

Metal mining constraints on the electric mobility horizon

Developed in collaboration with



MineSpans
By McKinsey

McKinsey Basic
Materials Institute

James Eddy, Chris Mulligan,
Jasper van de Staaij, Diederik
Klip, Nicolò Campagnol, and
Toralf Hagenbruch

April 2018



Energy Insights
By McKinsey

About the authors

James Eddy is a Partner and the Solution Leader of McKinsey Energy Insights based in London. Chris Mulligan is a Partner and the Solution Leader of MineSpans in McKinsey's New York office. Jasper van de Staaij is the Solution Manager of the Global Energy Perspective team of McKinsey Energy Insights based in Amsterdam, where Diederik Klip is an Analyst. Nicolò Campagnol is a Metals Knowledge Analyst in McKinsey's Brussels office. Toralf Hagenbruch is a Senior Metals Expert in McKinsey's Berlin office.

The uptake of electric vehicle (EV) technology appears to be progressing faster than expected, with industry forecasts routinely being revised upwards. This is in part the result of strong policy stimulus from the Chinese and Western governments, but is also increasingly due to favorable economics as battery costs have tumbled in recent years. However, the growth in battery demand has driven up raw material prices and given rise to concerns about potential cobalt, nickel, and lithium scarcities.

The rapid uptake of EVs will see the emergence of a new supply chain connecting previously unrelated industries. Mining, battery manufacturing, and automotive will become increasingly interwoven. Each industry has its unique characteristics, be it geopolitical risk, technical complexity, or policy risk, creating intra-sectoral uncertainty through interdependencies.

Between now and 2030, this emerging supply chain is expected to produce over 340 million electric vehicles (from passenger cars to trucks and buses)¹. The implications of the shift toward electric vehicles will be enormous for the global automotive supply chain and their raw material requirements. At present, the global value of lithium, cobalt, and nickel for batteries is estimated at USD-5 billion, of which cobalt represents the largest share (~60%), followed by lithium (~30%), and high purity class 1 nickel suitable for batteries (~10%). At current market prices, the combined value of these commodities to meet battery demand is expected to reach USD46 billion by 2025 and USD134 billion by 2030.

Our analysis of raw material requirements for batteries, which includes a radical shift away from cobalt- to more nickel-intensive batteries, shows that with expected metal supply developments, EV adoption is likely to be challenged by availability of cobalt and class 1 nickel around 2025.

However, multiple factors are at play that could potentially shift the balance either way. Market players will need to understand the impact of key uncertainties. Will material scarcities hamper the roll-out of EVs? Can the mining sector ramp up production fast enough? Will the adoption of new battery technologies alleviate potential supply shortfalls? How will other demand segments for cobalt, class 1 nickel, and lithium be affected?

¹ This figure includes all the electric mobility vehicle segments – including two-wheelers, passenger cars, vans and pick-ups, trucks and buses – and includes pure battery electric vehicles (BEV) as well as plug-in hybrid electric vehicles (PHEV).

Battery demand expected to boom as EVs become economic and electrification accelerates

Battery demand is set to grow exponentially with the energy transition changing the way we power our vehicles, industry, and homes.

