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Study on future demand and supply security of nickel for electric vehicle batteries

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Contents

Abstract

The objective of this report is to provide recommendations for long-term supply security of nickel suitable for nickel sulphate production and subsequent use in electric vehicle batteries. Eight Roskill nickel market, lithium-ion battery supply-chain and automotive sector experts analysed the European Union's i) ability to source and captively provide its own nickel units internally, and ii) strategic approach to establishing a nickel circular economy for EV batteries. Roskill provides a detailed outlook for nickel across a twenty-year forecast horizon to 2040. Firstly, at a global level, and second by placing the EU within the global context, though primarily focussing on automotive sector nickel demand. The following study areas were covered:

- Forecast Class I (and suitable intermediate product) supply/demand balances
- Identify what bottlenecks exist in the nickel supply chain
- Identify potential risks to Europe's access/ability to secure long-term supply
- Determine "best course of action" strategies for supply risk mitigation and the criticality of *circular economy* establishment
- Provide potential avenues for policy direction derived from the study findings

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Executive summary

This report analyses the supply and demand dynamics of the nickel market in the context of the automotive sector's transition towards electric mobility and development of a low carbon economy. The expected requirements for additional nickel are seismic for the market and there are multiple challenges to ensuring long-term supply security. This report provides a strategic review of the EU27's ability to source the quantities of nickel that it requires over the next twenty years in forms suitable for use in EV batteries.

Policy context

EU27 policy will play a crucial role alongside the organic responsiveness of the free market in establishing future nickel supply security. Challenges to achieving supply security are multi-faceted, and so our recommendations are that policy should address reducing future demand for nickel, establishing a domestic and global supply strategy, and investing in research and development. Ongoing assessments and reviews of policy suitability and their impact are therefore required. The need for promoting future nickel supply security, whether to support the needs of end-use or first-use sectors, is likely to evolve over time. We recommend that any policy enacted should be periodically reviewed against the goals it set forth to achieve and its effectiveness in doing so.

Key conclusions

The availability of suitable feedstock rather than processing capacity is the biggest "bottleneck" in the nickel sulphate supply chain and is the cause of the market potentially going into a structural deficit post-2027. We believe the lowest risk approach would be a combination of domestic and foreign sourcing. This could be structured under a "procure and own" approach. The former pertaining to primary nickel supply (mining and refining), and the latter underpinned by EOL recycling in a circular economy. Owing to a lack of development ready nickel deposits within the EU27, increasing access to new primary nickel supply in future is likely needing to be sourced internationally. This increases the need for instead directing investment focus towards a domestic battery recycling industry to fill the gap where new supply of feedstock for producing nickel sulphate is not able to be developed internally or sourced externally. Investment in both new primary supply and recycling is required to de-risk future supply security. To cover EU27 nickel demand from EV sales around €4.4Bn and €7.5Bn worth of investment is estimated to be required by 2030 and 2040, respectively.

Main findings

Automotive electrification is expected to represent the single-largest growth sector for nickel demand over the next twenty years. Within this sector alone, we forecast global demand to increase by 2.6Mt Ni to 2040, up from only 92kt Ni in 2020. Within the EU27, we forecast nickel demand from the automotive sector to increase by 543kt Ni, from 17kt Ni in 2020, under a base case scenario. Underpinning this growth is our expectation for EU27 OEMs to increasingly utilise high-nickel cathode chemistries from the mid-to-late 2020s and throughout the 2030s.

Demand for nickel from batteries requires a high-purity chemical product (nickel sulphate), which can only be produced from suitable feedstock forms (such as Class I nickel and intermediates). Post-2030 there is limited visibility on new projects able to supply Class I and intermediate nickel products. By this stage though nickel units available for recycling from EOL batteries are likely to become a growing source of raw materials to produce nickel sulphate. There are two tiers of this market balance that need to be considered. On an end-use basis (EV sales) in the EU27, we forecast the EU27 has the ability to meet internal demand until 2024/25 before deficits emerge. On a first-use basis (precursor/cathode maker), although demand is much lower, supply security of nickel is still a concern. Should a sizeable EOL recycling industry not be established, we expect a supply deficit to form in 2027 and then remain over the rest of the outlook period.

1 Introduction

Decarbonisation of transport is a key milestone in achieving the goals set forth in the European Green Deal. The European Commission (EC), together with the European Battery Alliance, are actively promoting the growth of electric vehicles (EVs) adoption/production within Europe, as well as fostering domestic battery manufacturing capabilities. In the context of nickel, the focal point of this study, this will inevitably lead to increased demand for Class I products for use as feedstock in sulphate production, which could be subject to bottlenecks in its respective supply chain. Knowledge of such bottlenecks are crucial to the EC's overall sourcing strategy and subsequent supply security. Hence, a deep understanding of Class I nickel's supply/demand dynamics for use in batteries is considered key. The focus of Class I nickel pertaining to EV batteries is salient as Class II nickel products are not suitable for use in EV batteries.

Over the past two decades, the nickel market has increased in value to US$35Bn in 2019 with total production reaching 2.4Mt Ni. This growth has been fundamentally fuelled by a rapid expansion in demand for stainless steel. A booming Chinese economy based on construction expenditure has boosted demand for, and incentivised large-scale investment in, stainless steel whilst also increasing the quantity of nickel required. In the last ten years alone, nickel demand from stainless steel has more than doubled to reach 1.6Mt Ni in 2019.

Whilst the stainless steel industry today still accounts for around 70% of total nickel consumed, growth has been driven by Class II (nickel pig iron and FeNi) nickel product use, with Class I (metal, chemicals) nickel product use growing but by a smaller total volume. The dominant driver of nickel demand growth in the future is forecast to change, and so too the nickel product mix. Such change is forecast to come in the form of lithium-ion (Li-ion) batteries, which have become the technology of choice for core automotive and energy storage system (ESS) applications. The importance of nickel within Li-ion batteries cannot be understated, as cells are now being manufactured with higher ratios of this transition metal. Nickel-rich Li-ion batteries show a superior energy density to other types, and lower metal cost to higher cobalt containing technology, making them the technology of choice for use in plug-in EVs.

The Li-ion battery's rise to prominence began in the form of lithium-cobalt-oxide (LCO) in the early 1990s, since becoming the staple technology used in portable electronic devices. For contemporary automotive applications, however, nickel-cobalt-manganese (NCM) or nickel-cobalt-aluminium (NCA) cathode chemistries are used, although other lower-performance technologies also compete. It is forecast that these will continue to be the main chemistries used in Li-ion battery for high performance, long-range EVs as original equipment manufacturers (OEMs) continue to invest in and transition production lines toward mass-scale plug-in EV manufacturing.

Such a transition in core growth end-use nickel demand sectors does not come without challenges. Not all nickel is classified as suitable for use in Li-ion batteries, where nickel itself must be in a chemical compound form (nickel sulphate hexahydrate: $NiSO_4.6H_2O$) for use in cathode precursor manufacturing. Roskill's forecast indicates that nickel demand from batteries could reach 36% of total nickel demand by 2030, increasing from 6% in 2020. This growth trajectory represents the main challenge faced by the nickel market.

It is important to highlight that final Class I nickel products are not the only form of nickel suitable for chemical conversion to nickel sulphate. It is common practice for nickel sulphate refineries to utilise a range of nickel feedstock options according to their respective plants' flowsheet technology. In 2019, Class I nickel (including powder, pellets and briquettes) only accounted for approximately 20% of nickel sulphate production globally. Conversely, alternative feedstock options (such as Mixed-Hydroxide-Product, Mixed-Sulphide-Precipitate and matte intermediates) collectively accounted for around 50% of nickel sulphate production. This equates to approximately 80,000t Ni-in-sulphate destined for batteries.

For these reasons, we deem it strategically salient not to limit government policy looking to establish domestic supply security purely to Class I products. We believe that both integrated (primary) and non-integrated (third-party) nickel sulphate producers are likely to continue utilising various feedstock types. Therefore, it is the overall market availability of suitable nickel feedstocks (including both Class I and nickel intermediates) that presents as a key challenge for nickel sulphate production in future.

Alongside primary production is a growing push for secondary sourcing of nickel units via recycling of spent batteries. This could theoretically present a degree of supply relief should primary supply shortages occur in future. Motivation for such may also rest on "closing the loop" of nickel units within domestic supply chains to ensure greater long-term supply security. Hence, reducing overall reliance on primary supply with its geographic concentration increasingly focussed on East/Southeast Asia (Indonesia and China).

The seismic push by government bodies and consumer transportation preferences alike are already having implications for policy development. Albeit, to date, policy has predominantly focussed on spurring downstream demand for EVs and/or nudging OEMs to shift their model focus toward such. Industry is now taking note on such a transition and is putting an increasing focus on the future availability and domestic security of raw materials labelled 'critical' to the battery movement. The context of this study seeks to provide insight to the nickel component of the battery movement and identify what comparative advantages Europe may have in securing a circular economy of nickel supply.

2 Methodology

2.1 Nickel demand

In this section, nickel demand-side forecast methodology will be discussed. There are two core sectors of nickel demand that are forecast to drive market growth over the coming twenty years. These being lithium-ion batteries (underpinned by electric vehicles) and stainless steel.

