Anode Supply Chain Forecasting:
Challenges in predicting the future

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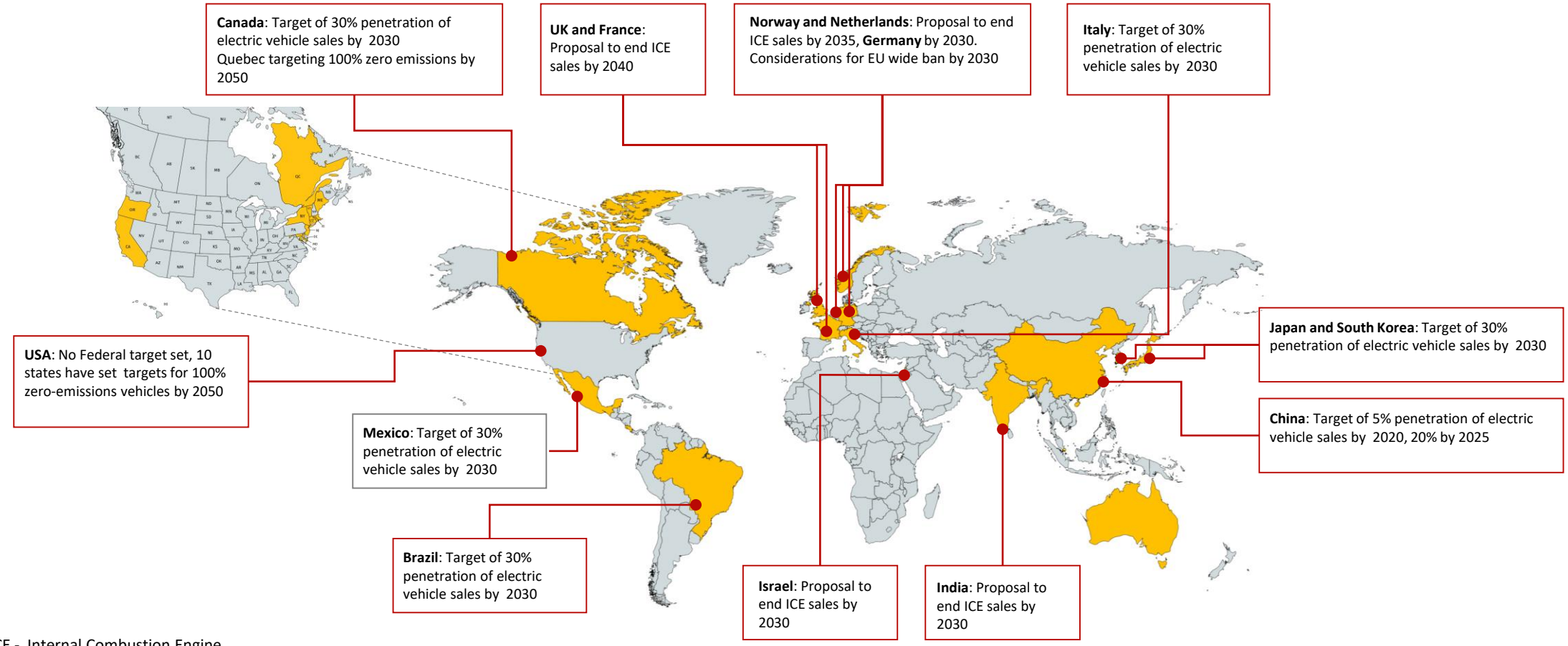
Government policies (and public opinion) are starting to shape OEMs commitment to zero emission vehicles



Note: ICE - Internal Combustion Engine

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Hope is NOT a strategy:

In a world destined for BEV's, how will the industry deal with "inevitable" Raw Material bottlenecks and Changing Power Dynamics?

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yota has set a sales
get of around 1m EVs
nd fuel-cell vehicles
s) by 2030, investment
billion to develop and
make batteries

arget of two
vehicle sales
y 2030

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Electric vehicles

Electric Vehicle adoption rates will have the biggest impact on lithium ion battery demand over the forecast period. According to Rho Motion, EV sales are expected to reach 15.8m units by as early as 2025, which would equate to a 14.8% penetration rate. Our demand model includes upside/downside cases to this base assumption.
Benchmark Minerals' base case forecasts a 29% CAGR in lithium ion battery demand from EVs over the coming 10 years.

Passenger/Light Duty EVs

A total of 96m passenger and light duty vehicles are expected to be sold in 2019 according to Rho Motion, less than 3m of which will be electric, rising to over 15m by 2025

Heavy Duty

The use of lithium ion battery for heavy duty vehicles has been a major growth driver in EV demand and ebus and etrucks continue to experience healthy growth rates, supported by regional subsidies in China

Battery Packs

The size of battery packs continues to increase with improvements in pack technology. The average pack size for passenger and light duty vehicles is expected to reach an average of 40.9 kwh in 2019, rising to >50kwh by 2023

