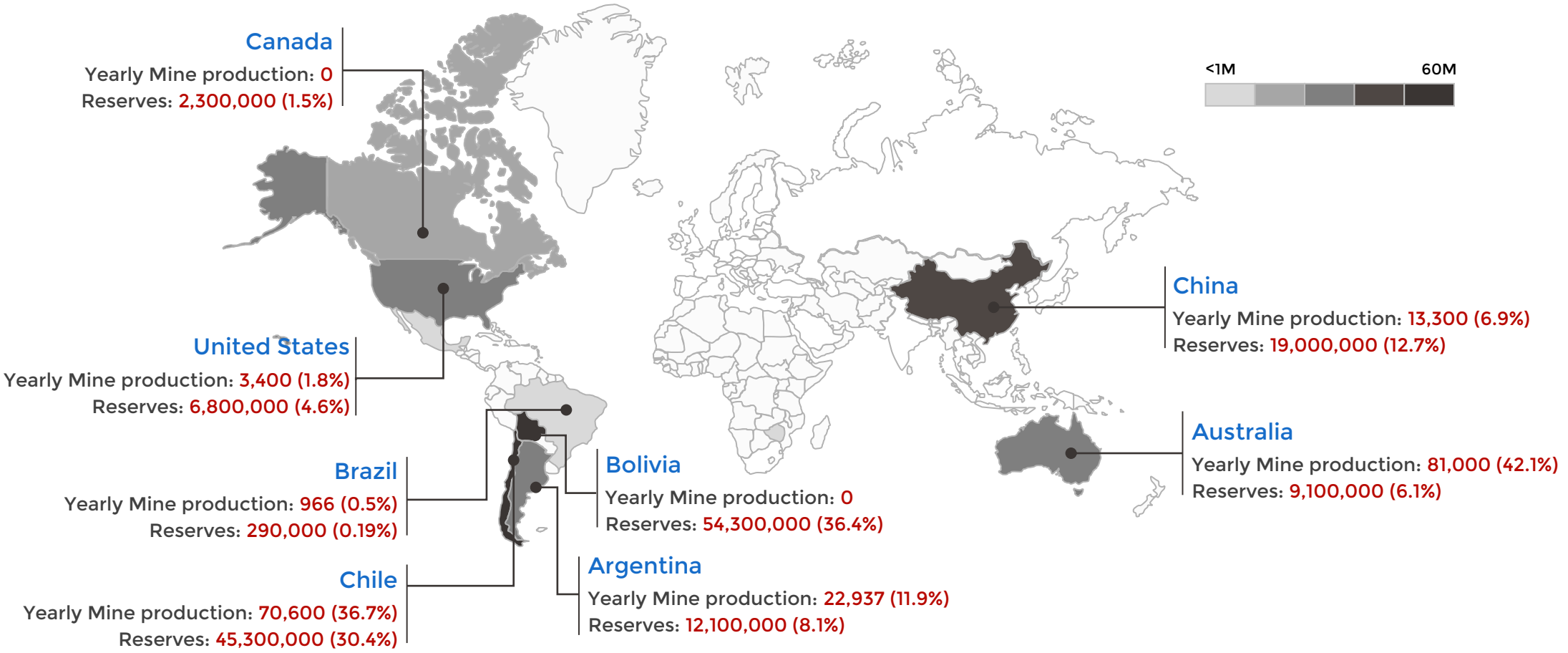
Deep Dive on Lithium Chemicals Industry

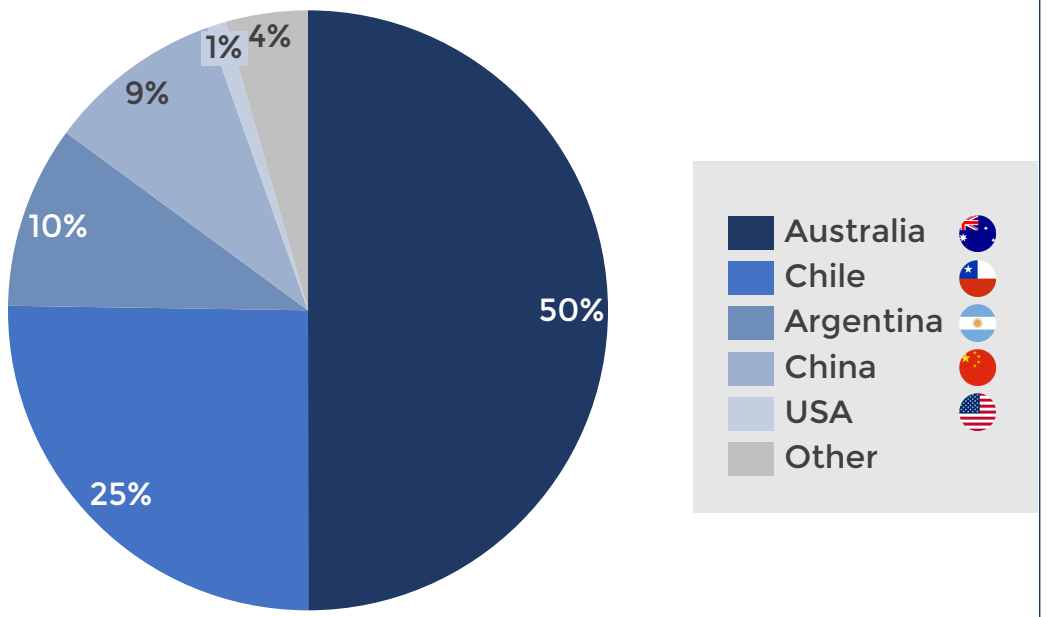
Lithium is plentifully available today from a geology standpoint…

Lithium resource availability – major countries



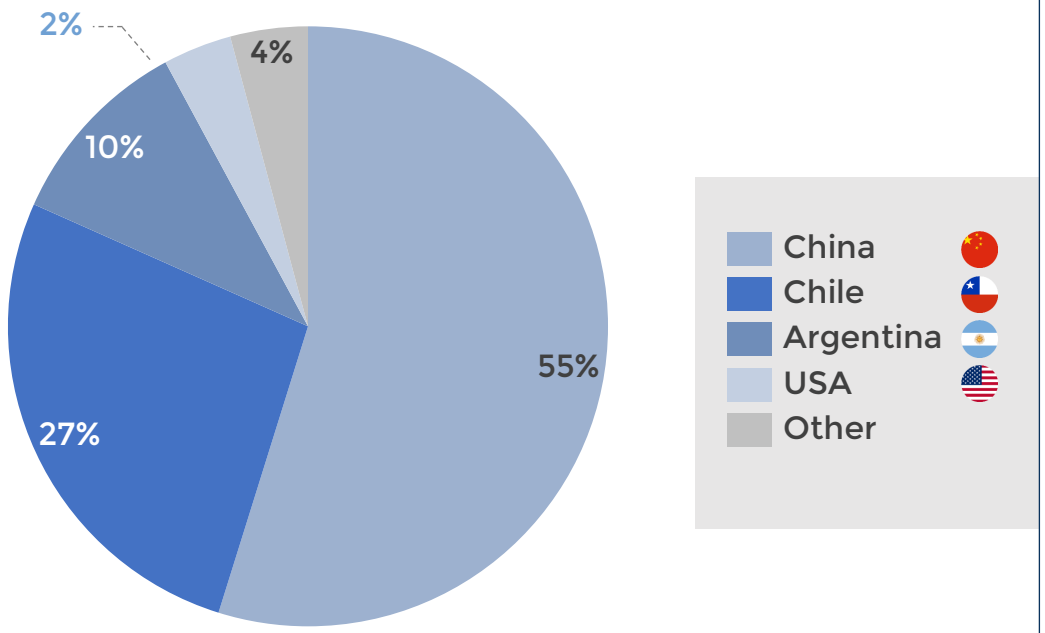
… but supply remains highly concentrated within a small number of regions…