2.1.1 Automotive sector & electric vehicles

2.1.1.1 EV demand modelling

Roskill has built its automotive forecast using two independent methodologies: a consumer/sales-focused methodology and a manufacturers-focused methodology. This ensures an output adjusted to consumers' behaviour towards EVs and also to the manufacturing and cost reality of electric vehicles:

1. **Sales-focused modelling:** this approach is based on a regression model using historical sales data by country and by manufacturer, both for the automotive market as a whole, and the xEV market in particular. The regression model uses independent or explanatory variables like GDP per country, regional subsidies and their impact on EV costs, CO_2 limits per region, or energy prices among others. As not every automaker has already launched their future EV models, the baseline or historical data may be limited to forecast further in the future using historical EV models. In this sense, the model estimates by ICE vehicle segment (A to F and SUV-A to SUV-E). This estimation is based on the existing proportions of each ICE vehicle segment by country and by automaker within those countries.

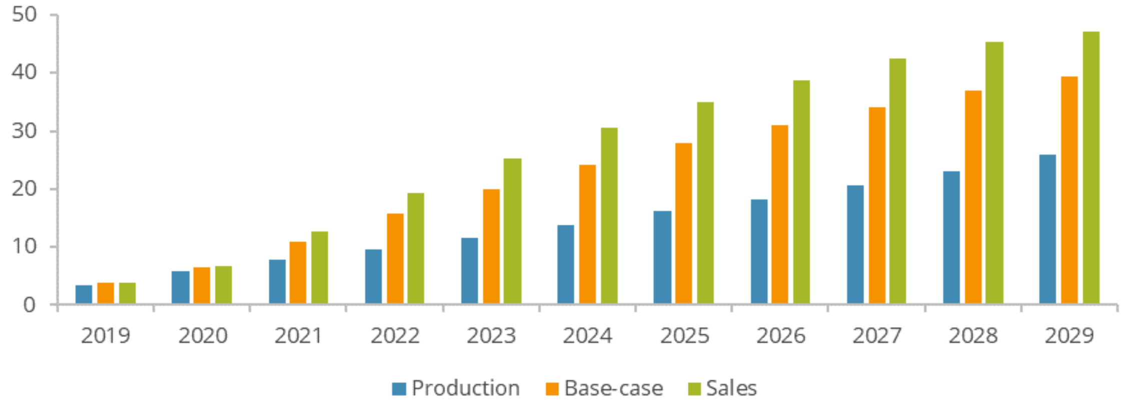
2. **Production-focused modelling:** Roskill has tracked the EV manufacturing plans of every existing large automaker (>300,000 annual units sold) based on their public announcements. In parallel, Roskill has profiled more than 200 manufacturing facilities of 53 automakers in which they plan to manufacture at least 370 mass-market electric vehicles models. However, as not every automaker is straightforward about its EV manufacturing targets, we have estimated the minimum proportion of electric vehicles these automakers need to manufacture to comply with the regulatory emissions mandates in certain jurisdictions. This is adjusted with the existing proportions of ICE models manufactured at each facility to give an indication of how many electrified vehicles could be potentially manufactured at these plants.

Overall, the output of both forecasts, albeit independently modelled, suggest a similar number of electric vehicles. However, both outputs present regional differences, powertrain type differences (more or less hybrids), and especially different or delayed EV adoption rates.

Although the base-case scenario is considered as the most sensible outcome for electric vehicle sales, the outputs of the two modelling approaches calculated below represent the hopes and difficulties of this fast-growing industry. Overall, the sales-focused approach based on historic sales present an industry rapidly moving towards transport electrification.

However, the production-focused approach still reflects the cost difficulties of mass-manufacturing electric vehicles with an output 45% lower than the sales-oriented scenario.

Figure 1: Global electrified (BEV, PHEV, HEV, 48V, FCEV) passenger car scenarios (example), (M units sold), 2019-2029

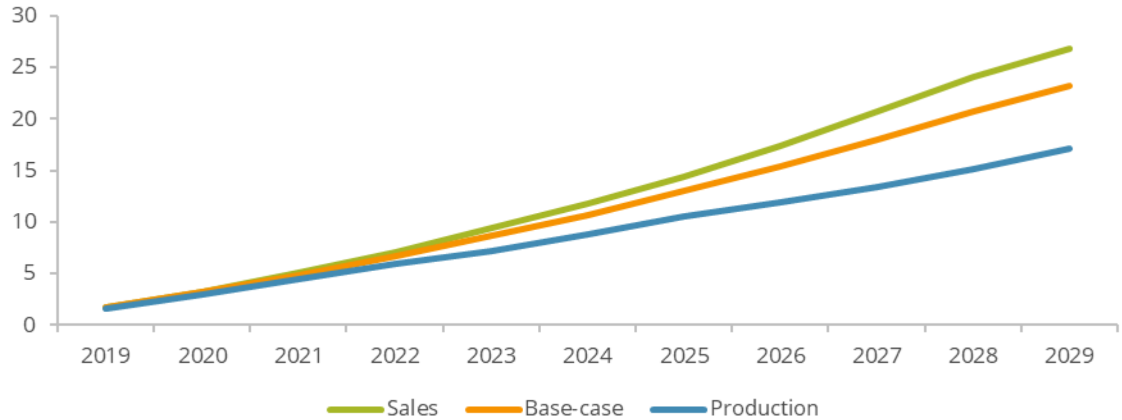


Source: Roskill, 2020.

This large difference results from the sales model suggesting a higher uptake of non-plug hybrids (HEV, 48V) given their similarities to conventional ICE vehicles. However, the production model suggest that automakers are not really considering this type of vehicles. This can be attributed to a lack of transparency on the auto OEMs plans to manufacture 48V vehicles rather than a genuine lack of interest in them. Sales of these non-plug hybrid vehicles could greatly reduce fleet-average CO_2 emissions when combined with plug-in sales.

When looking at plug-in vehicles only, the output of the production scenario is only 26% lower than in the sales scenario. This smaller difference results from both models converging more on the need for plug-in vehicles to reach fleet-average CO_2 emissions targets. However, it still represents the cost difficulties that automakers face to finance, design, build and improve these vehicles.

Figure 2: Plug-in (BEV & PHEV) passenger cars scenarios (M units)



Source: Roskill, 2020.

2.1.1.2 Assumptions used in Roskill base-case scenario

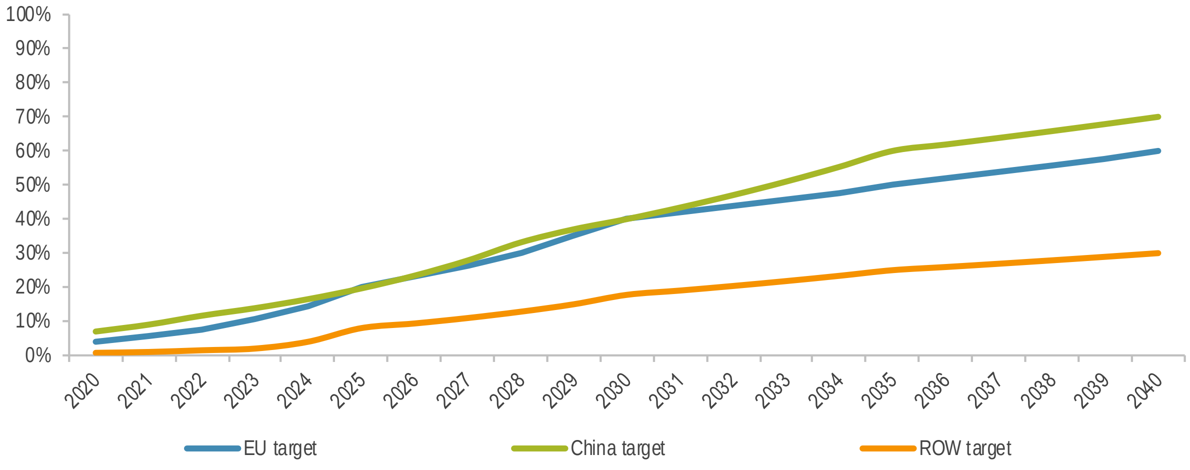
The base-case scenario relies on a set of different macroeconomic, technological, and materials assumptions across regions.

1. A **"Deep-V" economic scenario:** In which both the global and the European economy would quickly recover from the negative impact of the COVID-19 pandemic. GDP growth assumptions were assigned on a country by country basis and discussed further in Section 2.2. below. Overall, the macroeconomic assumptions drive the regression model that forecast automotive demand indistinct of powertrain type (ICE or electrified).

2. **CO_2 and government targets used in the base-case scenario:** The forecast of xEV sales uses four different proxies or data references to estimate the future penetration rates of electric vehicles by country and by type. Roskill has used the best available public data on 1. CO_2 government goals and 2. EV sales penetration targets as a reference of what automakers should achieve on a regional basis to comply with local regulations. Furthermore, Roskill has combined these references with its 3. Internal cost model and a database that tracks 4. Auto OEM manufacturing plans. Overall, Roskill has adjusted the weight of these four forecasting methods to obtain its base-case output.

More specifically, the base-case scenario assumes by 2030 a government plug-in EV sales target of 40% both in China and Europe, which increases to China's most recent goal of 60% by 2035. We have attributed considerable weight to this assumption. These targets have been sourced from official governmental sources as well as from regulatory proposals not yet enacted as law. At the European level we have used the official European CO_2 reduction target of 37.5% reduction vs. 2021 limit, and not the newly "proposed" 50% reduction targets vs. 2021 limit.