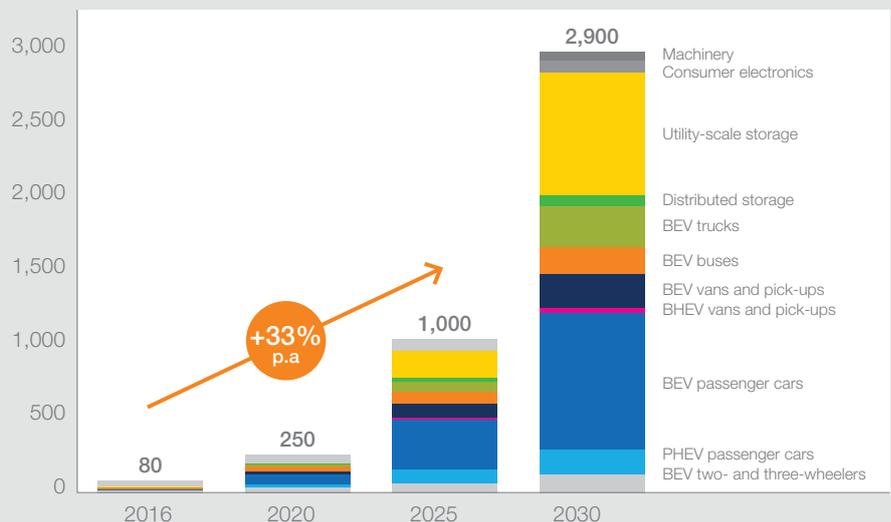
In our latest McKinsey Energy Insights Global Energy Perspective reference case, which describes how we see future energy demand evolving, we project total demand for battery storage, including from electric mobility, stationary power storage, consumer electronics, and other applications, to grow by 33% p.a. to reach ~1000 GWh by 2025 from roughly ~80 GWh in 2016 (see exhibit 1). Looking further ahead, after 2025, battery demand is expected to almost triple to reach ~2900 GWh by 2030.

Battery demand for electric mobility, including passenger cars, trucks, and buses, is expected to reach 735 GWh by 2025. By 2030, it will have surpassed 1890 GWh making up two-thirds of total battery demand. We project one in five passenger cars sold globally to be battery electric vehicles (BEV) by 2030 and global sales of BEV passenger cars to overtake those of internal combustion engine (ICE) vehicles by 2040. Encouraged by cities looking to improve inner city air quality, one in every 10 buses sold globally will be electric by 2026. Similarly, for trucks, one in every 10 trucks sold globally will be BEV by 2030.

340m

electric vehicles (from passenger cars to trucks and buses) will be produced by this emerging EV supply chain between now and 2030

Exhibit 1
Annual battery demand:
electric mobility segments,
stationary battery storage,
consumer electronics and
machinery
 GWh/yr



Source: McKinsey Energy Insights' Global Energy Perspective (March 2018), Avicenne



200 GWh

is the expected battery demand for power storage, including storage at home as well as at utility-scale by 2025

Battery demand for power storage, including storage at home as well as at utility-scale, is expected to reach 200 GWh by 2025. We expect stationary battery storage to boom post 2025, as the cost of batteries and solar PV decreases further and the levelized cost of electricity² (LCOE) of solar PV combined with battery storage outcompete fossil fuel alternatives in many regions of the world. This will result in total demand of 880 GWh by 2030, of which large utility-scale storage accounts for 810 GWh in 2030. Distributed storage, in homes and commercial buildings, is expected to add another 70 GWh to demand.

Whereas, traditionally, consumer electronics and machinery tools have represented the bulk of battery demand, with the advent of EVs, their share of total demand declined from ~90% in 2010 to less than ~20% in 2017. By 2025, this will only make up 7.5% at 75 GWh and by 2030 will have reduced to a mere 5%, representing 130 GWh.

Fears of a pending shortage have driven a shift in battery chemistries

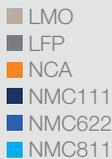
Presently, raw material costs make up less than 20% of total battery pack cost, however, their share has been increasing over time as other battery costs components have come down.

Nonetheless, in response to recent price increases and concerns about the future security of supply, market players have scrambled to reduce their exposure to raw material costs, specifically cobalt.

² The levelized cost of electricity is the net present value of the unit cost of electricity over the lifetime of a generating asset. This measure is often used to compare different generating technologies with one another.

Exhibit 2 Distribution of electric vehicle battery chemistries¹

%



¹ Other battery demand segments have been excluded

Source: McKinsey Basic Material Institute's battery raw materials demand model



There are multiple types of battery chemistries that differ with respect to their properties, such as stability/safety, energy density, lifetime, and material intensity (see appendix).