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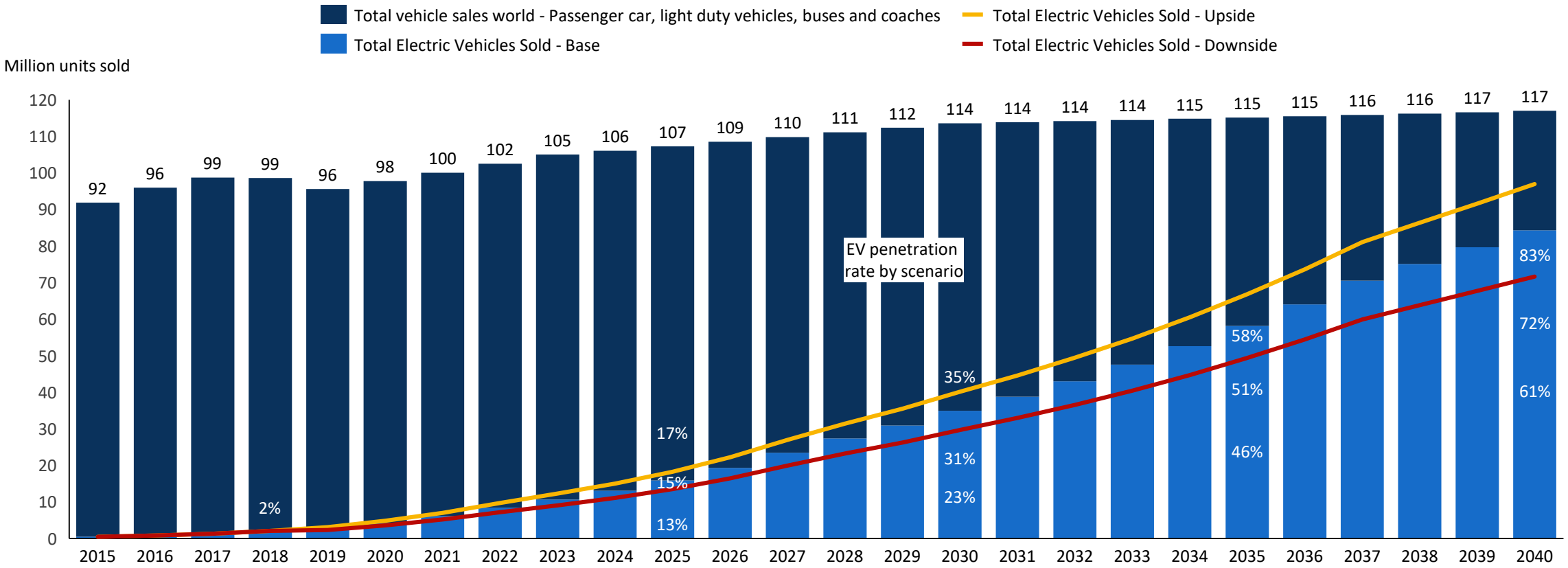
EV sales will continue to increase, fueled by over $600bn of investment in the supply chain – 2.8% forecast for 2019, 4.3% in 2020 and 14.8% in 2025



Source: rho motion

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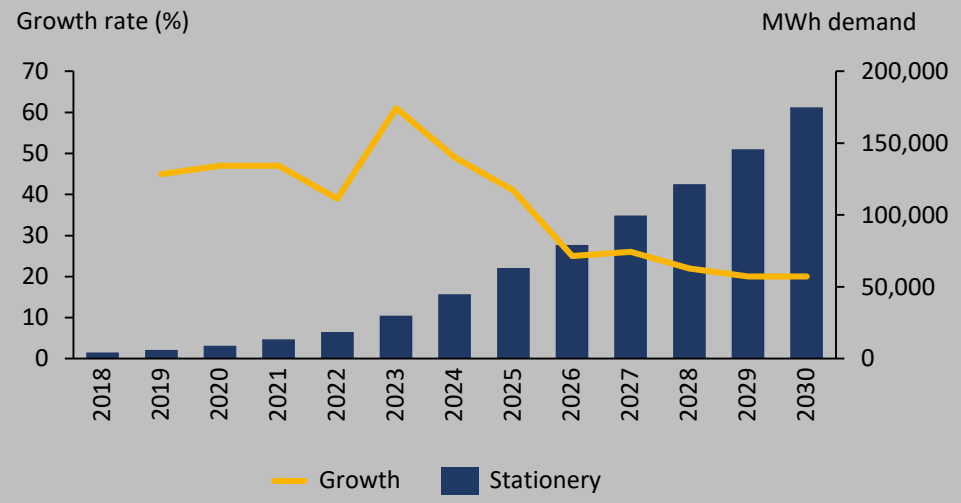
Stationary storage

Growth of lithium ion battery demand from stationary storage applications is expected to accelerate through to the mid-2020s when growth rates will slow as markets become more mature. The cost and quality improvements in battery chemistry for EV applications will facilitate high penetration levels in a range of residential and commercial markets, despite lithium ion not necessarily being the most efficient technology to use in these areas. Benchmark Minerals forecasts stationary storage demand to grow at a CAGR of 38%, over the next 10 years, overtaking portable electronic demand by 2026.



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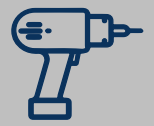
Portable electronics

Demand growth rates from portable electronics have gradually slowed since the mid-2000s . While growth will continue from these markets the rate will be limited due to the maturity of key application markets. The existing split between natural and synthetic anode inputs into these applications is expected to remain relatively stable, with some increased use of silicon based anodes as the first steps towards commercializing silicon-dominant technologies.
Benchmark Minerals forecasts a 4.3% CAGR in this market over the next 10 years.