Figure 3: Governmental EV sales target by region, 2020-2040 (% of plug-in sales over the correspondent total auto market)[12]



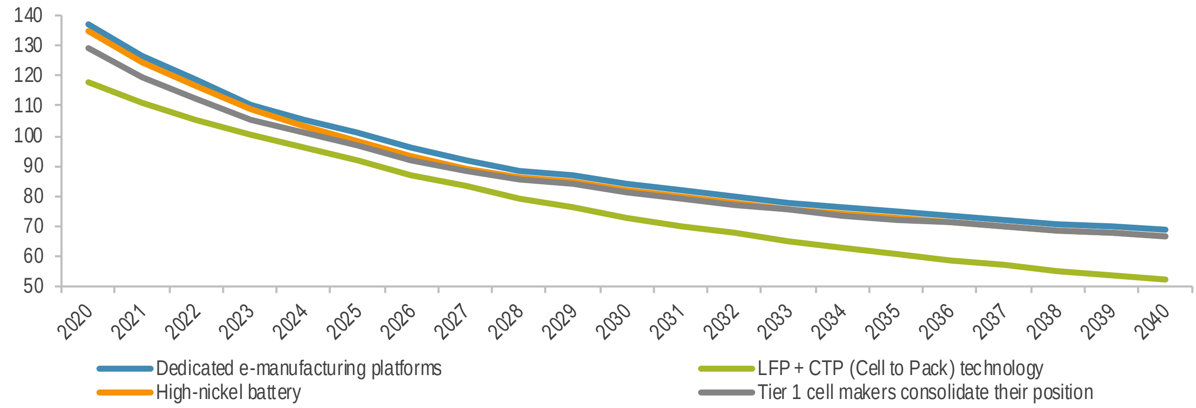
Source: Roskill, 2020.

([1]) ROW corresponds to "Rest of the World". This category has been averaged from a combination of other 30 countries

([2]) Roskill has extended in time the EV sales targets when a data void was found

3. **EV production cost assumptions:** different weights were attributed to the "Cost progression of EVs and batteries" assumptions in its base-case scenario. These assumptions translate into a cost per kWh at pack level (US$/kWh) that will impact the ability of car makers to approach the production cost of equivalent ICE models. In the base-case scenario, considerable weight was attributed to the cost of “High-nickel batteries” until the year 2030, with the “Tier 1 cell makers consolidate their position” scenario gaining more weight in the model thereafter.

Figure 4: Cost per kWh at EV pack level, 2020-2040 (US$/kWh)



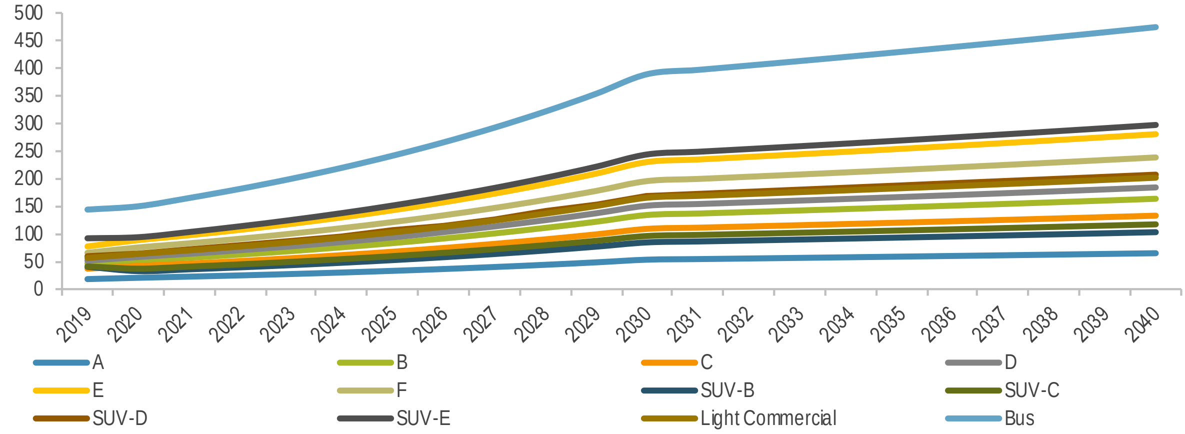
Source: Roskill, 2020.

4. **Battery capacity assumptions in the base-case scenario:** The individual battery capacity (measured in kWh) of each xEV is a key driver for battery demand and the subsequent raw materials. Roskill has created a battery forecast model based on:

   a) The weighted average battery capacity of existing models in the market (historic sales); and

   b) The weighted average battery capacity of the future xEV models announced by major auto OEMs. In addition, Roskill has added a 10% compounded annual battery growth in the period 2020-2030 and 2% growth thereafter to some of the existing EV models. The weighted average result of the model for passenger vehicles in EU27 is ~100kWh by 2030 and ~125kWh by 2040.

Figure 5: Battery capacity in EU27 attributed by vehicle segment (kWh) – Not weighted average, 2020-2040



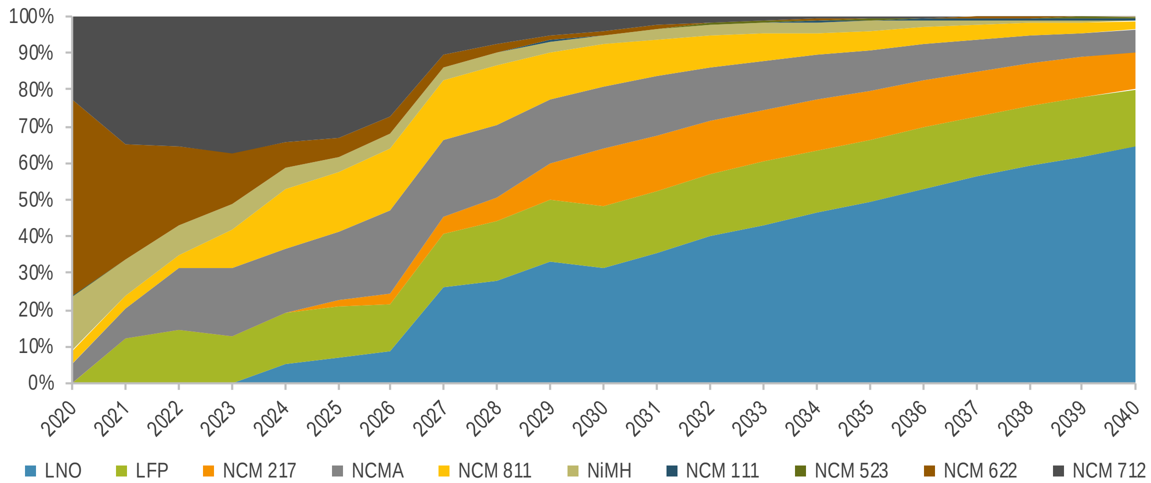
Source: Roskill, 2020.

5. **Cathode assumptions:** Cathode is perhaps the most critical part for the Li-ion battery upstream supply chain. The cathode choice will determine the cost of the battery and the demand for multiple battery active materials like cobalt, nickel, lithium, and manganese. We have created three main scenarios. The first scenario is "Technology developments by region" which forecast the penetration rate of each cathode type by region (e.g. EU27 will use more LNO while Korea will use more NCM-based chemistries). The second scenario considers a "Higher LFP penetration in China & Europe" with direct implications in the demand for nickel and cobalt. The last scenario is "Based on the baseline" or historic cathode chemistries and their future growth based on past market developments.

For the base-case, we have selected the "Technology developments by region" scenario as the most rational to estimate future cathode consumption in batteries. In this scenario, European cathode demand in EV batteries starts from a relatively high-nickel chemistry (NCM 622) in 2020. These will be progressively phased-out by higher nickel chemistries like NCM 712, NCM 811, and possibly NCMA until 2025. Also, this scenario envisions some commercial light, heavy and urban vehicles to install LFP batteries. From 2025 onwards, high nickel chemistries are expected to dominate at least 70-80% of the European cathode market with new ultra-high-nickel chemistries like LNO absorbing market share initially in high-end passenger vehicles. From 2030 onwards, Roskill envisions the co-existence of several chemistries. More specifically, the co-existence of high-nickel (NCM 811, NCMA), ultra-high-nickel (LNO), low-nickel (NCM 217), and no-nickel chemistries (LFP) until the end of the outlook period (2040).

This assessment has been partly based on the most recent production plans of automotive OEMs in Europe, the plans of domestic and foreign battery cell producers in Europe, and active battery materials companies in Europe. While the vision represented by Roskill until 2030 is partly based on actual corporate and strategy plans from existing battery supply chain companies, the outlook beyond 2030 (Period 2030-2040) is based on Roskill's expert opinion, corroboration with industry sources, and backed by third party academic research.

Figure 6: Cathode forecast in Europe[12] (% t of cathode materials)



Source: Roskill, 2020.