Lithium Raw Material Supply in 2019



Total: 359,000 tonnes LCE

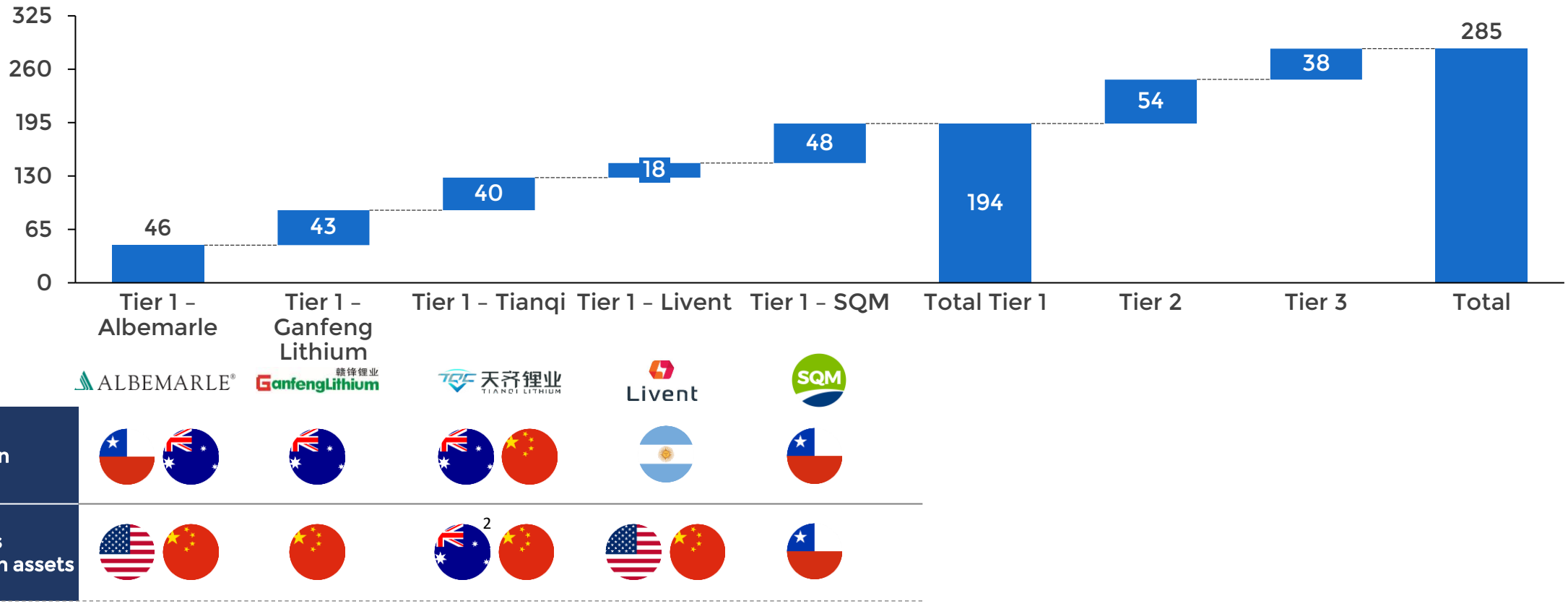
Lithium Chemical Supply in 2019



Total: 338,000 tonnes LCE

… with a small number of Tier 1 suppliers supplying the Western battery industry

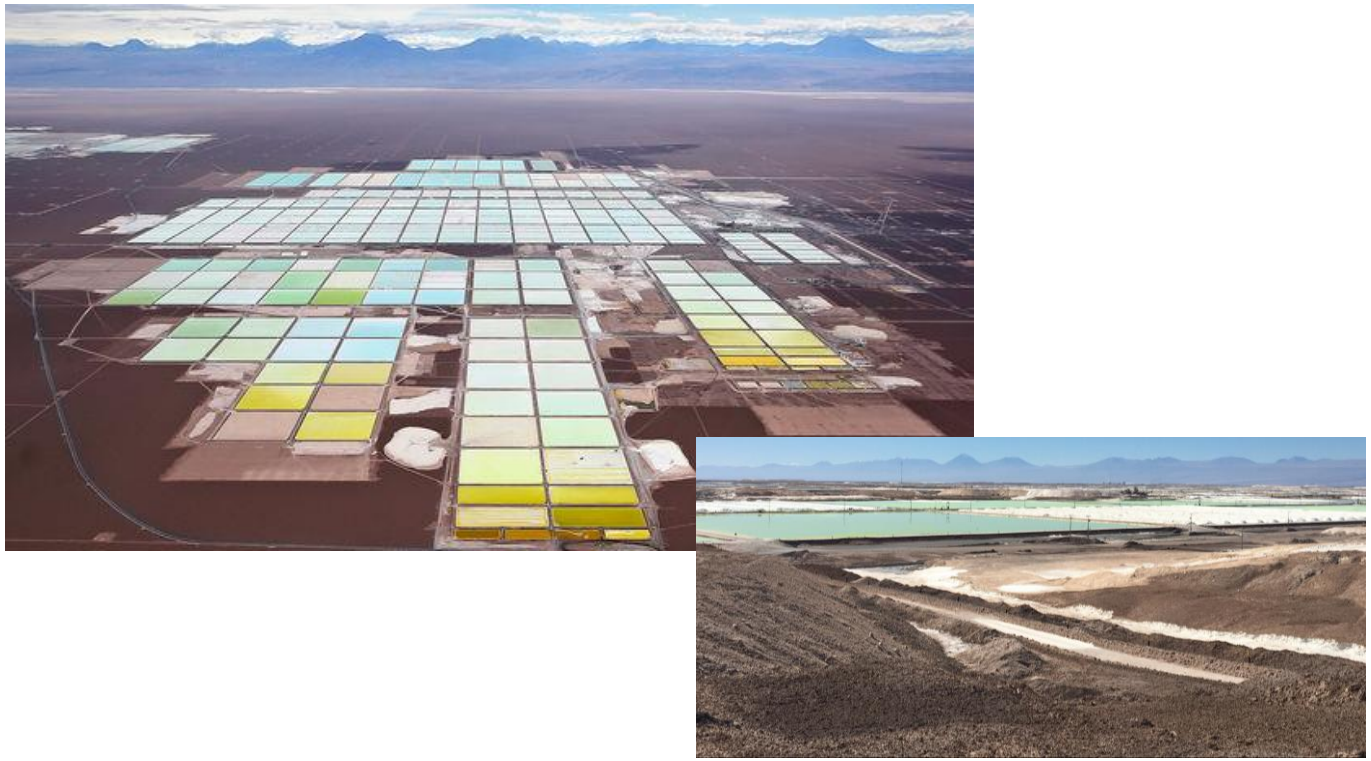
Supply breakdown – 2018 ('000s)



1. Current production 2. Currently ramping up production asset in Western Australia

Brine and spodumene are the two most prolific sources of material today, although specific forms of clay have potential to enter the supply chain in the future

Brine ponds – SQM, Chile



Spodumene mine – Greenbushes, Australia

Carbonate and hydroxide, the two most common forms of lithium chemicals used for battery manufacturing today, mildly differ in price