When assessing raw material requirements for batteries, we anticipate a radical shift in the distribution of battery chemistries up to 2030 (see exhibit 2). Whereas nowadays, Chinese preferences for battery chemistries clearly diverge from those in the rest of the world, with Lithium Iron Phosphorus (LFP) capturing 55% of the Chinese market, we expect preferences to converge toward Nickel Manganese Cobalt (NMC)³ chemistries, with NMC811 and NMC622 the winners capturing a combined market share of >90% by 2025-2030. These chemistries are less cobalt-intensive, NMC811 contains ~25% of the cobalt per kWh compared to NMC111, but also more nickel-intensive, with the nickel content in NMC811 a factor 1.75 higher per kWh.

Cobalt-free chemistries, notably Lithium Manganese Oxide (LMO) and LFP, have lost favor among OEMs. This is due to their lower energy density compared to NMC, which means a lower driving range for EVs – a key concern for prospective customers.

When EV uptake accelerates and battery demand hits the S-curve of technological adoption, additions in battery manufacturing capacity will need to keep up with demand to prevent shortages⁴.

In the short run, manufacturing capacity does not seem to be a bottleneck. Based on recent announcements, battery manufacturing capacity is expected to grow from ~110 GWh in 2017 to ~360 GWh by 2020 (from ~3 to ~10 Gigafactory equivalents), comfortably above the projected demand of 250 GWh. However, it remains uncertain whether manufacturing capacity can keep up with the steep growth in battery demand of 33% up to 2025. Looking even further ahead, whether market players have sufficient resources to roughly triple capacity, from 1000 GWh to almost 2900 GWh, in the 2025 to 2030 timeframe needs to be monitored closely. What is more important, however, is the availability of raw materials in the short to medium term.

³ Nickel Manganese Cobalt (NMC) type batteries are denoted by the ratio of these three respective metals, with NMC111 having equal shares of nickel, manganese, and cobalt, whereas NMC811 contains 8 times more nickel than manganese as well as cobalt.

⁴ The S-curve is commonly used to denote the growth trajectory of innovations, at first growth is slow, then accelerates, and declines again as the market matures and saturates, yielding an S-shaped curve.

>90%

of the combined market share by 2025-2030 will be Nickel Manganese Cobalt (NMC) chemistries NMC811 and NMC622

EV adoption likely to be challenged by cobalt and class 1 nickel availability

Our analysis shows that the market for cobalt will remain tight. The question to be answered is whether a radical shift toward less cobalt-intensive batteries is sufficient to avoid a shortage constraining EV adoption.

Correspondingly, the shift toward more nickel-intensive batteries will be a challenge for the currently projected supply capacity development. In essence, the scarcity problem could just shift from one commodity to the other. Irrespective of how low the share of raw material cost is of the total cost of an EV, adoption of EVs could face a physical supply challenge of one or the other commodity.

Cobalt

To keep up with demand, cobalt production will need to more than double by 2025 from 2016 production levels (see exhibit 3). Any potential setback in developing the proposed mining project pipeline can shift the supply-demand balance to a deficit. Similarly, if the shift toward other battery chemistries does not progress as quickly as expected or if demand for batteries is larger than expected, a shortage is likely to occur.

Total cobalt demand will grow by almost 10% p.a., reaching 210kt by 2025. This is mainly driven by strong growth for batteries reaching almost 16% p.a.

210kt

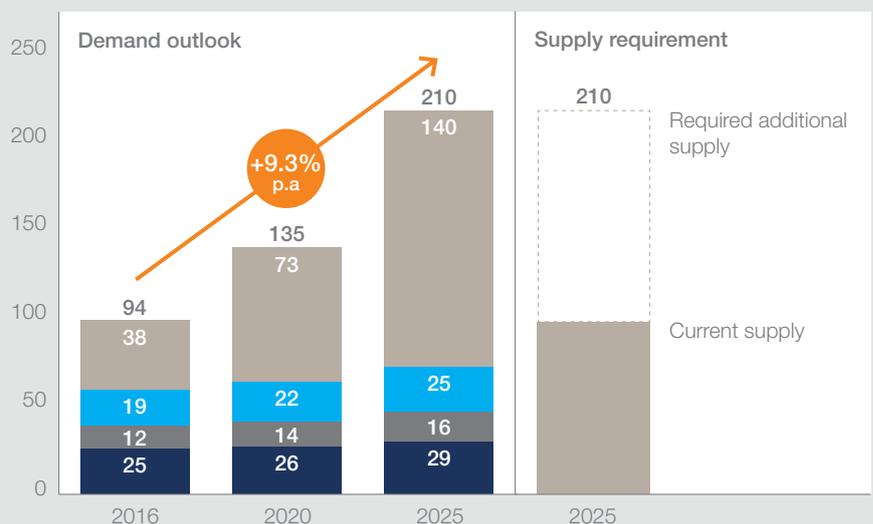
is what the total cobalt demand will grow to by 2025, at a rate of almost 10% p.a. mainly driven by strong growth for batteries