46%
Mobile phones



14%
Power tools

40%
Other portable

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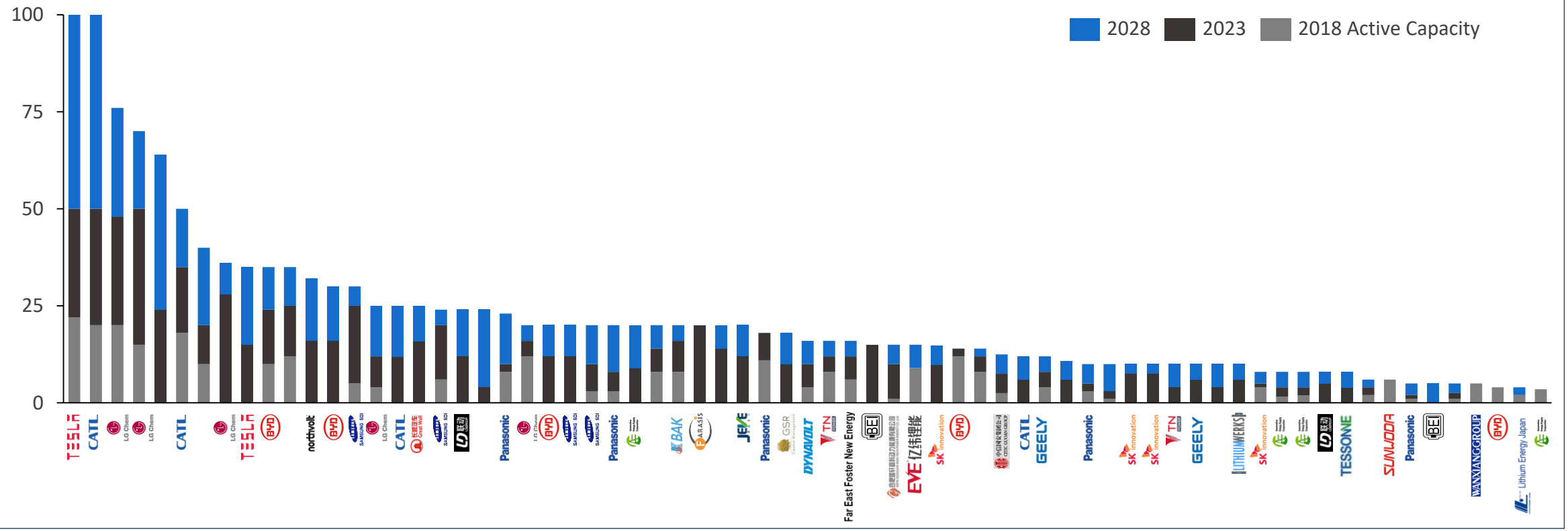
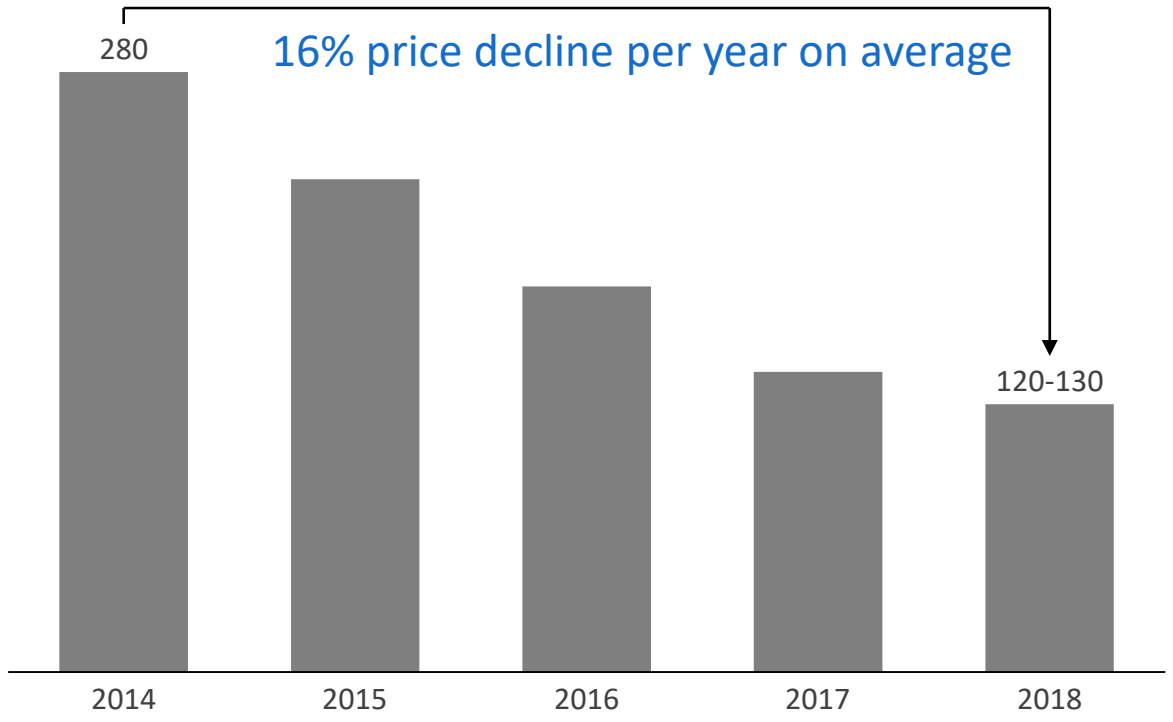
Over 100 battery Megafactories are now in the pipeline as of October 2019 - with over 2 TWH planned by 2029

Expected GWh battery cell manufacturing production through 2028 – major producers



Amid an environment of rising raw material prices 2014-2018, cell costs continued to drop. Making raw material costs more important.