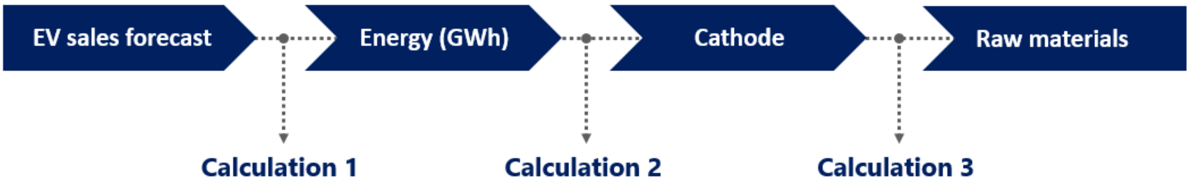
([1]) LCO = Lithium Cobalt Oxide, LFP = Lithium Iron Phosphate, NCM = Nickel Cobalt Manganese, NCMA = Nickel Cobalt Manganese Aluminium, LNO = Lithium Nickel Oxide, NiMH = Nickel-metal Hydride

([2]) Nickel Cobalt Manganese ratios (e.g. 523, 622 etc.) represent the respective raw material constituents within the cathode

2.1.1.3 EV battery capacity, active materials and nickel calculation

The resulting EV forecasts have been crossed with the known or estimated battery capacity (kWh) on a model by model basis and on a segment by segment basis (depending on the country and automaker). Similarly, the battery supplier of each EV model and the chemistry used has been crossed to obtain the total required battery capacity by the automaker in each world region as well as its cathode, anode, electrolyte, separator and raw materials. Therefore, the nickel raw material requirement is calculated in the following way:

Figure 7: Bottom up approach to calculating Ni demand from EV's



Source: Roskill, 2020.

- **Calculation 1)** Energy capacity per device:

  (a) Cell capacity x Voltage = Energy
  (b) Ah x V = Wh
  (c) Wh x Nº of devices =
  - Total Energy (millions of Wh = GWh)

- **Calculation 2)** Energy capacity installed/ Energy density per type of cathode:

  (d) MWh / (Wh/Kg) x manufacturing adjustments (losses etc) = Tonnes
  - Tonnes of chemicals or active materials

- **Calculation 3)** Raw material calculation:

  (e) Tonnes of active materials x materials composition of each cathode type = Tonnes
  e.g. NCM 811: 1,000t x 48% Ni = 480t Ni
  - Tonnes of nickel raw materials

It is worth highlighting the importance of accounting for material losses throughout the supply-chain and the variation between theory (assuming a 100% utilisation rate) and reality when calculating volumes at each supplier stage. Although losses in cell manufacturing are mostly expected to re-enter the production process via recycling. The losses accounted for at each stage of Roskill's methodology are shown below in Table 1.

Table 1: Manufacturing losses attributed to Li-ion supply-chain stages

Supply-chain stage	Material losses	Comments
Precursor	1-2%	A result of cleaning the mixer, the tank-reactor and recovery plant
Cathode	1-2%	A result of cleaning the mixer and the tank reactor. Temperature applied (depending on the manufacturing process) may also increase losses. Methods and equipment in precursor and cathode for loss mitigation can limit losses at 0.05% (e.g. continuous mixers instead of "batch" mixer), but this is dependent on type of precursor/cathode production
Cells	2-10%	Depending on the expertise of the manufacturer, position in the learning curve, and maturity of operation (new factory or +2 years old factory). Cell type can also impact manufacturing mistakes (e.g. prismatic and cylindrical are most prone to error during electrode cutting & electrolyte filling)

Source: Roskill, 2020.

As aforementioned, modelling such a high growth industry has inherent difficulty and so future accuracy is dependent on several caveats. These predominantly surround the constantly evolving cathode chemistry landscape and the rate at which technological advancements in manufacturing, cost and safety will drive the shift toward high-nickel cathode chemistries. This is to be considered in conjunction with the following:

- **Current and planned cathode chemistries:** it is difficult to definitively determine whether all announced cathode chemistries will reach commercial production phase and/or scale. At this same time, it is also naïve to ascertain that China and/or the battery industry will not be able to safely work with ultra-high-nickel cathodes.

- **Forecasts are always an approximate vision of the future:** despite multiple techniques and sound assumptions used in the modelling process, multiple short- and long-term factors (both internal and external to industry) could greatly affect battery demand.

- **Regulation-dependant industry:** regulation will continue to play a fundamental role until 2030. Changes in CO_2, EV quotas, city bans need to be factored on an ad hoc basis. Such factors are constantly evolving and so until EV's reach a maturity threshold it is likely that regulation and/or subsidies will be the main incentivisation factors behind OEM EV production.

- **Other non-electrochemical storage technologies may surpass lithium-ion:** in an industry underpinned by evolving technology, there will always remain a risk of superior technological substitution. Examples of this include FCEV, bio-fuels and other battery technologies which may disrupt the market and create sudden industrial losers. However, Roskill considers lithium-ion based technologies to remain dominant over the 2020's.

2.1.2 Stainless steel

Stainless steel demand begins with collating and calculating historical country/regional apparent consumption. This is calculated as follows:

- Crude stainless steel production **+** net trade in stainless steel products

Roskill collects stainless steel data from a variety of industry sources, with crude stainless steel production typically sourced quarterly by the International Stainless Steel Forum. As trade figures become available, we adjust our stainless steel apparent consumption forecast for the current year. This is done on a on a quarterly basis for apparent stainless steel consumption.

Stainless forecast is based on macroeconomics and GDP growth. Long run growth in stainless steel consumption estimated by region/country based on econometric relationship to GDP. Alternative long run growth scenarios calculated based on different trends in "total factor of productivity" and economic convergence.

Stainless steel apparent consumption forecast is then used to estimate the required stainless steel production. This is based on a historical yield between crude stainless steel production and consumption and takes into account losses in the manufacturing process. The required stainless steel production is then split between 200, 300 and 400-series stainless steels (based on sector-specific drivers).

The required stainless steel production is then allocated to producing countries. This is a function of where the capacity is being built (e.g. China and more recently Indonesia), and where some grades are typically made (e.g. 200-series mostly produced in China, India and the USA, very little produced in other countries).

Once stainless steel production has been forecast at the country and grade level, nickel requirements can be calculated. This takes into account typical nickel contents in 200, 300 and 400- series stainless steels. The forecast uses estimates of average scrap contents for internal scrap and for external scrap, with scrap use by grade then taken into account on a country/regional basis. This yields a total nickel requirement, which can be split between nickel in scrap and primary nickel

Roskill regularly benchmarks its demand estimates against those published by the International Nickel Study Group. Primary nickel in alloy steels and in castings is based on an estimated nickel content in those products, and on alloy steel production estimates. Primary nickel in non-ferrous alloys is based on estimated shipments (based on trade flows) and estimated nickel contents. Primary nickel in other applications are estimated based on industry contacts and estimated total primary nickel consumption. Forecasts are therefore based on a combination of macroeconomic and sector-specific drivers.

2.2 COVID-19 & macroeconomic considerations

In this section COVID-19 and its wider impact on the nickel market will be discussed. The intent is to provide the most up to date forecast of short- and long-term global economic growth recovery scenarios. The relevance of COVID-19 and expected GDP growth extends strongly to that of future nickel demand. This is largely a function of nickel demand being reliant on stainless steel end-use sectors. Although with the EV sector considered a core demand growth driver moving forward, macroeconomic recovery now holds importance for disposable income levels of consumers intended for an EV purchase. The following outlook was completed in our Q3 2020 update and subsequent analysis in this report is therefore based on such. Our current base case lies between the below views. In addition, with modelling second wave downside risk scenarios the short-medium term impact on metals demand could be lowered further. Although, such is dependent on various stimulus policies being enforced globally, most notably in China with respects to ongoing construction.

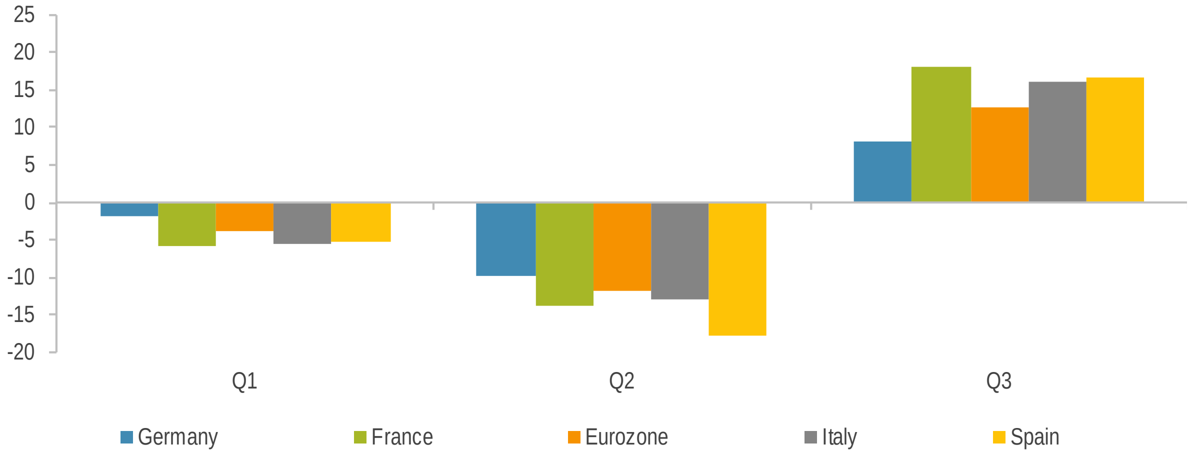
2.2.1 Short-term to 2022

The short-term global economic outlook remains clouded by the on-going COVID-19 pandemic and economic forecasts remain subject to considerable uncertainty and are subject to ongoing revision. As of early November, cases of the virus reported globally have almost reached 50 million and deaths exceed 1.2 million.