Exhibit 3
Cobalt supply-demand balance

Kt refined metal

- Battery demand
- Superalloys
- Cermet tools and hard materials
- Other

Source: McKinsey Basic Material Institute



Cobalt demand for superalloys (20%) and cermet tools (13%) will see growth of 3% p.a., while other applications will either decline (e.g., magnets) or grow less quickly (e.g., pigments). As such, battery demand is expected to make up two-thirds of cobalt demand by 2025.

To avoid demand outstripping supply, an additional supply capacity of 116 kt would need to come online, compared to 2016 production levels. Currently, >60% of cobalt production comes from the Democratic Republic of Congo (DRC), a country that is considered prone to instability and difficult to do business in. Furthermore, production from so-called artisanal mines, which are sometimes illegal and employing child labor, currently makes up ~10-15% of DRC production. Since most of the additional required supply is expected to come from the DRC, potential setbacks in bringing additional supply to market are a real concern.

To complicate matters, most cobalt is produced as a by-product of nickel or copper. Therefore, investments in new production are also subject to the market dynamics of these commodities. Based on our research, most new cobalt supply will come from copper mines and the share of cobalt from dedicated cobalt mines is expected to decrease from ~15% to 5% by 2025.

Nickel

Whereas the market is currently awash with class 1 nickel supplies, we believe class 1 nickel will be in short supply as projected supply additions fall short of projected demand (see exhibit 4). To avoid a supply shortfall, investments will be required in higher cost supplies. We, therefore, expect the price of class 1 nickel to increase from the current level, at which producers are merely able to cover their cash cost, to a level where they will be able to earn back their investments in expanding brownfield mining capacity.⁵

At present, nickel demand for batteries makes up only a small share (~3%) of class 1 nickel demand. However, growth in nickel-intensive batteries is expected to boost demand for batteries by a factor of ~17 up to 2025 (from

> 60%

of cobalt production comes from the Democratic Republic of Congo (DRC), a country that is considered prone to instability and difficult to do business in

⁵ Brownfield projects are an expansion of an existing mine, with the aim of increasing production from the currently mined orebody or tapping into satellite orebodies, either at or near the site. These projects are relatively low risk and cheaper to develop as geologists can use existing data and CAPEX for mining and processing facilities have already been incurred.

Exhibit 4
Class 1 nickel supply-demand balance
Kt

■ Battery demand
■ Class 1 non-stainless steel
■ Class 1 stainless steel

¹ Based on McKinsey nickel mine supply model, includes existing projects, brownfield and greenfield expansions in certain, probable, possible and unlikely projects.