Average $/kWh for battery cell manufacturing – major producers



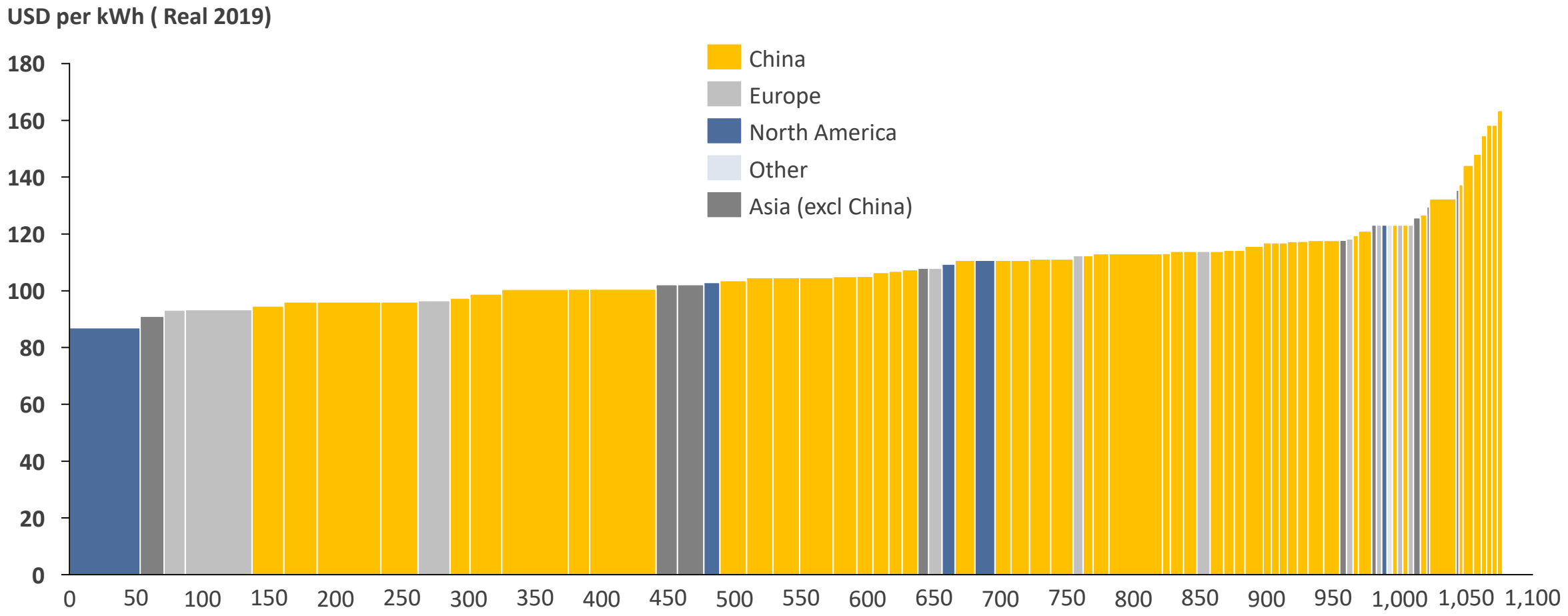
Cell-level cost reductions mostly concentrated on:

- Cost management along materials supply chain
- 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

Battery Cell Production Cost Curve 2023: 78 plants modelled covering NCM/ NCA and LFP technologies



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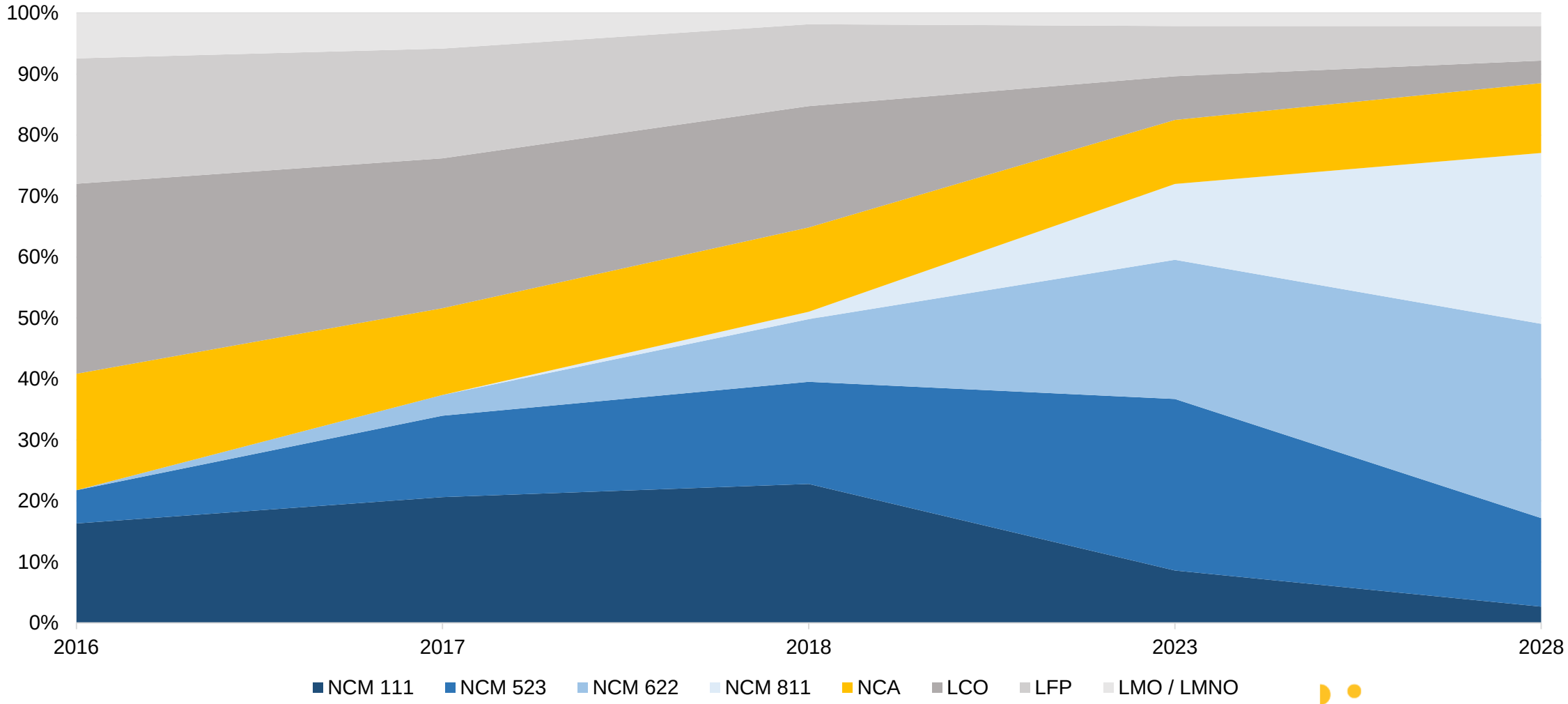
NB: Panasonic is producing batteries for Tesla as part of a captive JV, no margin is added here.