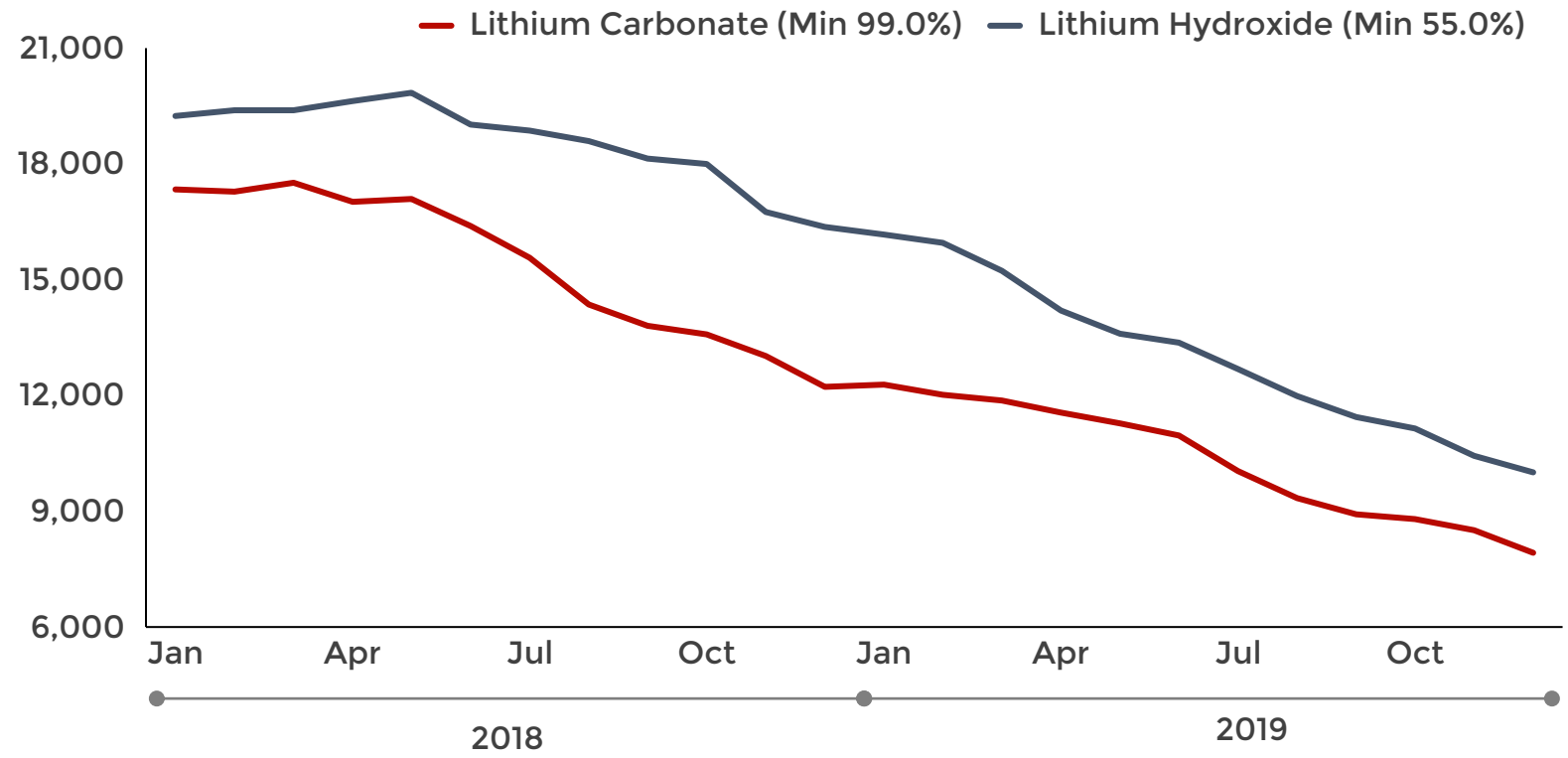
Carbonate

- >60% of the produced and consumed lithium chemicals today
- Expected to make-up a meaningful part of the market in the long-term

Hydroxide

- Fastest growing segment due to shift due to shift towards higher nickel chemistries

Weighted Average Lithium Prices: Jan 2018- Dec 2019



Given the growth in the industry, supply chain players have exercised creativity in structuring new business models to feed material into this evolving supply chain

EXAMPLE – Supply chain of spodumene material from Sigma Lithium in Brazil to a Western automaker

Sigma Lithium
Lithium Spodumene

Mitisui
Trading Company

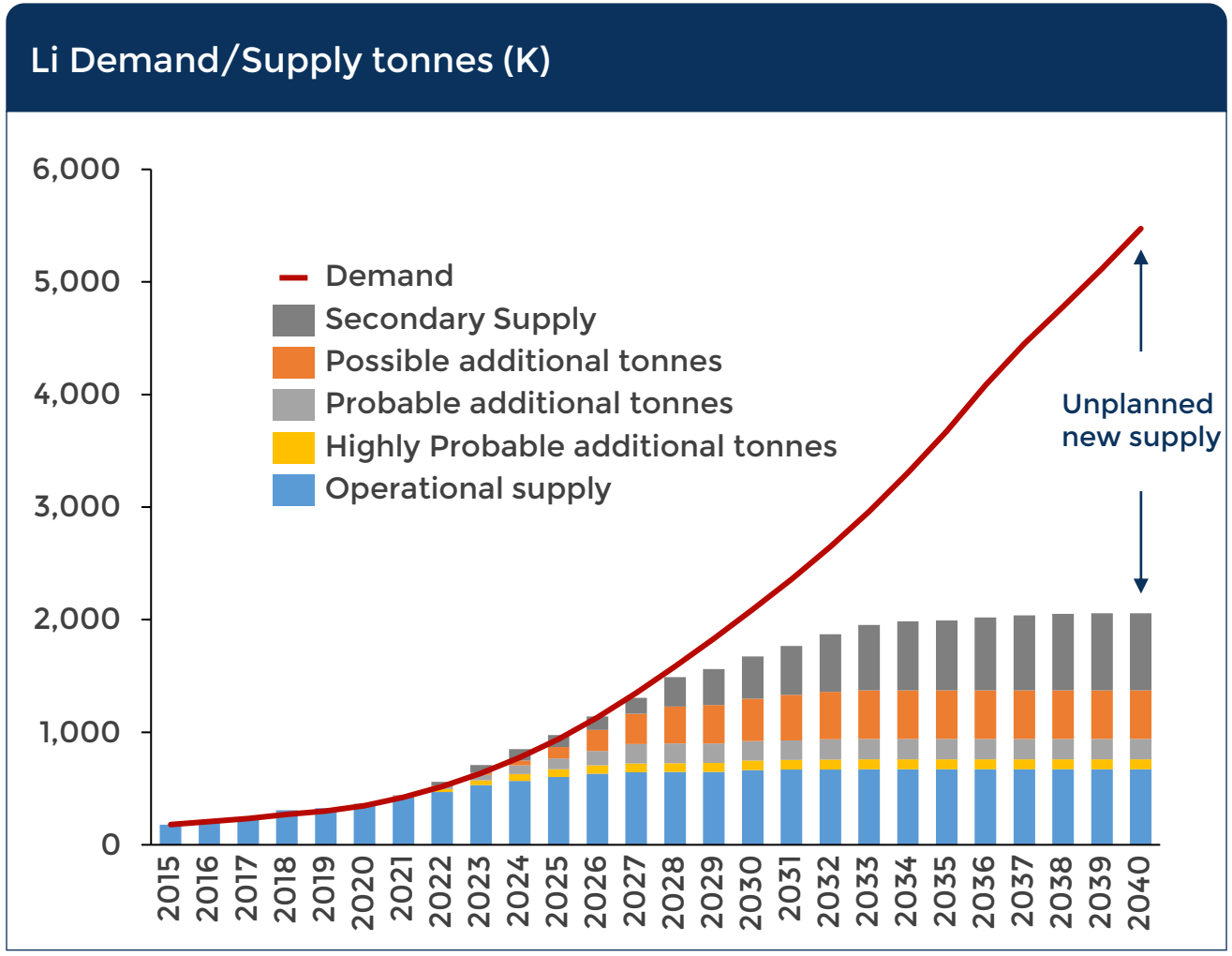
Lithium
Chemicals Maker

Cell Maker

Western
EV Manufacturer

- Sigma is ramping up 660k TPT spodumene production in Brazil
- Secured $30m pre-payment from Mitsui, who are responsible to ship spodumene from Brazil for production in China to lithium chemicals ultimately bound for Western automotive batteries
- **Mitsui** plays central role in piecing together the supply chain here