Source: McKinsey Basic Material Institute

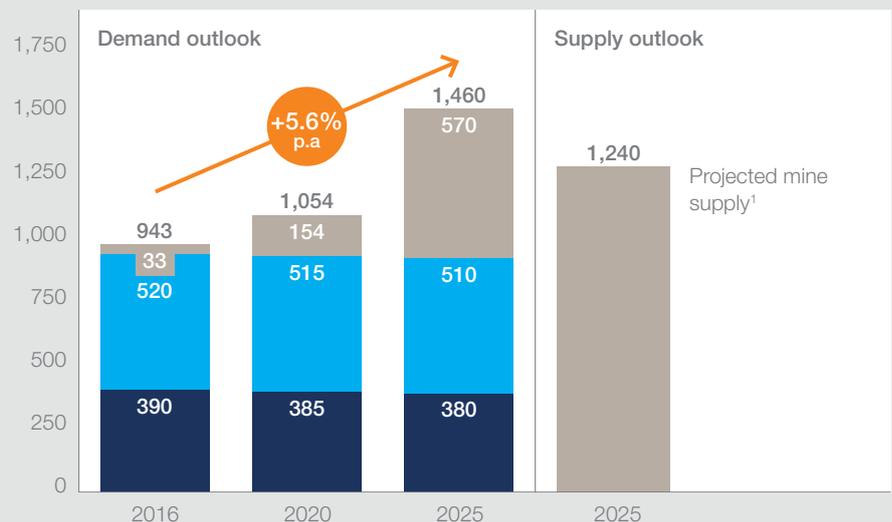


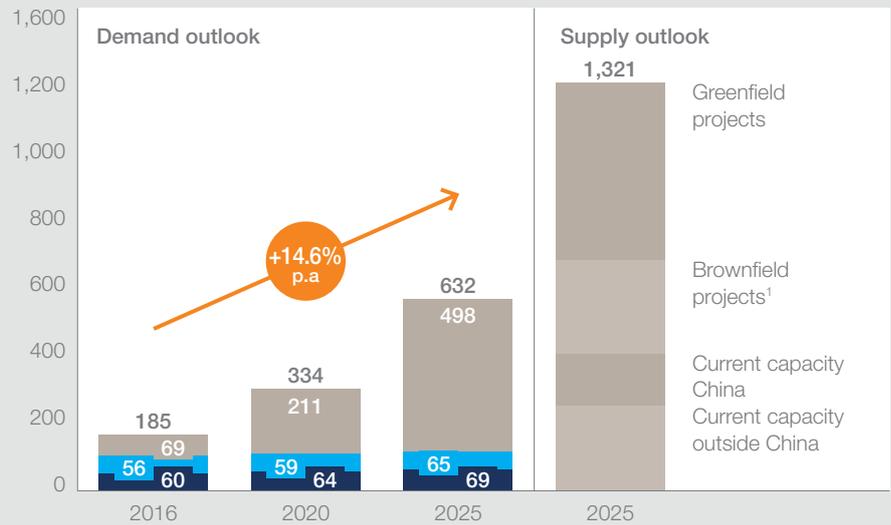
Exhibit 5
Lithium supply-demand balance

Kt lithium carbonate equivalent (LCE)

- Battery demand
- Glass and ceramics
- Industrial

1 Including 10kt brownfield expansion in China

Source: McKinsey Basic Material Institute



6 Greenfield projects aim to develop new mining capacity in areas that have not been previously mined. These projects are riskier, compared to brownfield projects, as the quality of the deposits is more uncertain. Moreover, greenfield projects are costlier to develop, as expenses are incurred for exploration as well as the construction of new processing facilities.

~30 kt to 570 kt). The increased demand for battery-grade class 1 nickel is likely to drive a wedge between class 1 and class 2 nickel prices.

The nickel industry is currently going through a slump with prices near an all-time low. This begs the question if the industry can react fast enough and invest in higher cost supplies to meet demand. With long lead times to bring new mines online, timing will be of the essence.

Lithium

Even though lithium production will face the highest annual demand growth, we do not expect a physical shortage to occur in the short or medium term (see exhibit 5). Despite recent fears of shortages and price spikes, mostly due to a shortage in capacity at the refining side of the value chain, the market is currently well supplied, which is likely to prevail as additions in production capacity are expected to match demand.

Lithium demand will see the fastest growth of 14.6% up to 2025, with battery demand growing from ~70 kiloton Lithium Carbonate Equivalent (kt LCE) to ~500 kt LCE toward 2025. By 2025, batteries are set to make up close to 80% of the global market, as other demand segments, such as glass and ceramics as well as other industrial applications, will see only modest demand growth (~2% p.a.).