Independent cost assessment of cell manufacturing plants. Excludes cost of land and depreciation of equipment is over 10 years. Source: Benchmark Mineral Intelligence.

Current plans show high nickel NCM/ NCA dominating, but this may change as new formulations are proven



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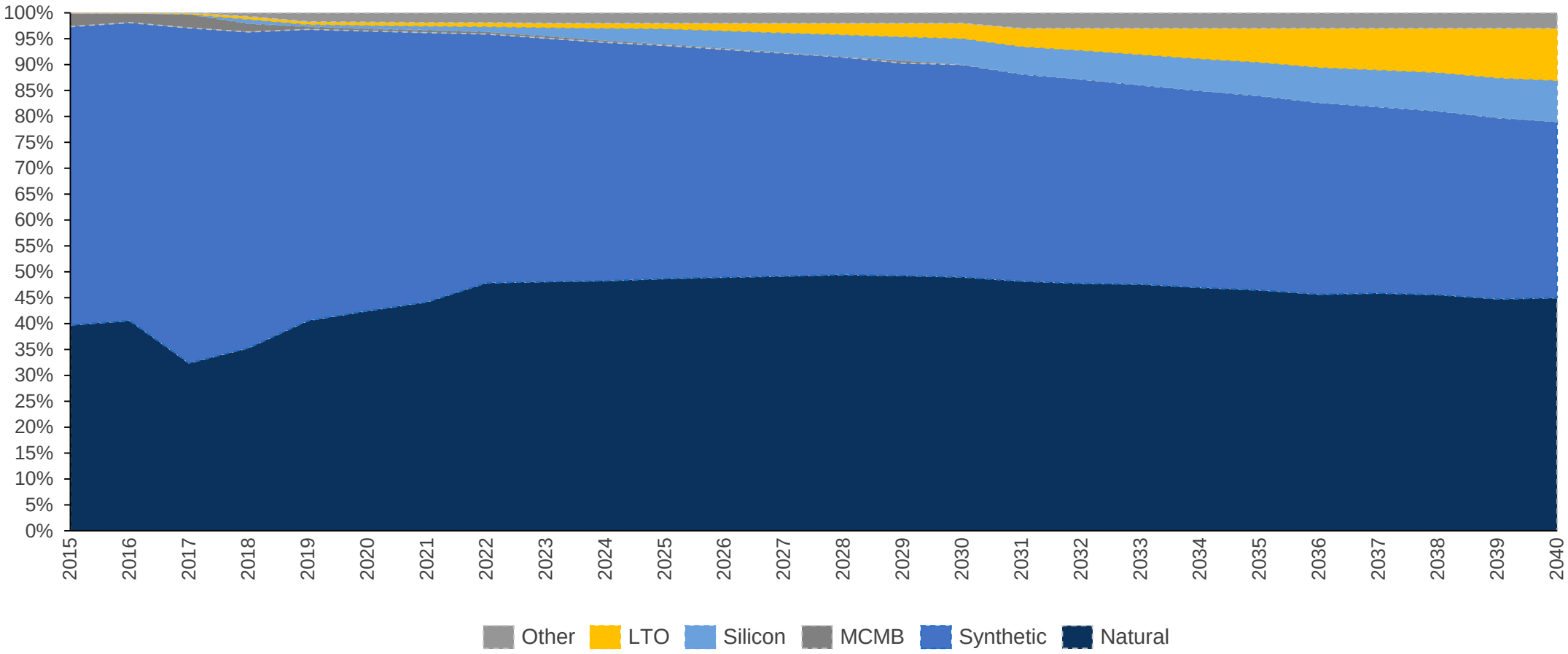
The blend of synthetic, natural and other additives creates significant differentiation in the anode



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Anode material selection remains a challenge in balancing cost and performance

The natural vs synthetic graphite debate rages on

Most anode producers aiming for a mix of input raw materials to gain benefits from both