After a brief pause in the spread of the virus globally in the middle of this year as major economies “locked down”, the number of new daily cases around the world started to pick up due to rising occurrences across the Americas, Russia, Africa and the Middle East. The virus in these counties is now largely declining, but only gradually, and since late August a “second wave” of the virus has been reported across Europe. Though not as severe as the “first wave” after taking into account more widespread testing this has again led to many restrictions on activity being re-imposed. Disappointing news about the spread of virus in these regions though needs to be contrasted with better news in most of Asia, where the pandemic seems to be under better control, though subject to periodic flare-ups. China seems to have the virus under complete control at this point in time. Progress on developing a vaccine continues to progress at a rapid pace, although its approval and roll-out will still take some time.

Economies around the world saw their GDP held back by 25-35% during periods of “full lockdown” earlier in the year. However, as and where restrictions were then eased output recovered relatively strongly. China has been at the forefront of that recovery; GDP in Q3 was up 4.9% y-o-y, close to its pre-COVID-19 trend. Although some commentators have questioned the GDP data industrial production in the country was up 6.9% y-o-y in September, electricity and steel output was up by similar amount and passenger car production was up 10% y-o-y. European economies followed a similar trend with gains in GDP in Q3 offsetting 70-80% of the deep losses reported earlier in the year.

Figure 8: Change in GDP in major European economies in 2020 (percent, q-o-q)

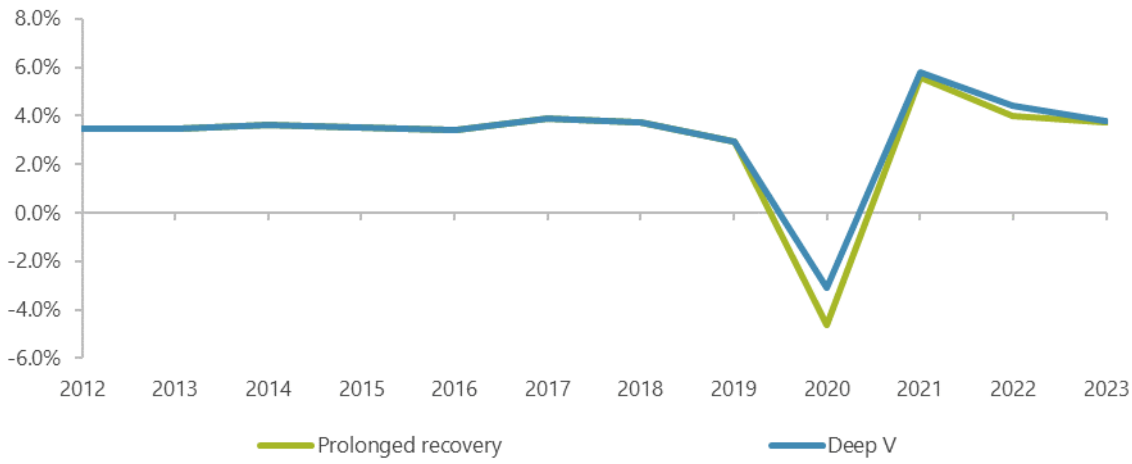


Source: Roskill, 2020.

The durability of that recovery has, however, yet to be tested. The pick up in Chinese industrial output is not yet fully supported by a bounce back in consumer spending and has been overly-depended heavily on investment. The pace of recovery in Europe and the USA has also slowed significantly in more recent months and the new restrictions that have again been imposed in many European economies in response the second wave of the virus may lead to another contraction in GDP in Q4. Although fiscal and monetary policy in the region has been pro-active, the longer that restrictions on economic activity have been, or remain, in place the more likely the pandemic will cause permanent scars on the future potential level of global output through permanent changes in risk appetites and investment, temporary layoffs becoming permanent cuts to employment and from causing the bankruptcy and breakup of previously viable businesses.

Roskill's core macroeconomic scenarios are for either a "deep V recession" or for a more "prolonged global recession". The former forecasts output in the world economy to return close to "normal" levels by end-2021, with only a relatively small permanent loss of output, while the latter suggest a more "U-shaped" recovery with a more significant permanent loss of production. Global GDP growth in the "deep V recovery" scenario this year is assumed to be -3.1% with a 5.8% recovery in 2021.

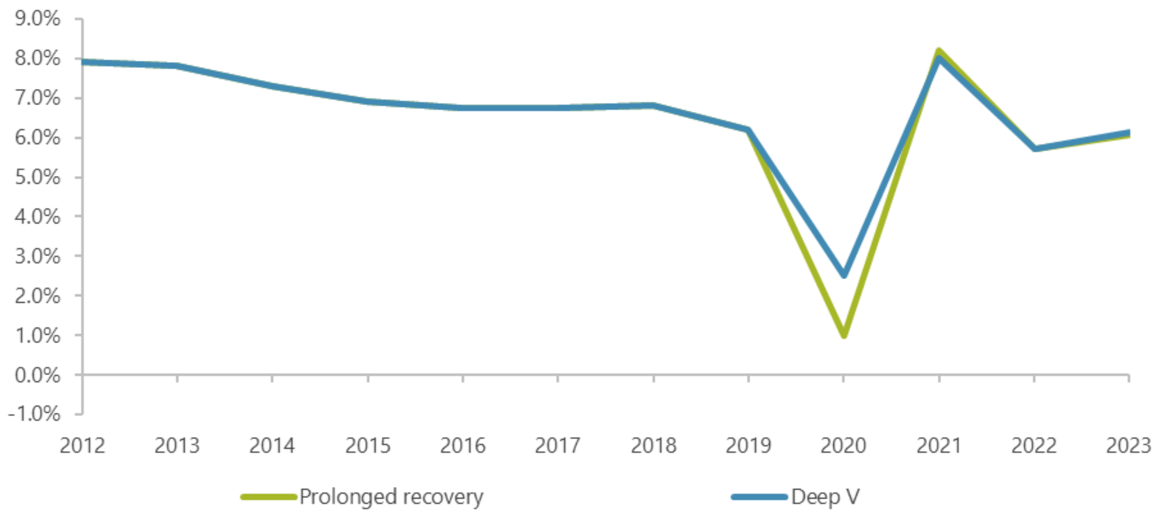
Figure 9: Forecast Global GDP growth scenarios, 2012-2023 (%)



Source: Roskill, 2020.

Chinese growth in this scenario is assumed to be 2.5% followed by 8.0% in 2021. Under the new prolonged recovery case global GDP falls by 4.6% this year followed by a 5.6% recovery in 2021. Growth in Chinese GDP in this scenario is 1.0% in 2020 followed by 8.2% in 2021.

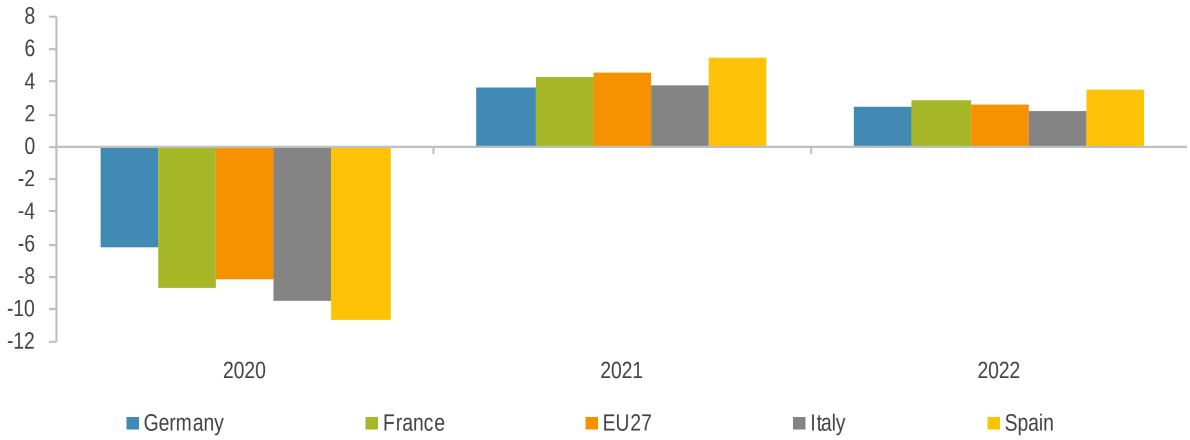
Figure 10: Forecast Chinese GDP growth scenarios, 2012-2023 (%)



Source: Roskill, 2020.

Roskill's assumptions for GDP growth in the main European economies are summarised in the figure below based on the average of Roskill's two GDP scenarios. The EU27 economy is forecast to shrink by 8.1% this year, before recovering by 4.5% in 2021 and 2.6% in 2022.

Figure 11: Forecast EU GDP growth, average of Roskill's Deep V and Prolonged Recovery Scenarios, 2020-22 (%)



Source: Roskill, 2020.

The size of the contraction in global GDP this year in both of the core short run GDP scenarios is extraordinarily compared to historical changes, where during the 2008-9 Global Financial Crisis the world economy only contracted by 0.1%. Consumption of metals in general is expected to relatively outperform its historical, highly geared, relationship to movements in GDP. That reflects the particularly severe effects on the COVID-19 pandemic on the retail, services, hospitality and entertainment sectors, which are all major components of GDP but which are not especially metals-intensive parts of the economy. Some sectors important for particular metals, notably aerospace, are being disproportionally hit by the COVID-19 pandemic and the effect of the current recession on demand for different metals will vary according to their specific pattern of end uses.