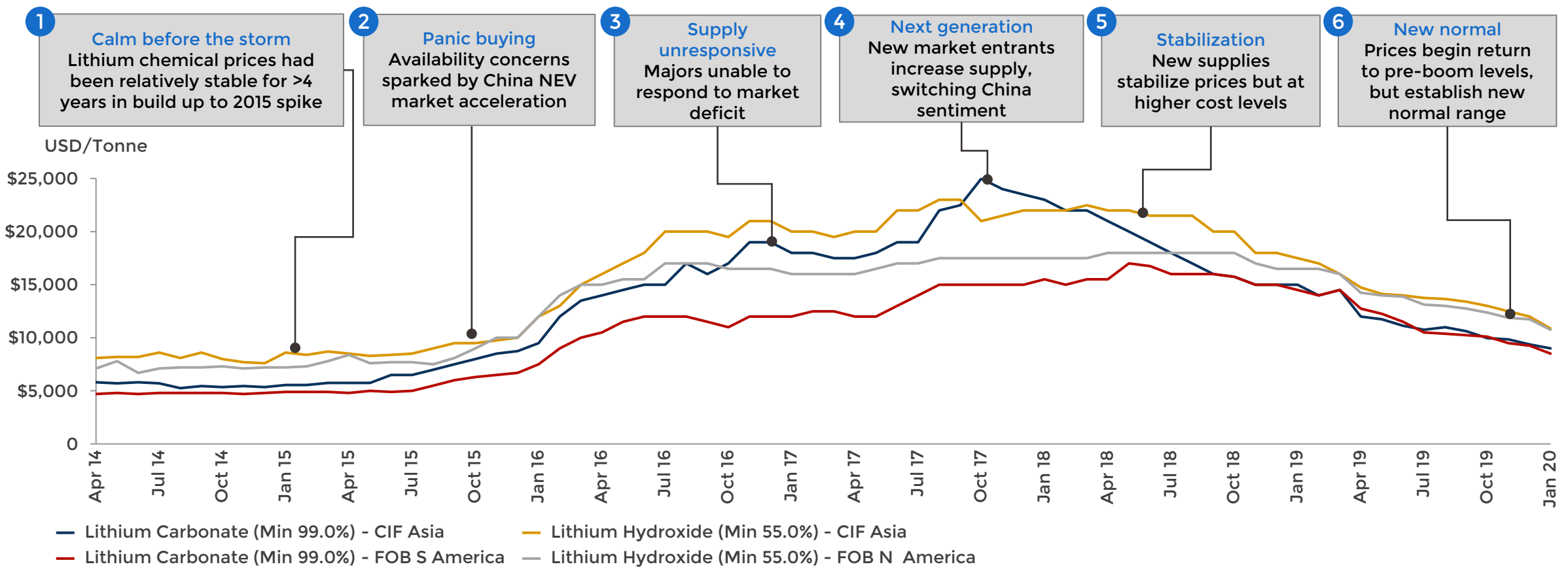
However, projected severe shortages of lithium chemicals still plague the industry, which begs the question – why aren't more people investing?



- The demand outlook for lithium is undoubted, the speed and rate of demand growth is the major question
- Entering a period of transition with new supplies beginning ahead of the roll out of megafactory capacity
- Major supply expansions still required to reach demand requirements of 2021 onwards
- **The slow introduction of new projects into the market is a warning sign for a market which is only in the early stages of its growth cycle**

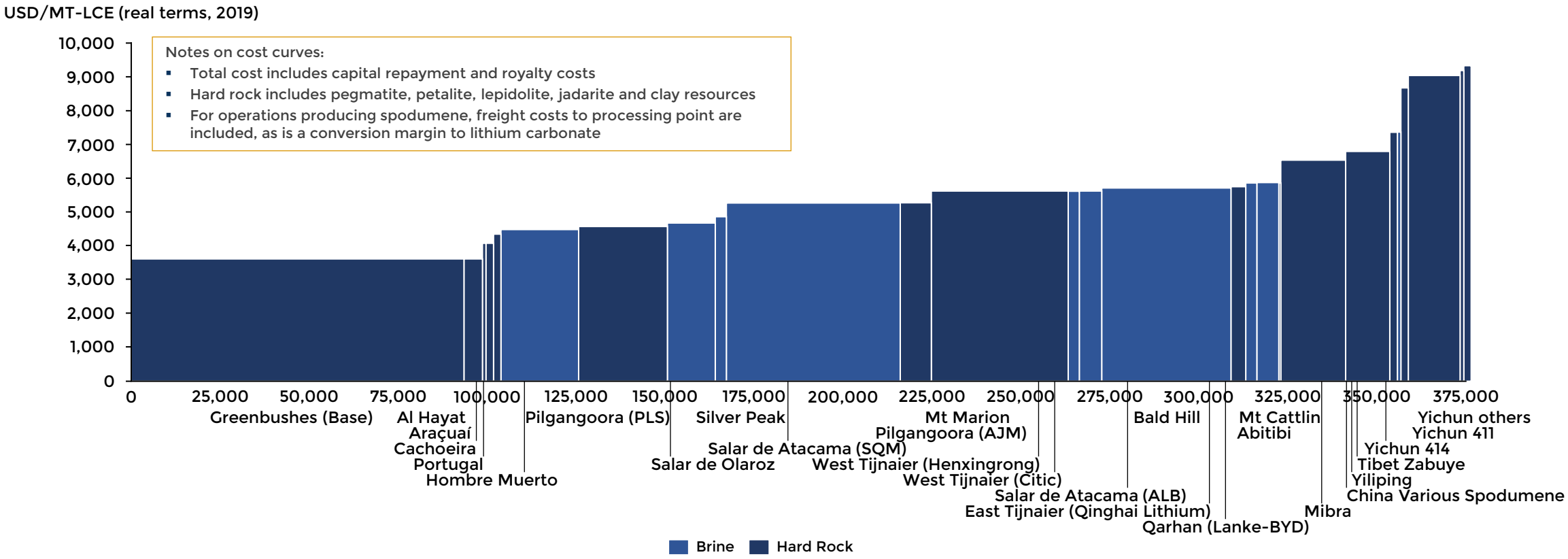
Reason #1 - Value chain is concerned about price volatility; after decades of stability, lithium prices have gone through a boom/bust cycle in just 6 years

Lithium prices: Mar 2014-Feb 2020



Reason #2 - Regardless of price swings the lowest cost producer is best position for value creation, and these projects are becoming harder to find and develop

Lithium industry brine and hard rock total cost curve - 2019

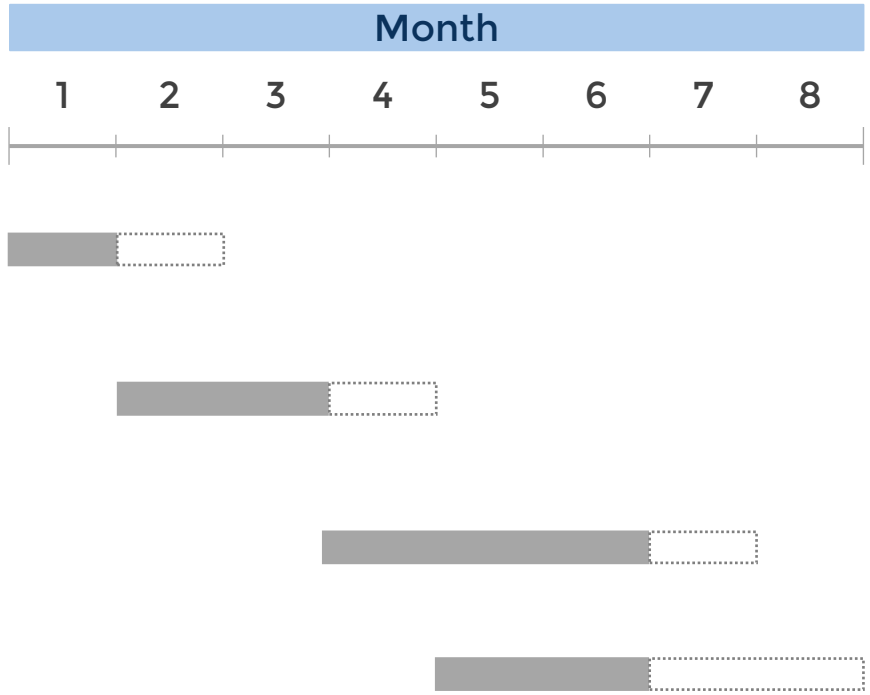


Reason #3 – Even if a project is developed, it has to be "qualified" for battery-grade supply before a large supply contract can commence

Qualification – the auditing process to ensure that material is fit for purpose before commercial supply commences

Example raw material qualification process and timeline – best case scenario

Does the material…	Quantity
1 … comply with spec?	10 – 50 KG
2 … perform in cathode?	100 – 500 KG
3 … perform in battery cell?	1000 – 5000 KG
4 … come from a reliable manufacturing line?	