80%

of the global lithium market will be made up of batteries by 2025, with other demand segments and industrial applications seeing only modest demand growth

At present, lithium mine supply capacity outstrips demand. The global utilization rate for mine production capacity is only at approximately 50%, with utilization being as low as 15-20% in China. Going forward, we believe sufficient production will be brought online from brownfield as well as greenfield expansions.⁶ Even if some of these projects are not realized, we expect supply capacity will be sufficient to meet demand. We can already see market players committed to developing new lithium mining capacity. In short, sufficient supply additions are likely to stymie any concerns of a pending supply shortage. Consequently, the current high lithium prices do not seem sustainable in the long term.

Key uncertainties could shift the balance in either direction

Fulfilling exponential demand for batteries and related metals is expected to put pressure on supply chains and commodity prices.

Whether temporary or sustained, price flare-ups will incentivize market parties to either develop new supply or curtail demand, in what will be a multi-faceted response leading to uncertain outcomes. If market players want to be successful in this emerging supply chain, it is crucial that they understand their exposure and the potential impact of a number of key uncertainties (see exhibit 6 overleaf).

Battery demand for EVs

The key uncertainty is the actual demand for EVs. On the one hand, EV demand could be greater than expected as large OEMs pile in to assert their share in this growing market. On the other hand, price increases in key metals like cobalt and nickel could thwart the expected cost declines that have so far been the basis of optimistic EV demand projections. Slower progress in terms of cost could delay Total Cost of Ownership (TCO) parity with ICE vehicles, which is an inflection point at which EV adoption accelerates. If TCO parity is delayed, EV demand may well turn out to be lower than expected.

Further, in the event of potential cobalt or nickel scarcities, OEMs can choose to reduce battery size. As this will reduce driving range, OEMs may be hesitant to pursue this option.

Battery technology developments

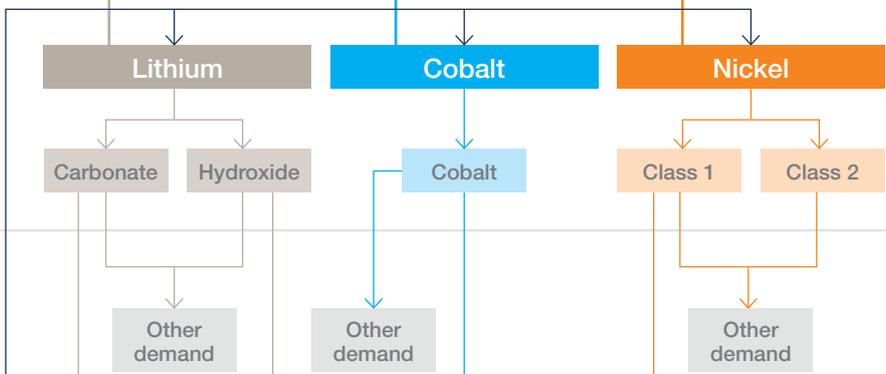
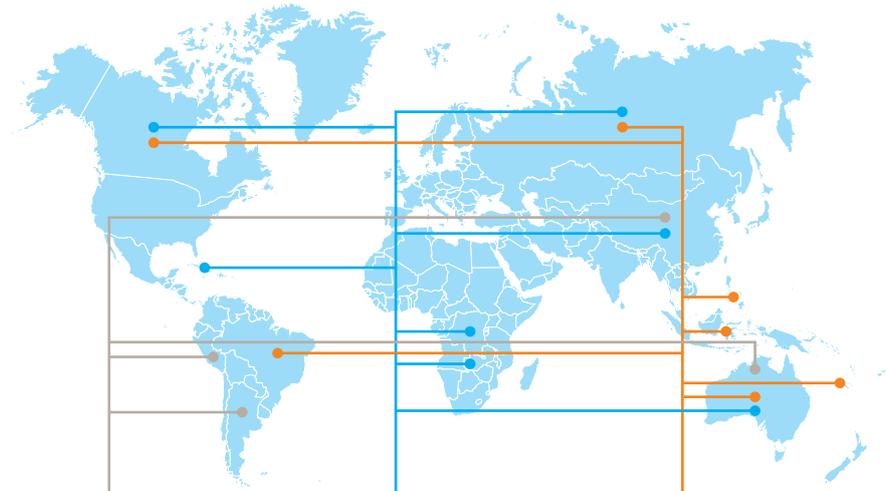
The key question is how fast battery technology advances and how fast less cobalt-intensive battery technologies can be commercialized and adopted. The pace of adoption is a key uncertainty that could potentially increase the risk of a nickel shortage, or aggravate the mismatch in supply and demand balance for both commodities if OEMs hold on to inferior battery chemistries for longer than expected.