2.2.1.1 Long-term 2022-2030: Global GDP developments

In addition to modelling alternative short run scenarios for the impact of COVID-19, we have plotted high- and low-case scenarios for world GDP growth over the long-term to 2030.

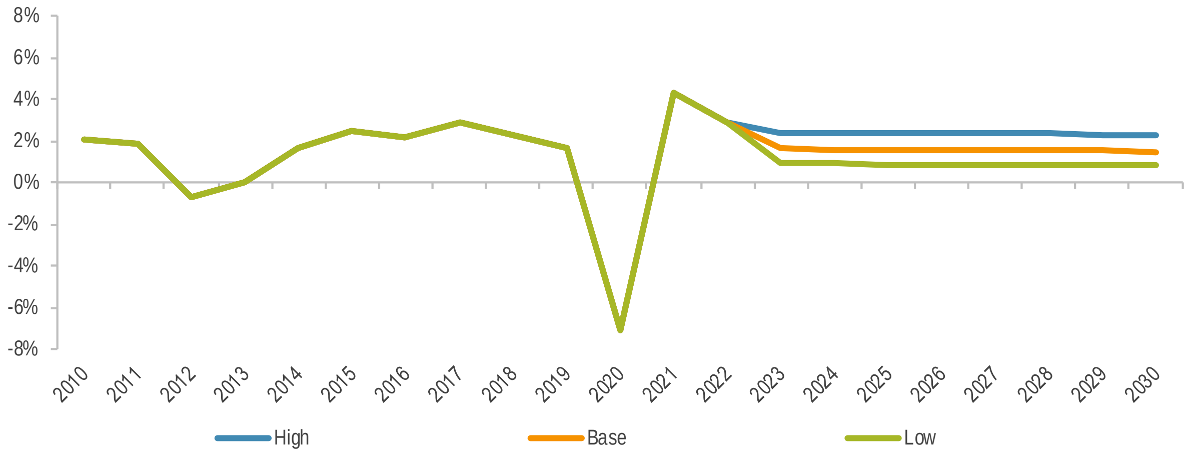
Figure 12: Forecast long run global GDP growth scenarios, 2010-2030[1] (%)

Source: Roskill, 2020.
([1]) Based on "deep V" short run scenario.

These scenarios are based on different trends for growth in "total factor of productivity" (TFP) in the world economy and different assumptions about the rate of economic convergence achieved by developing countries. The long-term low-case scenario tracks an average global GDP growth rate of 3.3%py (compared to 3.7%py in the base case). Growth in the high case averages 4.2%py.

For the EU27 the long-term low-case scenario tracks an average global GDP growth rate of 1.1%py (compared to 1.7%py in the base case). Growth in the high case averages 2.4%py.

Figure 13: Forecast long run EU27 GDP growth scenarios, 2010-2030[1] (%)



Source: Roskill, 2020.
([1]) Based on "deep V" short run scenario.

2.3 Nickel supply

In this section nickel supply-side forecast methodology will be discussed. There are two core sectors of nickel supply that Roskill forecast both in parallel to and in overlap with each other. These being primary nickel supply and nickel sulphate supply. With the former determining the availability of various nickel feedstock units suitable for use in Li-ion precursor materials and the latter being the physical production of nickel sulphate from such feedstocks for direct use in Li-ion precursors.

2.3.1 Primary nickel

Roskill's nickel supply database relies on the effective collation of plant capacity and physical production information. On the capacity front, respective plant nameplate capacities represent the theoretical production maximum as designed and engineered for. Capacity is considered a fixed amount over the life of the operation, unless in a future period the company plans to increase such by installing additional equipment or de-bottlenecking. Information on an operation's capacity is predominantly sourced from project technical reports (which are released prior to construction). Where such technical reports are not publicly available, Roskill obtains capacity numbers via the following additional sources:

- Public announcements – annual reports, quarterly updates, investor presentations etc.
- Direct communication with existing producers/project developers
- Conference papers

When forecasting future production, a key assumption in the methodology for future projects to come online, is that the nickel market will remain in approximate balance between supply and demand over the outlook period. This allows for the assessment of project incentivisation dynamics based on the preceding market balance at any given year in future. All nickel supply data is expressed on a 'tonne of contained nickel' basis. Production data is collected via both public and private sources:

- Public announcements – annual reports, quarterly updates, investor presentations etc.
- Trade data – access to Global Trade Tracker
- Industry study groups – including International Nickel Study Group (INSG)
- Direct communication with existing producers/project developers
- Conference papers

Once supply data has been collected, Roskill undertakes the following three steps when updating its databases and forecasting future output:

1. **Consolidation of historical supply:** shown on a product, asset, regional and country basis broken down into the three following interconnected layers:

   (a) Mine supply – often reported by company on an asset basis, or estimated using trade

   (b) Intermediate supply – occasionally reported, often calculated using reported refined production and applying a processing loss depending on the specific product

   (c) Refined supply – most commonly reported by company, but occasionally reported INSG data used

2. **Forecast for existing producers:** completed on an asset basis where, unless companies announce changes to production plans or increases to capacity, production is forecast to remain level over the outlook

3. **Addition of potential producers:** completed by assessing the global suite of nickel projects at various stages of development. Start-up dates for such projects vary and are based on company planned start-up dates, where information is available. However, if this is unavailable, then we apply a typical 'assumed time to start-up' based on project's current stage of development (see Table 2). For advanced projects a similar process is undertaken for the estimated production ramp-up of the project (see Source: Roskill, 2020. Table 3).

Table 2: Roskill assumptions to project potential start-up timeline

Time to start-up	Metric	Early exploration	Resource development	Scoping study	PFS	DFS	Permitting & licensing	Financing	Construction	Commissioning
Regular	Years	2.0	1.0	1.0	1.5	2.0	1.0	2.0	2.0	0.5
Fast-track	Years	1.0	1.0	0.5	0.5	1.0	0.5	0.5	1.0	0.0

Source: Roskill, 2020.

Table 3: Roskill project ramp-up schedule assumptions

Project type	Year									
	1	2	3	4	5	6	7	8	9	10
Greenfields	10%	30%	50%	70%	85%	90%	90%	90%	90%	90%
Fast-track/ re-start	25%	45%	75%	90%	90%	90%	90%	90%	90%	90%

Source: Roskill, 2020.

4. In conjunction with the project development and associated ramp up timelines, refined forecast supply is weighted by selectively including those projects that are deemed likely to come online. For nickel sulphate projects, all of these are included but supply is weighted by the analyst assigning each project with the likelihood of it coming online (see Table 4: Roskill new project probability/ forecast discount rates). A probability is assigned to each project based on a set of criteria including development stage, size and location of the project. The development stage of the project is the most important factor considered during this selection

This results in an 'expected' production versus that of total 'possible' supply. With the former being discounted and the latter the unweighted equivalent where the asset makes it to full commercial production. Possible supply acts as a potential supply upside to that of expected supply. It should be noted that forecast mine supply is also calculated using this weighting method.

Table 4: Roskill new project probability/ forecast discount rates

Category	Probability	Discount
Unlikely	15%	85%
Probably	30%	70%
Possible	70%	30%
Highly probable	80%	20%
Definite	90%	10%

Source: Roskill, 2020.

2.3.2 Nickel sulphate

In addition to the primary nickel supply database, Roskill has developed a separate (but linked) nickel sulphate database. This includes a comprehensive list of 80+ existing operations and 50+ new projects profiled with an associated breakdown on the feedstock type used at each asset. The need for overlap and interconnection between the primary nickel and sulphate databases lies in determining the availability of various nickel feedstock materials used in the production of nickel sulphate. Without which, future nickel sulphate production cannot be effectively determined according to individual producer expansion plans and required feedstock type. Within the sulphate database, production is categorised as one of three main types:

- **Type I:** primary production (also included in the primary nickel model)
- **Type II:** conversion from refined nickel products (mostly Class I nickel)
- **Type III:** secondary production (recycling of battery and non-battery scraps)

Prior to forecasting nickel sulphate supply, assets are classified as either integrated or non-integrated producers. Future production is then forecast under the following approaches:

- **Integrated production** (from processing captive nickel feedstocks) – same methodology applied as in the primary nickel model
- **Non-integrated production** (from processing external nickel feedstocks):

  (a) Step 1: assess future availability of various feedstocks (align with primary nickel supply model and battery model)

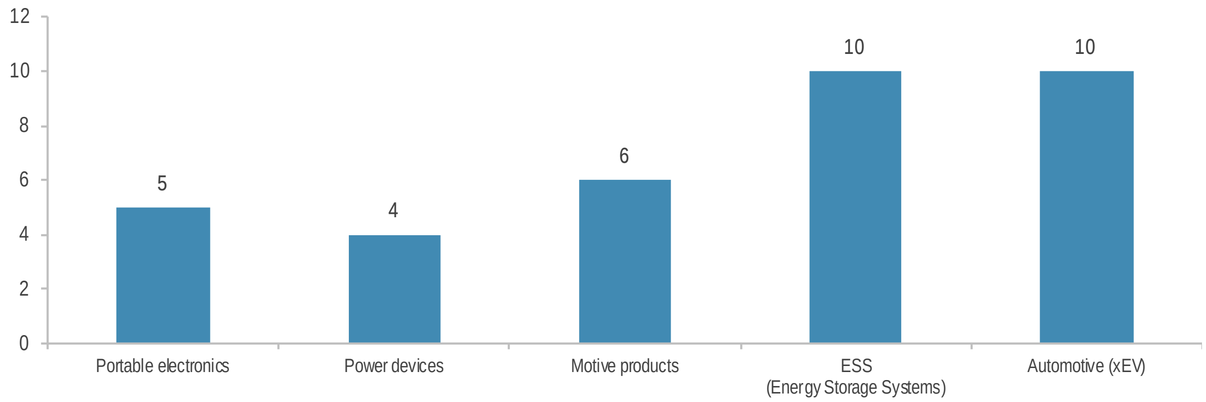
  (b) Step 2: forecast supply for each type of production based on available feedstock supply

2.3.3 Secondary nickel supply

2.3.3.1 Battery recycling

We have estimated quantities of battery materials available for recycling through an assumptions-based model. This model utilises the total battery capacity in sold end products (portable electronics, power devices, ESS, EVs) both historically and over the outlook period. This battery capacity is then divided by cathode chemistry. We assign the battery capacity from historical and forecast sales a specific service life depending on its end-use application and cathode type. After each end-use application finishes its service life, we consider that battery to have reach the “End of life” (EOL).