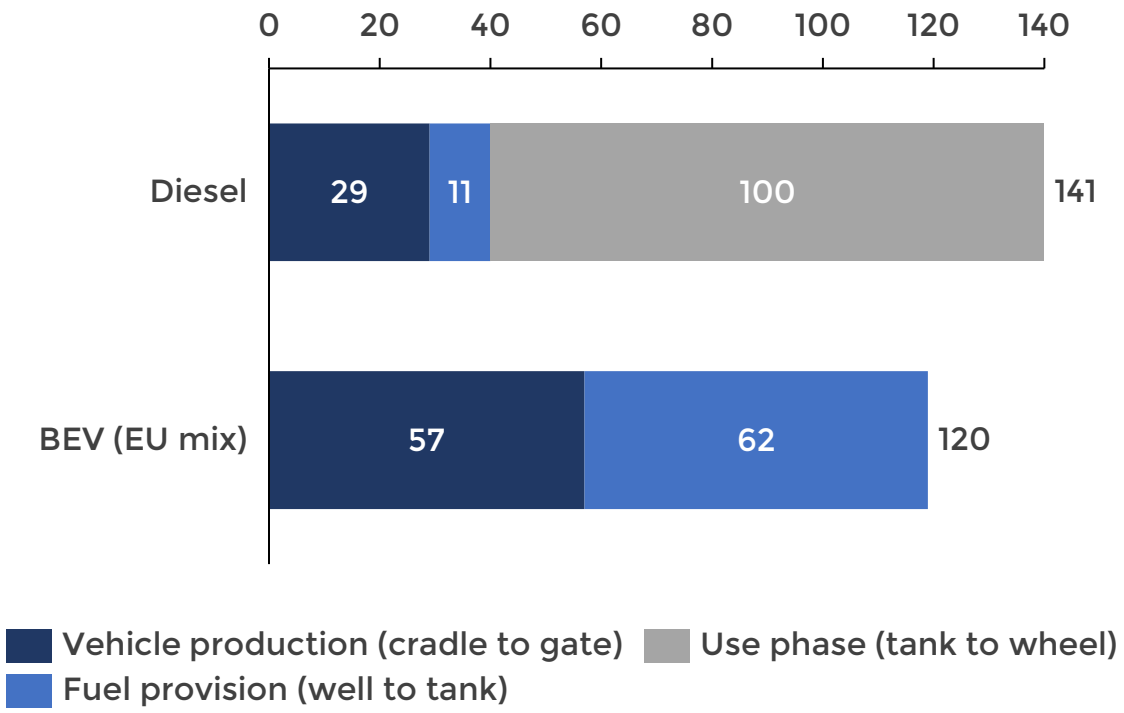


Concerns for OEMs

- OEMs must qualify large quantities of new suppliers to create effectively large pool of available material to source
- Risk of qualification failure is high with new suppliers

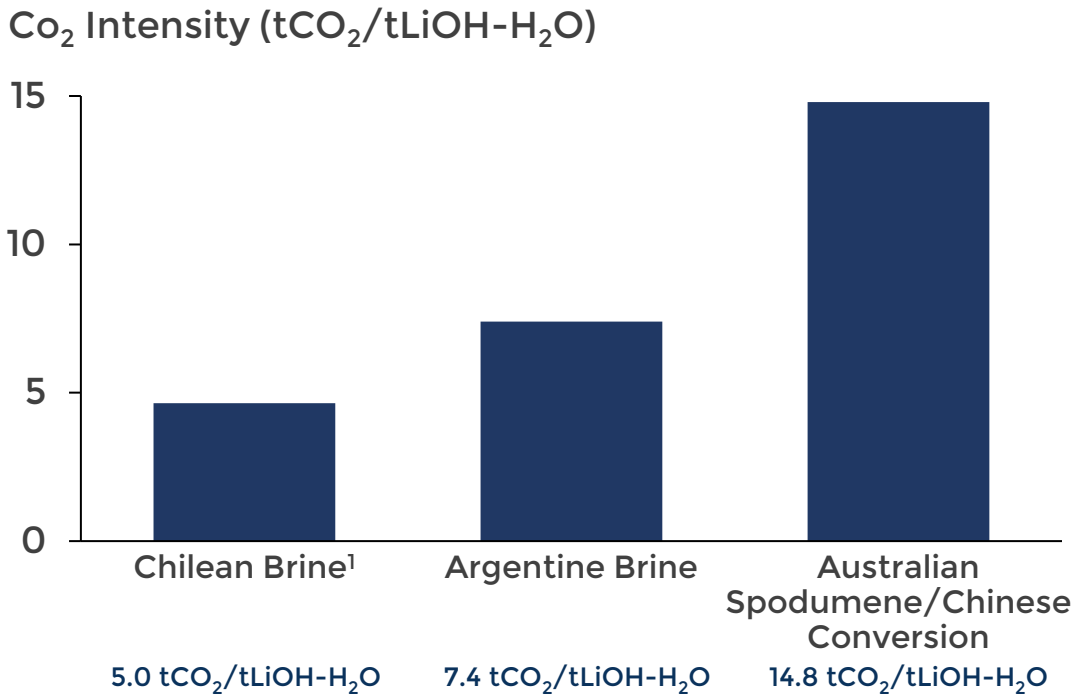
Reason #4 – Against a backdrop of rising ESG concerns in mining investing, the environmental footprint of this supply chain has faced tough scrutiny

Comparative carbon footprint of VW's EV vs. ICE



Source: VW ID.INSIGHTS Sustainable E-Mobility Presentation – February 15, 2019

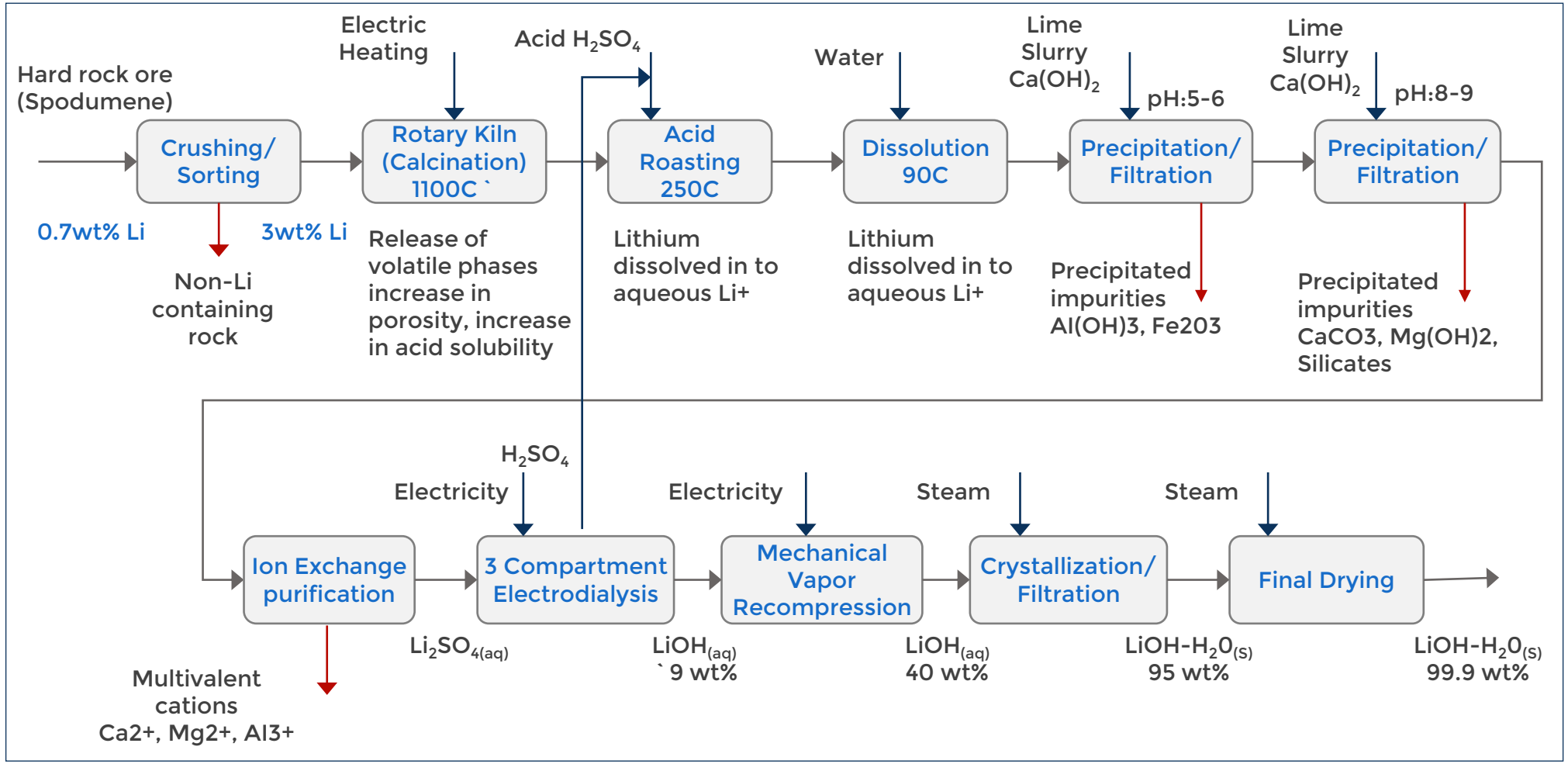
Technical grade lithium hydroxide carbon intensity ($tCO_2/LiOH\text{-}H_2O$)[1]