Price rises in H2 2017 helped the spherical graphite market gain traction

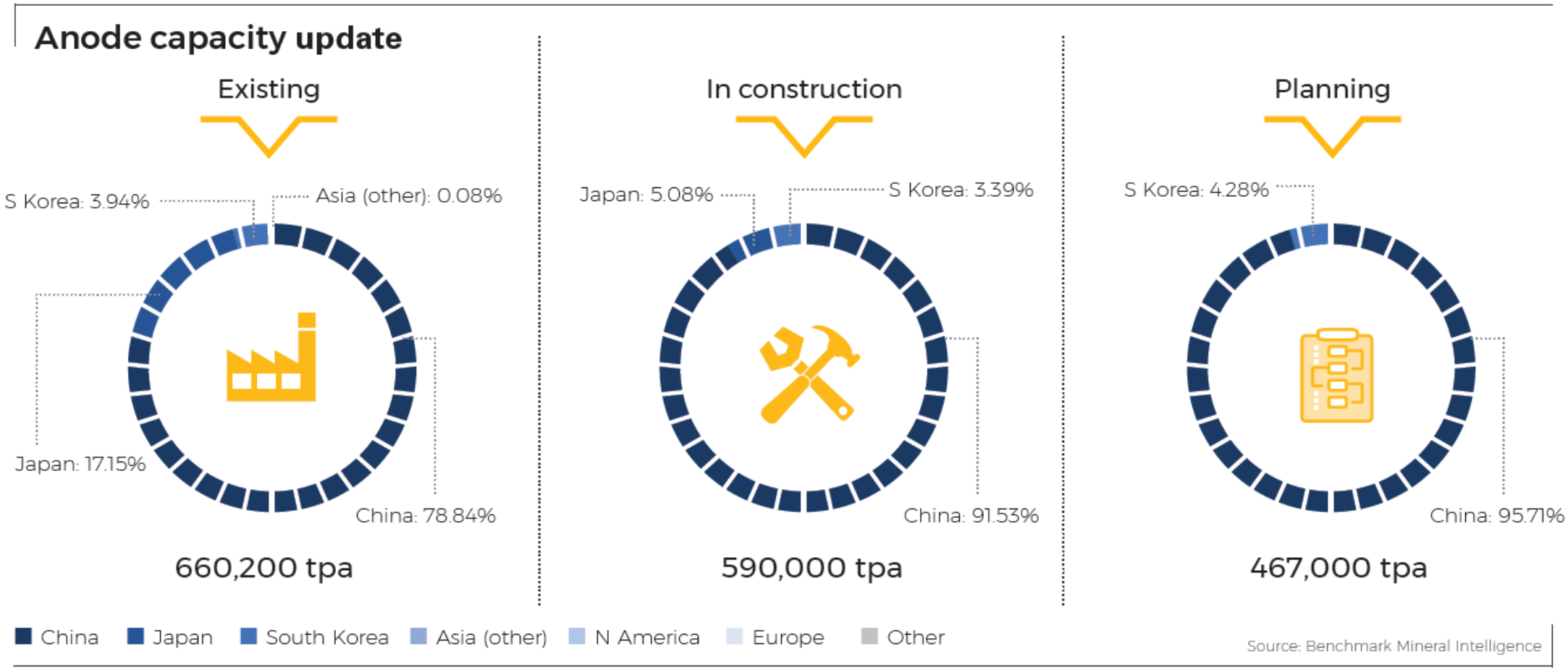
Supply chain concerns persist for natural anode materials

- Grade
- Environmental footprint
- Consistency of supply

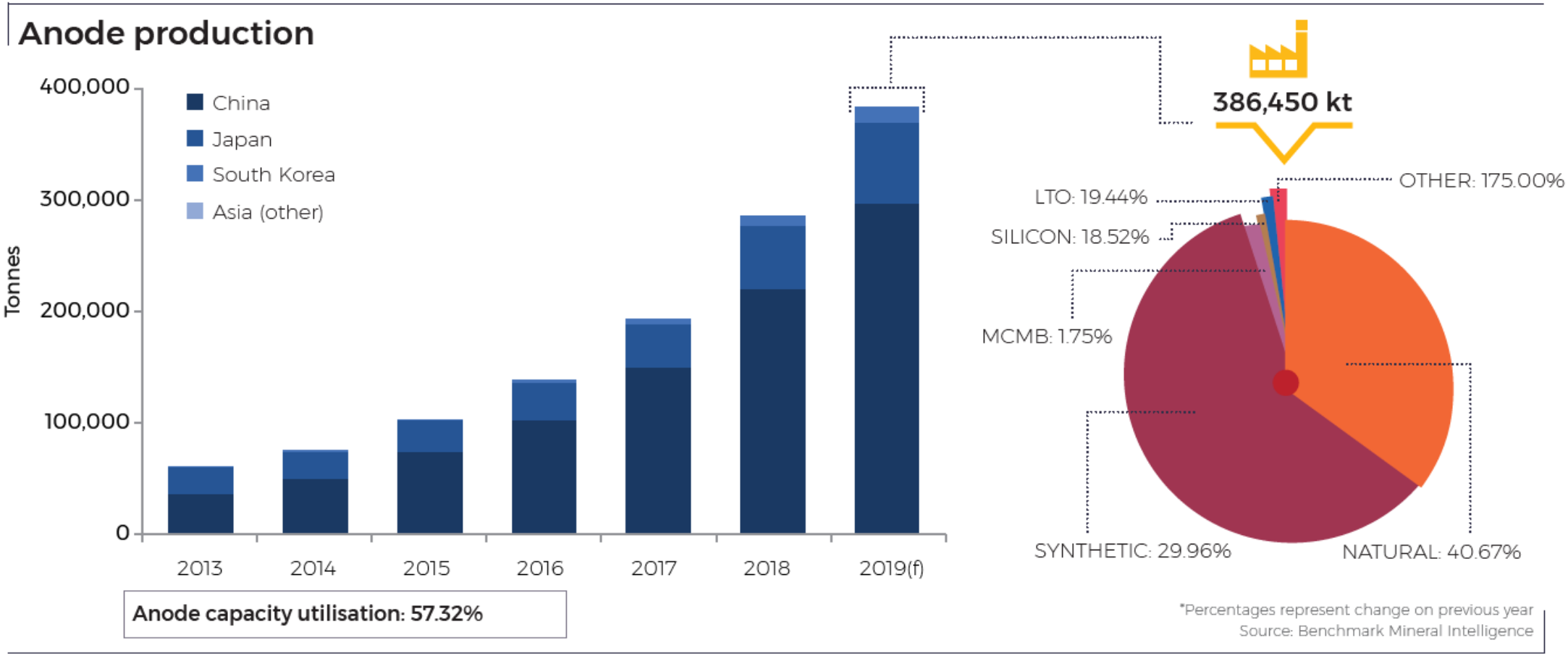
Synthetic supply also a concern despite major attempts to increase production and efficiency in China