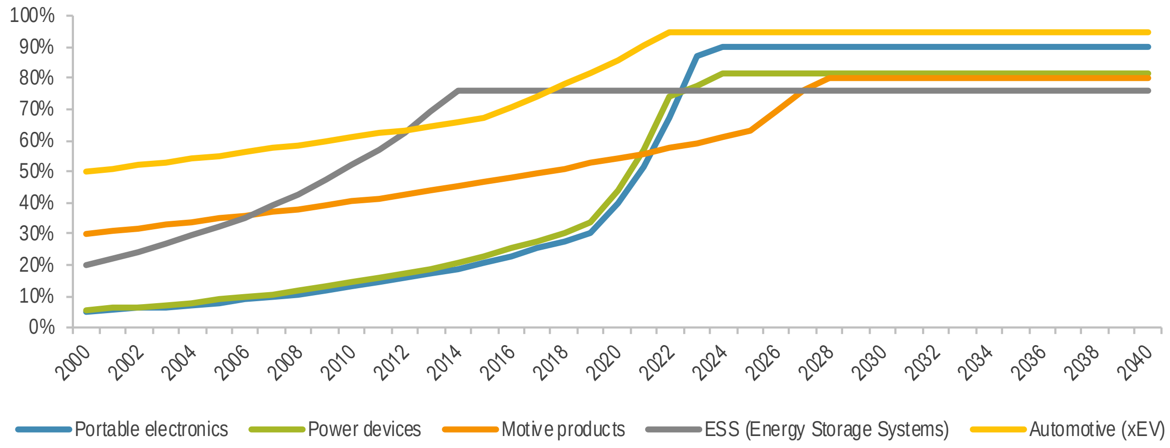
Figure 14: Service life by battery end-use application (years)



Source: Roskill, 2020.

This results in the battery capacity that will theoretically reach its EOL. However, not every single battery available for recycling will be recovered by battery collection networks. This can be attributed to some end-use applications not being disposed of correctly or are stored by the consumer for an indefinite period of time. Also, some batteries initially used in portable electronics or electric vehicles can be reused in second life applications like power banks or ESS. In this sense, Roskill applies a “Collection rate” to EOL batteries to estimates the battery capacity “available for recycling”.

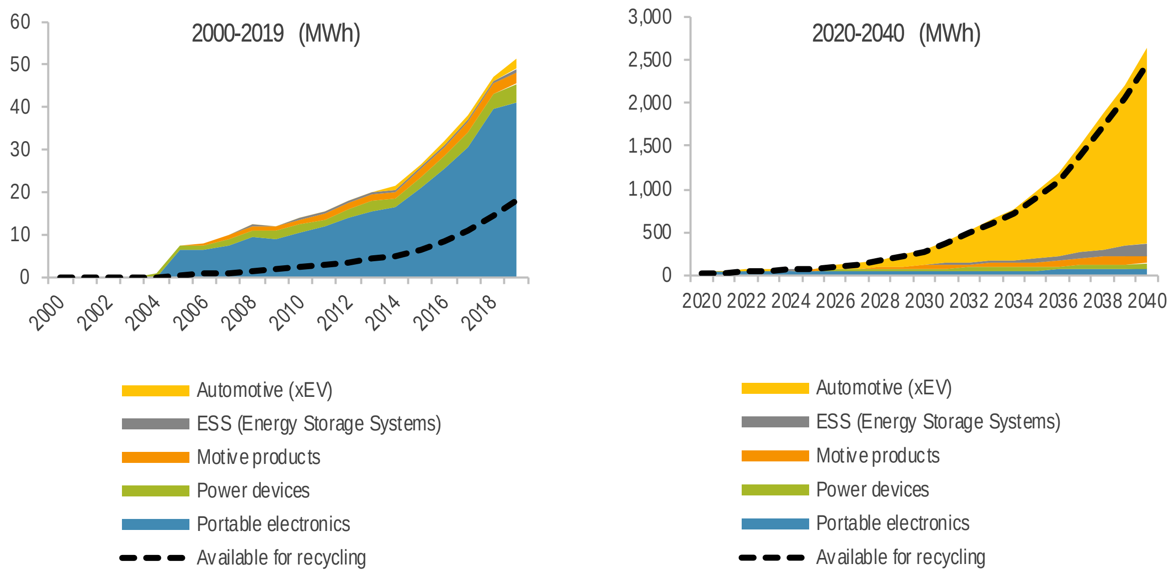
Figure 15: Collection rates by end-use applications (% of energy recovered)



Source: Roskill, 2020.

Consequently, more batteries will reach their EOL than will be physically recycled during the outlook period. However, as more EV batteries enter the automotive market during the outlook period, more batteries will be potentially "available for recycling" as regulatory forces strengthen the collection mandates by automakers or other dedicated third parties.

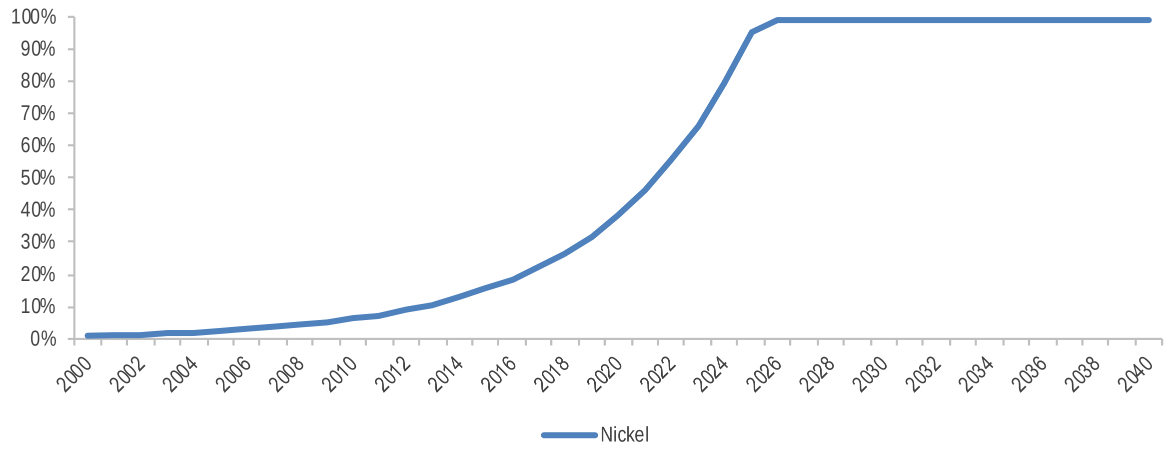
Figure 16: Potential battery capacity across "EOL" and "available for recycling" (MWh)



Source: Roskill, 2020.

Once the total battery capacity available for recycling has been obtained by cathode chemistry, we assign a "metal recovery rate" depending on the perceived market interest for each metal. As an example, in recent years, the market has placed a strong focus on cobalt recovery. This was reflected in the market price of cobalt, the impact of cobalt in the battery cost structure, and the direct market knowledge of battery processing plants in China targeting the recovery of cobalt over other battery metals like lithium or nickel. Moving forward, however, we consider the interest in nickel recovery from batteries to significantly increase. This will be a combination of future nickel prices, market supply, the impact of nickel in the battery cost structure, and environmental/circular economy perspectives.

Figure 17: Metals recovery rates in-house assumptions (% of metal content recovered per tonne)



Source: Roskill, 2020.