Source: The CO2 Impact of the 2020s Battery Quality Lithium Hydroxide Supply Chain" by Alex Grant, David Deak, and Robert Pell (January 2020); Minviro

1. Technical grade, not battery quality

Reason #5 – Stalled innovation in the flow sheet for lithium chemicals production reinforces questions about environmental sustainability and value creation



- **High electricity costs** from high temperature baking of ore and electrodialysis of leach liquor
- **High operations/labor cost** from ore mining and material transport
- **High lime slurry costs** to neutralize acid addition and to promote impurity precipitation
- **Low byproduct revenue**

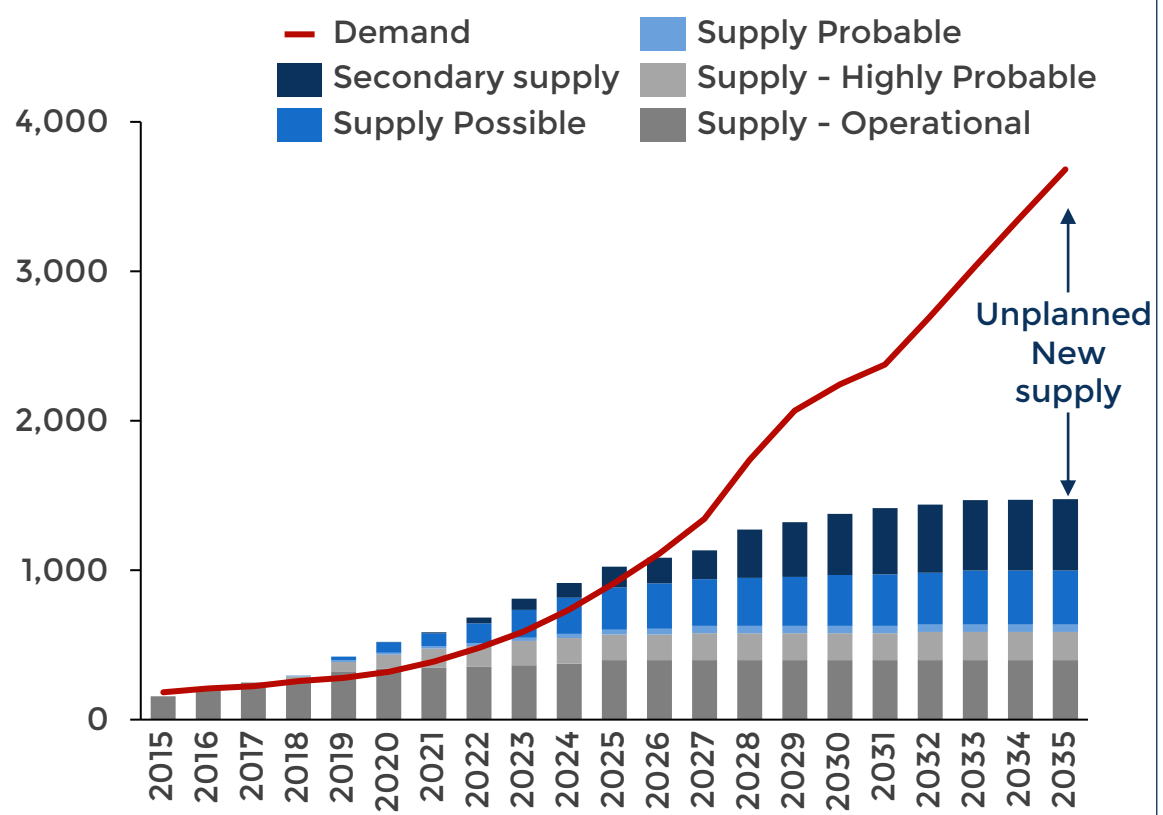
5 reasons that lithium supply growth is projected to fall behind demand

1. Price volatility
2. Production operating cost
3. Project qualification
4. ESG concerns
5. Lack of technology innovation

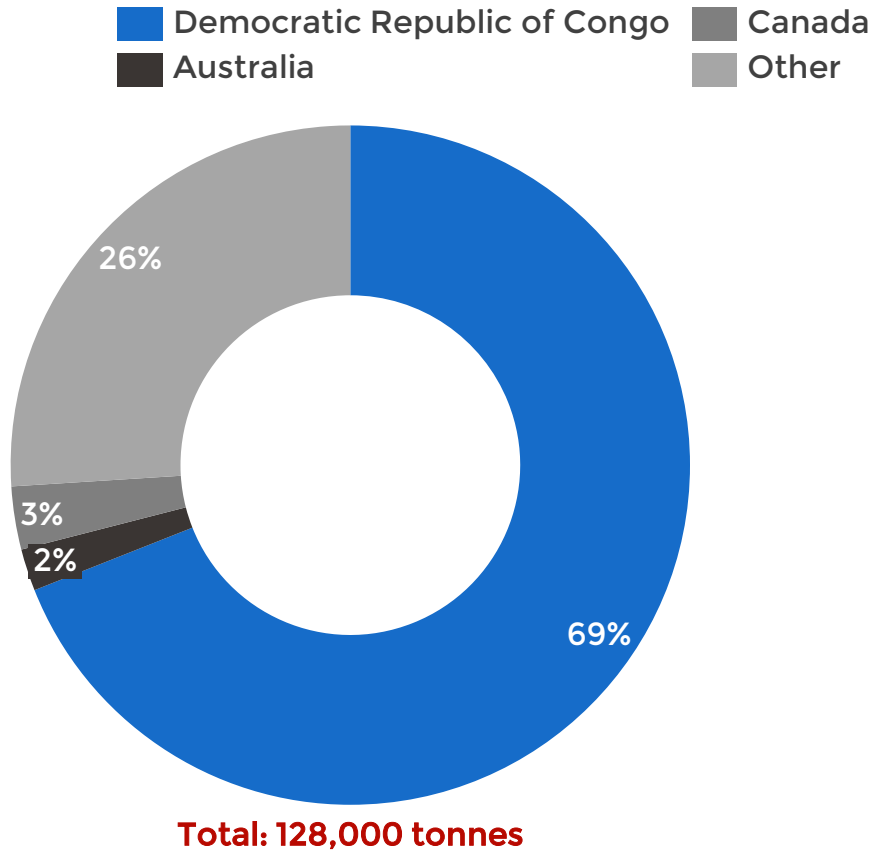
Growing the battery recycling industry

Industry's concerns about severe materials shortage, geopolitical risk, and governance has led them to seek alternatives to traditional mining/chemicals

Forecast lithium chemicals demand/supply tonnes ('000)