- Production timescales
- Capital intensity of expansions
- Environmental footprint

Benchmarks new Anode report tracks capacity and announcements in the supply chain…

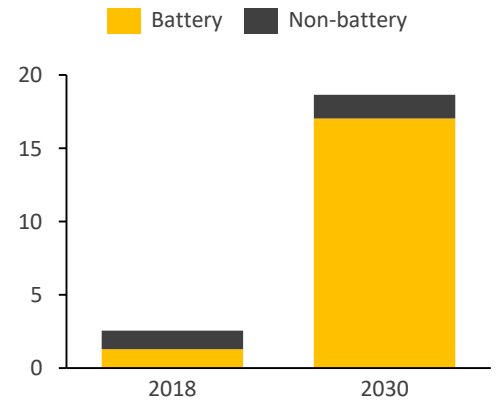


Production and growth rates are included along with major precursor materials



All Raw materials require significant investment, and a price that will incentivize this production

Lithium demand (LCE basis) 2018-2030 (in 000s)



CAGR	Total Capex Required[1]
18.1% 2.0% (Non-battery) 21.4% (battery)	$24bn

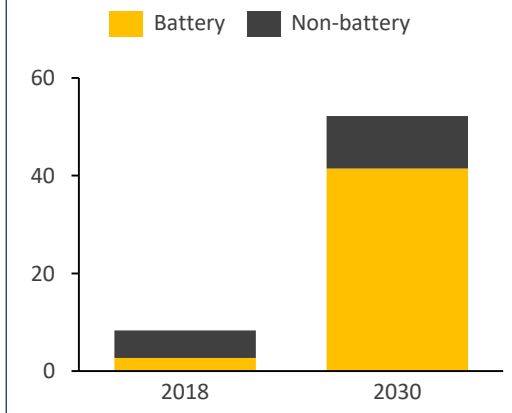
Challenges

- Quality & consistency of product
- Lack of chemical experience
- Lack of a futures price
- Potential oversupply in medium-term

Locations

- **Latin America**
- **Australia**
- Europe
- North America
- Africa
- China

Natural flake graphite demand 2018-2030 (in 000s)



CAGR	Total Capex Required[2]
16.6% 5.5% (Non-battery) 25.6% (battery)	$13bn

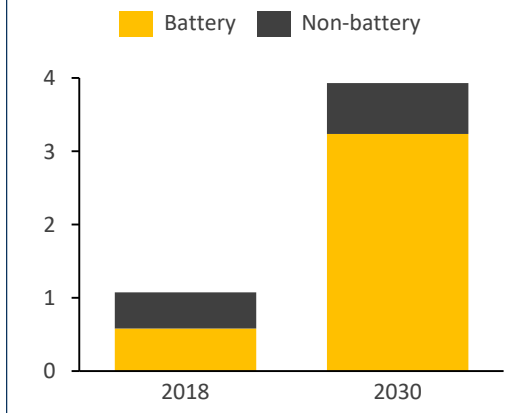
Challenges

- Substitution due to solid state battery adoption
- Confusion over role of synthetic graphite
- Not seen as a core battery raw material
- Environmental concerns

Locations

- Africa
- North America
- Brazil
- China

Cobalt demand 2018-2030 (in 000s)



CAGR	Total Capex Required[3]: >$50bn combined in copper and nickel
11.4% 2.9% (Non-battery) 15.4% (battery)	

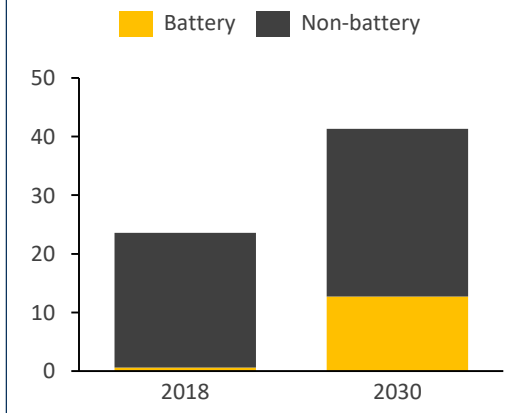
Challenges

- 70% DRC raw material
- (brand image, lack of western investors)
- High cost/substitution
- By-product
- Near-term over-supply

Locations

- DRC, DRC, DRC
- North America
- Australia
- Brazil

Primary nickel demand 2018-2030 (in 000s)



CAGR	Total Capex Required[4]: $39bn
4.8% 1.8% (Non-battery) 29.0% (battery)	