There are also new battery technologies on the horizon that could lift energy density, such as Solid-State lithium and Lithium-Air batteries on a potential next horizon. Multiple OEMs, including Toyota, BMW, and Renault-Nissan-Mitsubishi, have announced that they are striving to implement Solid-State technology. Toyota is the most ambitious and aims to launch a model using Solid-State technology by 2022, whereas the other OEMs are aiming for the 2025-2030 timeframe. Although the commercialization of these technologies seems distant, higher raw material prices will likely spur market parties to increase their R&D efforts. Solid-State technology impact on cobalt and nickel is expected to be modest, but might increase the demand for lithium. While the impact of Li-air batteries is expected to come as a game-changer for raw material requirements, its development is still in an early stage.

Exhibit 6
A new supply chain in the making

Mining and processing

- Is there enough nickel, cobalt, and lithium to meet battery demand in the future?
- How much of additional cobalt supply will come from the Democratic Republic of Congo?
- How will mining companies deliver on the request from automotive OEMs for sustainably produced cobalt?
- Will the industry be able to ramp up class 1 nickel production in the current investment climate?
- How will the relative demand for lithium carbonate from South America and lithium hydroxide from Australia be affected by the shift toward advanced batteries? Will there be a shortage or processing bottlenecks?
- Will new extraction technologies be a game-changer?

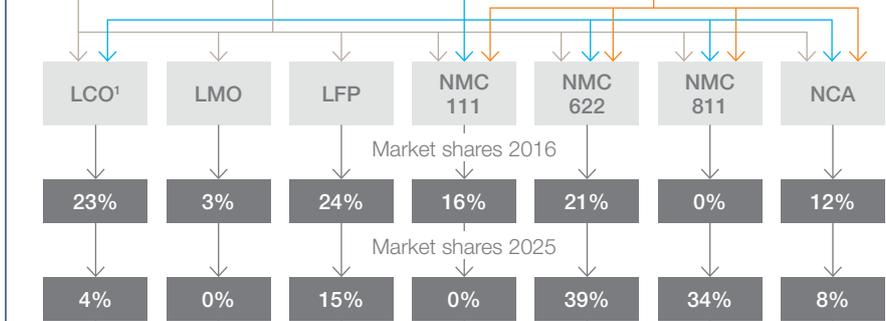


Other metal demand

- Can lithium, cobalt and class 1 nickel be substituted in other demand segments when faced with higher prices?

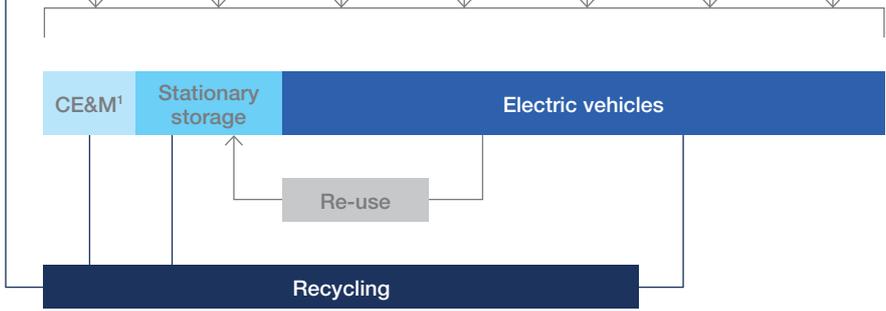
Battery manufacturing

- How fast will the transition away from cobalt-intensive batteries to nickel-intensive ones go?
- What will be the effect of more rapid progress in new battery technologies, such as Solid-State and Li-Air, on raw material demand?