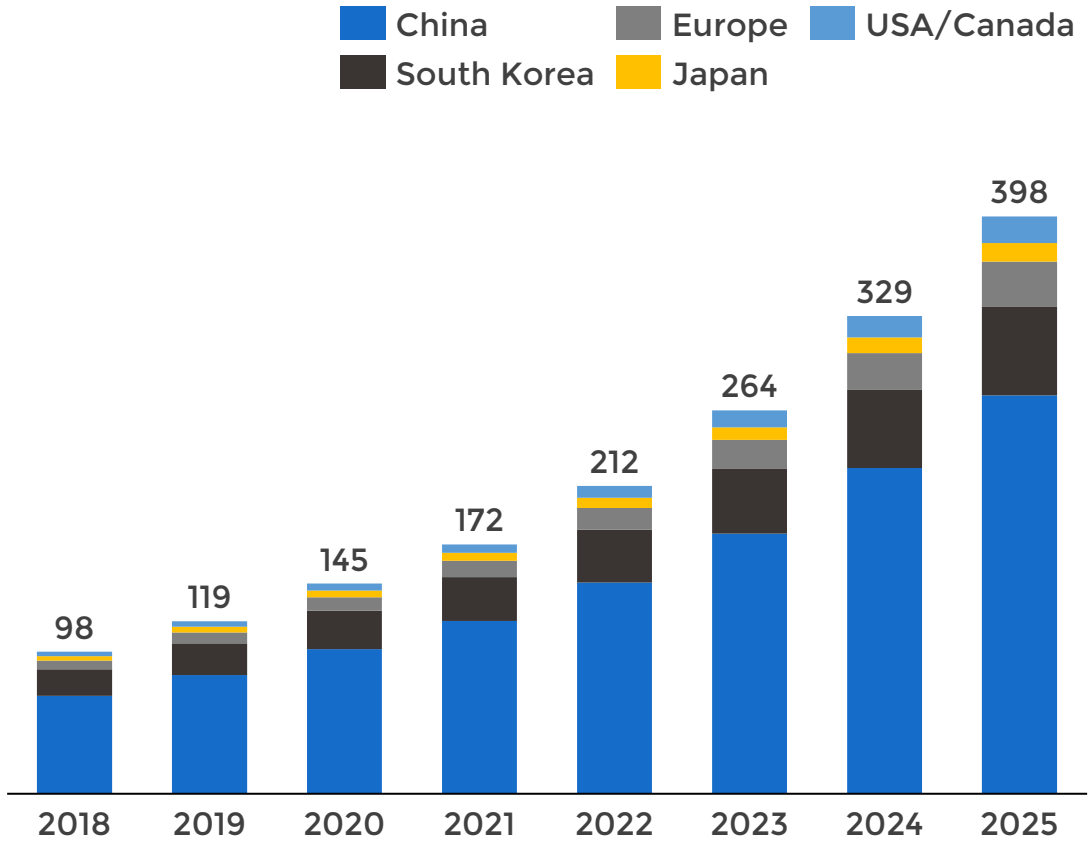
Cobalt Raw Material Supply in 2018

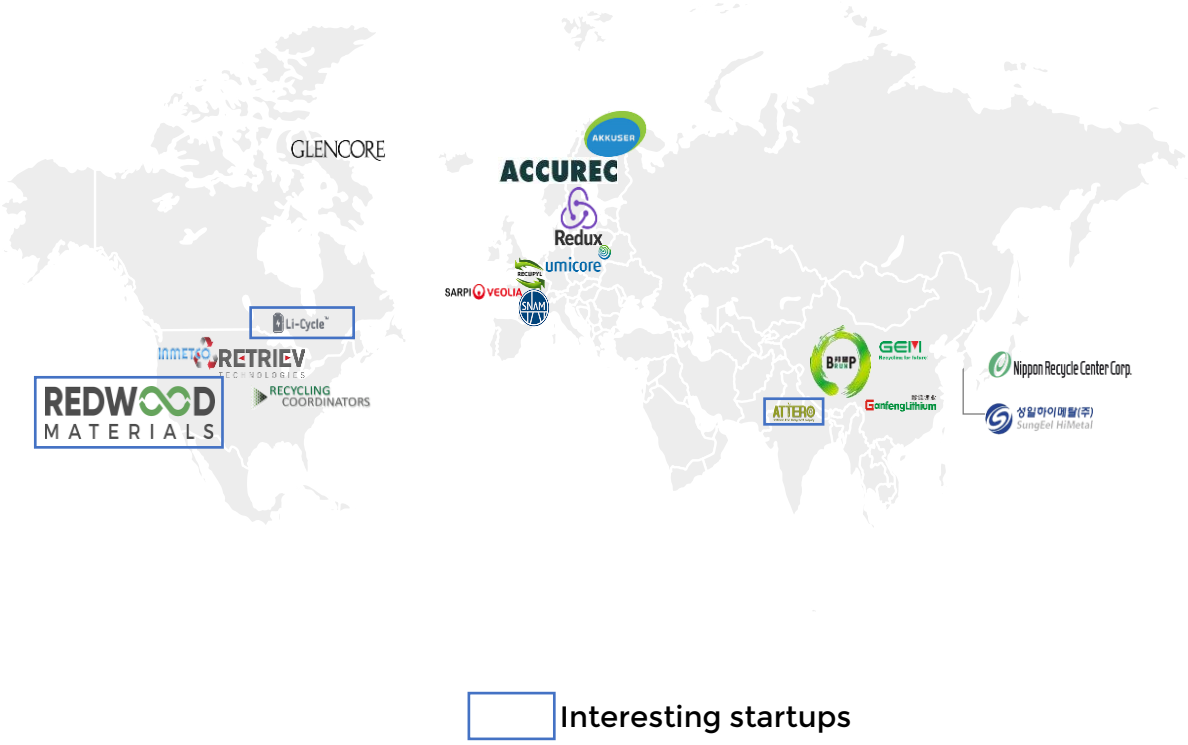


Source: Benchmark Mineral Intelligence data

Batteries sent to raw material recycling centers expected to grow nearly 4x by 2025, and in response multiple companies are pursuing capacity build-ups

Tons of lithium ion batteries sent to recycling by geography ('000)

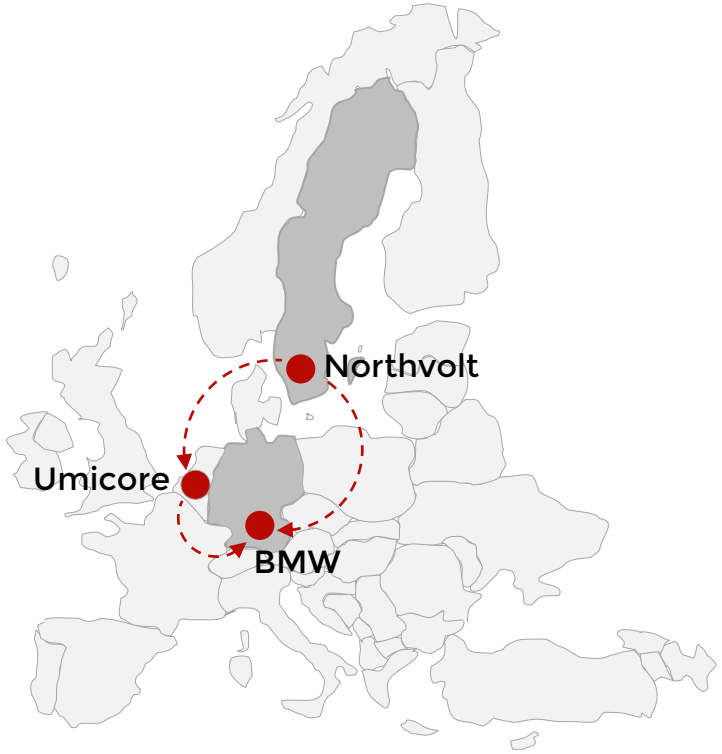




Source: Hans Eric Melin – Circular Energy Storage

BMW/Northvolt/Umicore deal an example of European pan-industry collaboration on closed loop sustainable battery materials supply chain; more deals expected

Umicore Cathode manufacturer / Recycling	Northvolt Cell manufacturer	BMW EV manufacturer



- Project aims to create a “closed life cycle loop” for battery cells
- Cells will be manufactured using a recyclable design and used in electric vehicles, then possibly as stationary storage devices before finally being recycled and reused

Source: Reuters - BMW, Northvolt and Umicore team up on battery sustainability (Oct 2018)

Attractive project economics featuring a payback <1 year at demo plant scale, but sensitive to continuous process cost improvement and chemicals market prices

NCA demonstration plant project economics

Metal	Market Price (USD/kg)
Lithium Carbonate	$17.00
Cobalt	$79.00
Nickel	$14.70
Manganese	$2.03
Aluminium	$2.20