Challenges

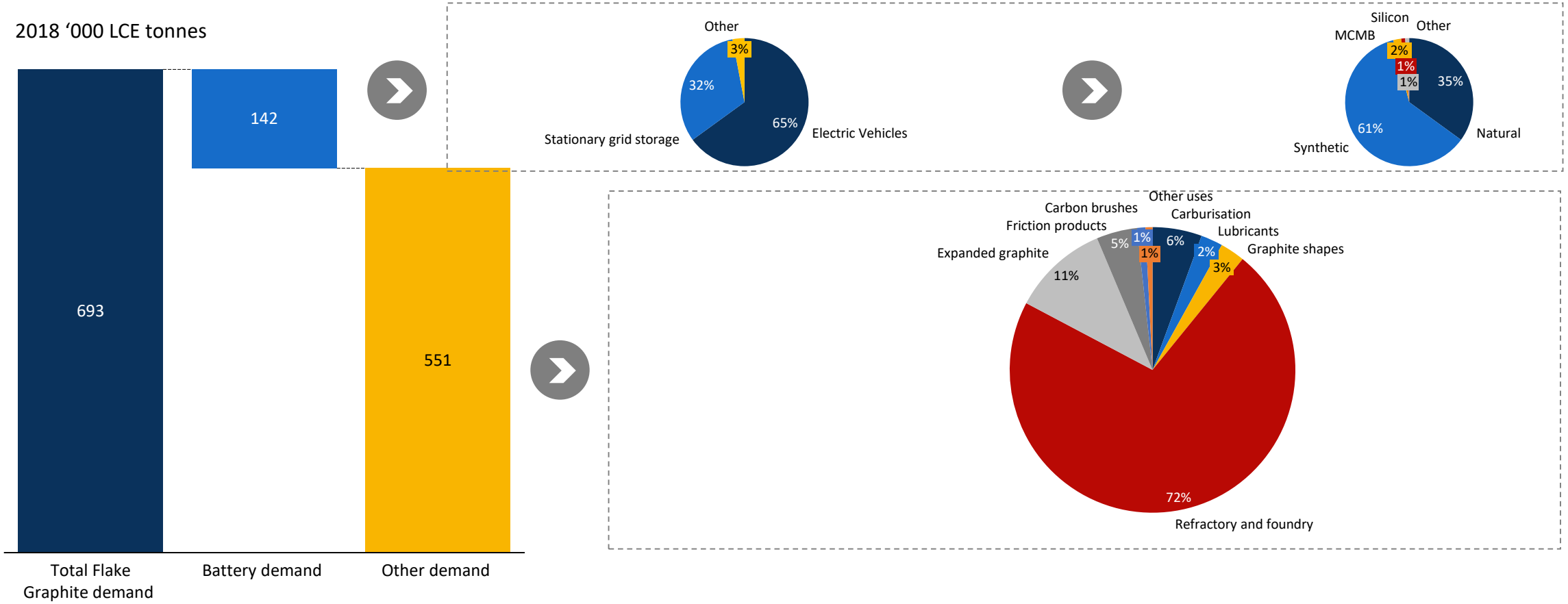
- Historically low price
- Laterite challenges
- Non-core assets
- Recycling
- Sulphuric acid supply

Locations

- Indonesia
- Philippines
- Australia
- PNG

1. Capex includes processing capacity to either a carbonate or hydroxide 2. Capex estimate includes processing to spherical uncoated
3. Cobalt is today, and is expected to remain in the long-term, a byproduct of nickel and copper production 4. Capex is average of Class 1 and NPI/FeNi production

Flake Graphite demand breakdown by end-use, 2018



Note: LTO - Lithium–titanate

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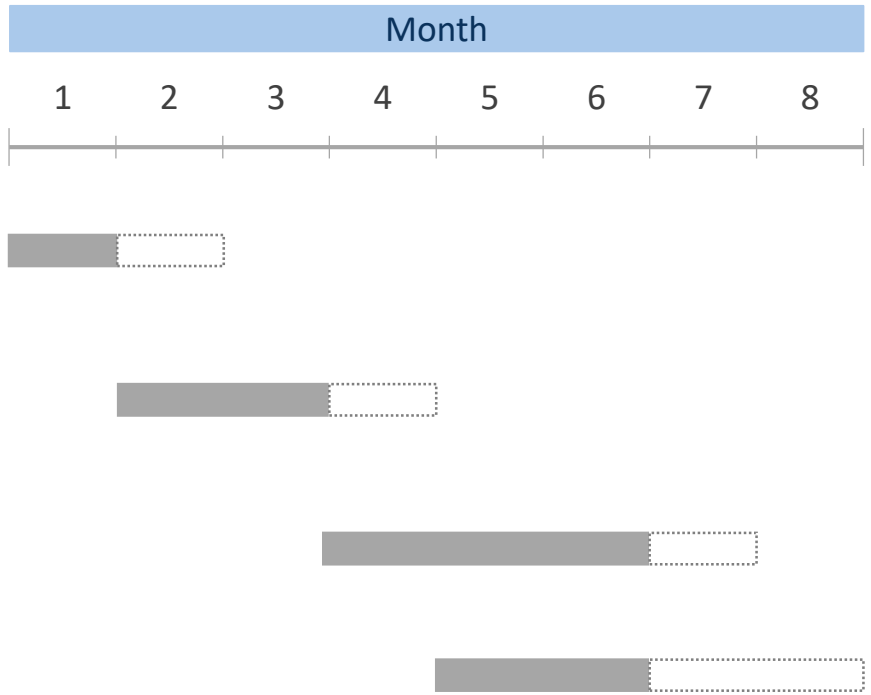
Final thought: Material qualification for new supply chains is an intense and often under-estimated process

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 anode?	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

Key Takeaways from the Crystal Ball:

- Anodes will make up the largest differentiator in battery performance post 2025
- Solid State will only reach mass light vehicle commercialisation post 2030
- Given the scale of investment and qualification lead times in automotive, the speed of technological adoption will slow
- Portable electronics will be a key proving ground for new technologies, while ESS is ripe for disruption
- Prediction: One of the more top ten OEMs will fail in the next decade