Automotive and other applications

- How do OEMs secure long-term supply and what are the key risks when battery technology progresses faster than expected?
- How should Western OEMs respond to the Chinese move toward upstream integration?
- Will EV adoption be hampered by scarcity and higher commodity prices?
- What will be the effect of recycling and re-use on raw material demand?



¹ Battery demand for consumer electronics and machinery

Recycling and re-use

Increases in the price of cobalt and lithium may cause recycling to become a lucrative business, with several startups already stepping in to seize the opportunity. Currently, there is little recycling of lithium. However, we believe lithium supply from recycling will gain in importance and could supply up to ~5% of total demand leading up to 2030.

Cobalt recycling first commenced around 2010 and has reached 5-10% in recent years. Strong demand growth, combined with the fact that a part of the recyclable cobalt stock will be locked up for the lifetime of an electric vehicle, means that the share of recycled cobalt in total supply will only grow modestly, just surpassing 10% leading up to 2030.

Besides recycling, EV batteries can also still be re-used for stationary storage applications, thereby dampening raw material demand.

~5%

of total lithium demand leading up to 2030 could be supplied from recycling, even though there is currently little recycling of lithium

Appendix

Overview of battery chemistries, relevant parameters and raw material intensity

■ Strong ■ Moderate ■ Weak

Cathode material	Chemistry	Description	Raw material cost	Energy density	Ni content	Co content	Li content
			USD/kWh	kWh/kg	kg/kWh	kg/kWh	kg/kWh
LCO (Lithium Cobalt Oxide)	LiCoO ₂	<ul style="list-style-type: none"> Low stability/safety Good energy density Poor lifetime 	High	High	–	High	Med
NMC (Lithium Nickel Manganese Cobalt)	LiNi _x Co _x Mn _x O ₂ (NMC 111)	<ul style="list-style-type: none"> Low stability/safety Very good energy density Good lifetime 	Med-high	Med	Med	Med	Med
	LiNi _x Co _x Mn _x O ₂ (NMC 622)	<ul style="list-style-type: none"> Good stability/safety Very good energy density Good lifetime 	Med	High	High	Med	Med
	LiNi _x Co _x Mn _x O ₂ (NMC 811)	<ul style="list-style-type: none"> Good stability/safety Very good energy density Good lifetime 	Med	High	High	Low	Med
LMO (Lithium Manganese Oxide)	LiMn ₂ O ₄	<ul style="list-style-type: none"> Very good stability/safety Low energy density Poor lifetime 	Low	Low	–	–	Med
LFP (Lithium Iron Phosphate)	LiFePO ₄	<ul style="list-style-type: none"> Very good stability/safety Medium energy density Very good lifetime 	Low	Med	–	–	Med
NCA (Lithium Nickel Cobalt Aluminum Oxide)	LiNiCoAlO ₂	<ul style="list-style-type: none"> Good stability/safety Excellent energy density Poor lifetime 	Med	High	High	Med	Med



This insight has been developed in collaboration with McKinsey's Basic Materials Institute and MineSpans, leveraging the strengths of our proprietary models and solutions:

- McKinsey Energy Insights' Global Energy Perspective model, including granular EV TCO projections until 2050
- McKinsey Basic Materials Institute's battery raw material perspective, including a granular understanding of demand drivers, bottom-up mine-by-mine supply models, and in-depth perspective on battery cost and technologies
- McKinsey MineSpans' dynamic mining supply models and market insights

In today's uncertain context, we provide you with a unique set of perspectives and bespoke services so you may quantify your exposure to key uncertainties in this emerging supply chain, identify future areas of growth and understand the drivers behind them.



MineSpans
By McKinsey

McKinsey Basic
Materials Institute

About McKinsey Energy Insights

We are a global market intelligence and analytics group focused on the energy sector. We enable organizations to make well-informed strategic, tactical, and operational decisions, using an integrated suite of market models, proprietary industry data, and global network of industry experts. We work with leading companies across the entire energy value chain to help them manage risk, optimize their organizations, and improve performance.

For more information please contact
info_energysinsights@mckinsey.com
www.mckinseyenergyinsights.com



Energy Insights
By McKinsey