Battery Chemistry	NCA
Lithium Carbonate (kg)	*1,154*
Cobalt (kg)	*276*
Nickel (kg)	*1,466*
Manganese (kg)	*0*
Aluminium (kg)	*42*
Total Annual Revenue	**$23.02 M**

Annual Operating Expenses	
Reagents	$1.07 M
Labour and G&A	$3.26 M
Utilities	$0.13 M
Feed Material Delivered	$2.3 M
Maintenance	$0.53 M
Building Rent	$0.18 M
Shipping & Packaging	$0.68 M
Total Annual Operating Expense	**$8.15 M**

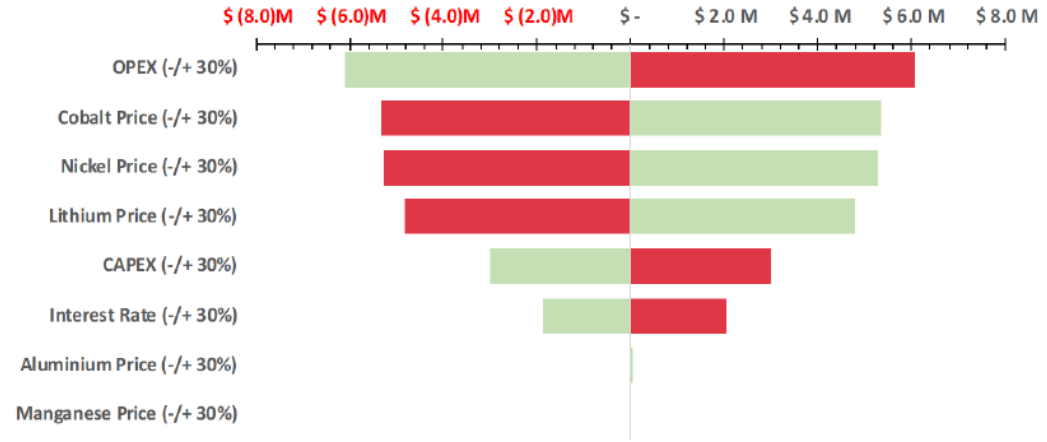
Annual Operating Profit	**$14.87 M**
Operating Margin	**65%**

Interest Rate	10%

Period	Cashflow	Balance
Year 0	$ (10.0)M	$ (10.0)M
Year 1	$ 14.9 M	$ 4.9 M
Year 2	$ 14.9 M	$ 19.7 M
Year 3	$ 14.9 M	$ 34.6 M

NPV	Payback	IRR
$26.97 M	0.68 Years	138%

Impact on NPV by Change in Assumption (NCA Battery Chemistry)



- Variability potentially introduced with changing perceptions of feed material value
- Potential premium due to low-carbon and closed-loop material could guarantee higher prices

Source: Argonne National Lab EverBatt recycling model for American Maganese 1,200 tpa plant

The recycling industry is in nascent stages, and faces multiple threats to reach full scale and profitability as global lithium-ion battery capacity ramps up

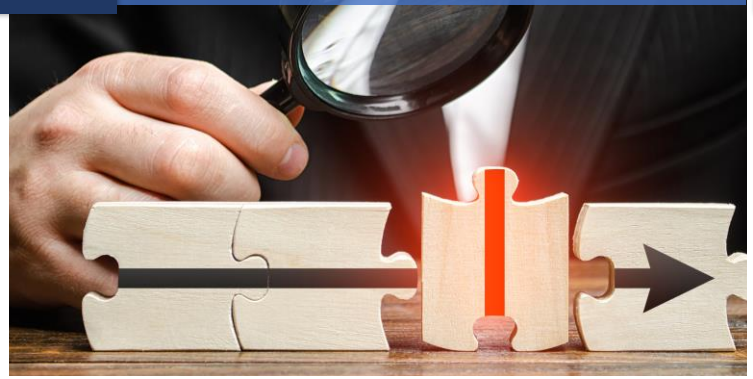
1 Second use batteries

2 Low collection rates from consumers

3 Non-differentiated regulation between lead-acid and lithium-ion batteries

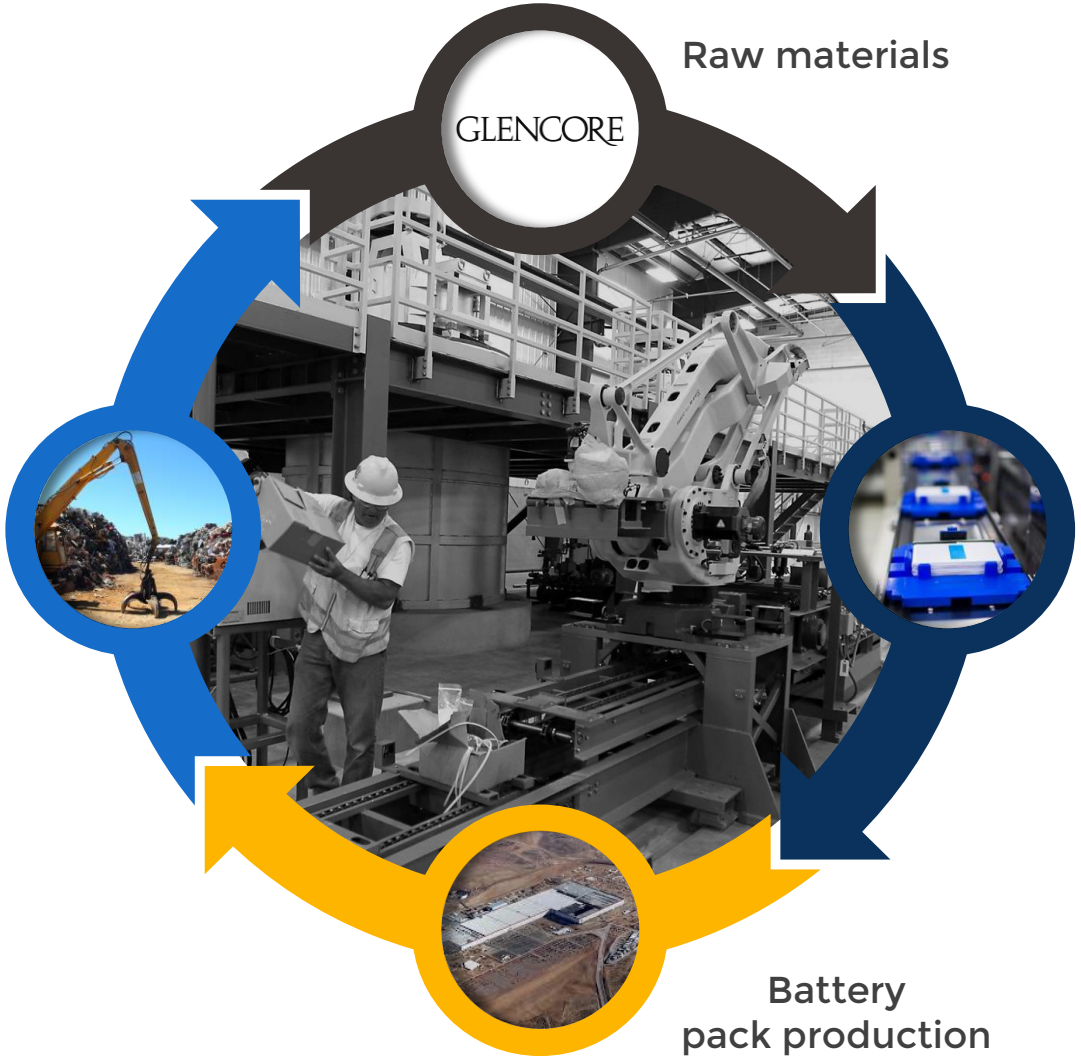
4 Input feedstock heterogeneity

5 Chemical process inefficiency



6 Competing priorities with battery life longevity push

OEMs and battery manufacturers are looking at opportunities to recycle used lithium-ion batteries and scrap to create a closed loop battery supply chain



Main advantages of battery recycling

- Lower CO2 footprint supply chain
- Decreased geopolitical and logistics risk
- Fulfills regulatory mandates
- More likely to be attractive to customers
- Reduces $/kWh battery costs

The battery industry is fundamental to the race for clean air worldwide, and requires innovative new solutions in this time of unprecedented change






Reach out with any questions, and download presentation

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