2.3.3.2 Stainless steel scrap

Secondary sources of nickel are a key feedstock in the production of stainless steel. Scrap also plays a key role in determining how much critical demand for Class I metal the stainless sector requires. Higher uses of scrap and/or Class II material results in a lower volume of Class I demand. There are two main sources of stainless steel scrap:

1. Internal – scrap generated within the mill during the production of stainless steel; and
2. External – scrap sourced from domestic and/or international suppliers

For historical data, the total amount of scrap used as feedstock by a mill is estimated by dividing the sum of internal/external scrap by the mill's total stainless steel production. This metric is referred to as the "scrap ratio". We calculate respective scrap ratios of stainless steel producing nations according to a variety of quantitative and qualitative factors including, but not limited to, the following:

- Published stainless steel production data by type of product (nickel containing vs non-nickel containing)
- Published scrap data
- Trade data – imported scrap by type of product (nickel containing vs non-nickel containing)
- Interviews with market participants

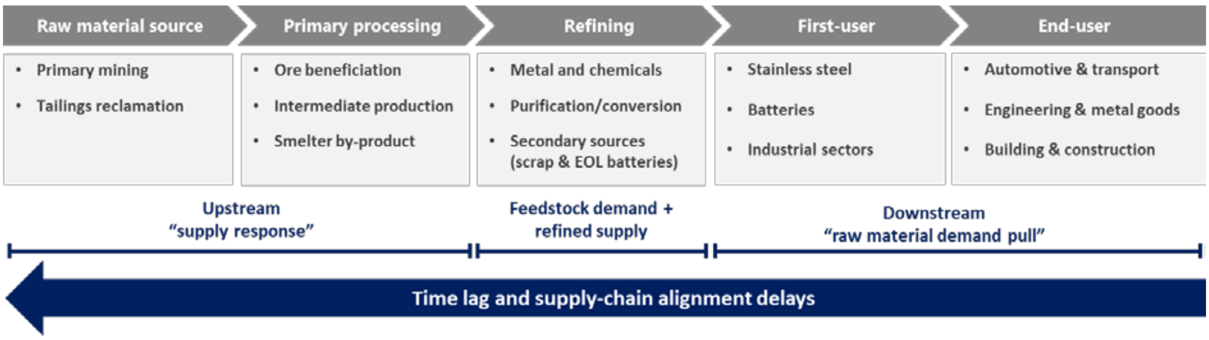
The total volume of and types of scrap used are "sense checked" and correlated against the first dot point above. Physical production of stainless steel by product type is a key determining factor of the total amount of nickel that was required within the feedstock. Hence, the type(s) and ratios of scrap utilised. It is important to note that there are variances in the use of scrap by mills regionally. An example of this would be Indonesian (which mainly uses integrated primary NPI/Class II feedstocks) versus European (which uses a higher ratio of scrap-to-primary nickel feedstock) stainless production. With the latter's higher use of scrap a function of having greater availability of domestic scrap sources from factors such as infrastructure demolition. This compares to Chinese steel mills that use a higher proportion of primary nickel feedstock owing to its lower mine-integrated costs and the country having a higher level of dwelling construction versus demolition.

We also forecast each country's use of scrap in stainless steel production. This is calculated by estimating both the internal and external scrap ratios. Internal scrap ratios of countries are held constant throughout the outlook period according to their respective historical trends. Whilst external scrap volumes are forecast using regression analysis underpinned by Roskill's in-house market expertise (qualitative factors). Such is complimented by quantitative 'sense checking' of the volume of scrap estimated by the end of the forecast period. This includes aligning with the expected macroeconomic assumptions (globally and regionally) and subsequent forecast stainless steel production (by product type) within such.

2.4 Market balances

It is important to note the inter-relation of the demand-side forecast to that for supply and the alignment (or misalignment) of such volumes. This assumes supply is in a constant state of 'responsiveness' toward demand pull dynamics at any given point in time, according to preceding market environments. Given this constant balancing act between demand and supply, Roskill considers the entire mine-to-end user supply-chain dynamics extremely salient when 'marrying' the two market components together.

Figure 18: Nickel market balance supply-chain dynamics



Source: Roskill, 2020.

Once the demand outlook is established and supply has been updated according to the most recent producer/project developer information, a preliminary market balance is formed. The preliminary balance is then assessed on its merits from both holistic and sub-sector product perspectives. We consider this a 'layered' and iterative approach to determining final market balances. Partially a function of nickel's significant market size and various product sectors underpinned by their own respective market fundamentals. The market balance is then adjusted from the supply-side considering variables such as warehouse stocks, market pricing (and price bifurcation), demand time lags and delays to supply chain alignment.

With regards to this study, a standalone EU perspective is required alongside that of the global market. We have established such by detailing the EU specific upstream (supply) and downstream (demand) market segments. This analysis was conducted on its own merits independent to that of the global market, where EU supply-chain dynamics were emphasised. This analysis underpins the evaluation of the EU's ability to sustain domestic competing demand sectors with local upstream and refined supply. Gaps that have been identified are compared to the context of the global nickel market and how international sourcing strategies may, or may not, be required in future (see Section 6.4).

3 Nickel supply: mining and recycling

Chapter Summary

Supply status quo: Refined nickel production reached 2.38Mt Ni in 2019, which represented a 9.3% y-o-y rise. This was a function of rising output in both China and Indonesia. Although, most of this growth was in the form of Class II nickel, which is not suitable for use in batteries, instead destined for the stainless steel industry. Outside of China and Indonesia, supply fell for a fourth consecutive year, as a result of closures and general supply variability. Class I nickel is >99.8% Ni and finds use in all of nickel's first use sectors and, along with intermediate and recycled sources, is also a suitable feedstock for nickel sulphate production (powder and briquettes). Nickel sulphate is used in the production of pre-cursor materials used in cathode manufacturing for Li-ion batteries.

Global supply: Nickel ore is mined from either sulphide or laterite sources. Most growth in mine supply in recent years has come from laterite ore sources, which is converted to refined products destined for consumption by the stainless steel industry. Mine production is forecast to grow by 4.7%py to 2030 reaching over 4Mt Ni, with the majority of this growth coming from Indonesia. Indonesia has nickel resources suitable for both battery-grade nickel products as well as stainless steel feeds. A large proportion of intermediate nickel supply will continue to be locked up in integrated supply chains to produce Class I nickel. However, production of battery-grade intermediates will see large growth especially from high-pressure acid leach (HPAL) projects being developed. Mixed hydroxide product (MHP) produced at these projects will be further processed to nickel sulphate in Indonesia or shipped elsewhere in Asia for the same purpose. Total intermediate nickel production is forecast to reach 1.7Mt Ni by 2030 growing at 4.4%py.

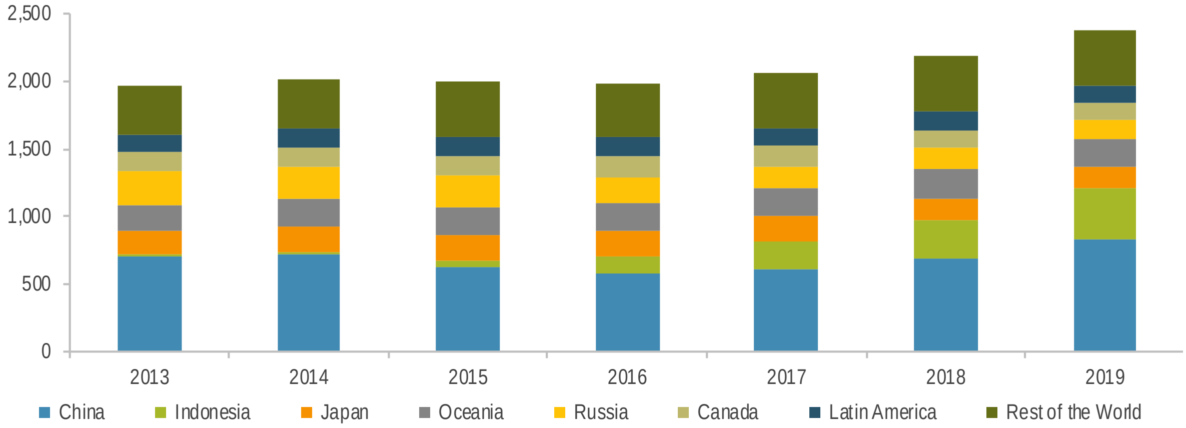
Refined nickel supply growth will come from both Class II products (not suitable for batteries) and nickel sulphate (used in battery precursor). We forecast supply growth of 1.6%py to 2030 for Class I nickel. Such limited growth largely represents a lack of investment appetite in and no recent discoveries of large sulphide deposits. This has been exacerbated by the popularity of finished nickel products produced from laterite ores, most of this occurring in South East Asia. Demand for nickel from the battery industry will be met by nickel sulphate production, which can be produced from battery-grade intermediates, Class I nickel and recycled sources. We expect total nickel sulphate production to reach approximately 2Mt Ni by 2040 growing at 13.5%py, from 159kt in 2020. During 2020-2030, the main feedstock source will be intermediates including MHP. Over 2030-2040, we expect recycled EOL batteries could overtake intermediates.

Nickel sulphate costs: Nickel sulphate production costs are mostly sensitive to the type, and subsequent cost, of the feedstock used. Class I nickel metal is a significantly higher cost feedstock than that of intermediates such as MHP, where users of Class I metal are predominantly non-integrated producers of nickel sulphate. Mine-to-refinery integration can significantly lower feedstock costs. However, the effectiveness of such is a function of the mine assets' operational economics. Other major cost drivers, such as utilities, reagents and labour, vary regionally and typically account for <20% of total production costs.

3.1 Supply status quo

Refined nickel production rose by 9.3% y-o-y in 2019 to reach 2.38Mt, a faster rate than was achieved in 2018 (5.7% growth rate). China and Indonesia were the main drivers behind the increase in refined nickel production in 2019. Where nickel pig iron (NPI) from these two countries alone accounted for approximately 40% of global production. China saw record NPI production of 590kt Ni in 2019 as domestic producers processed ore imported from Indonesia, the Philippines and New Caledonia. In January 2020, Indonesia banned exports of unprocessed ores and concentrates. As a result of the loss of raw material supply, it is likely that Chinese NPI will not reach the levels seen in 2019.

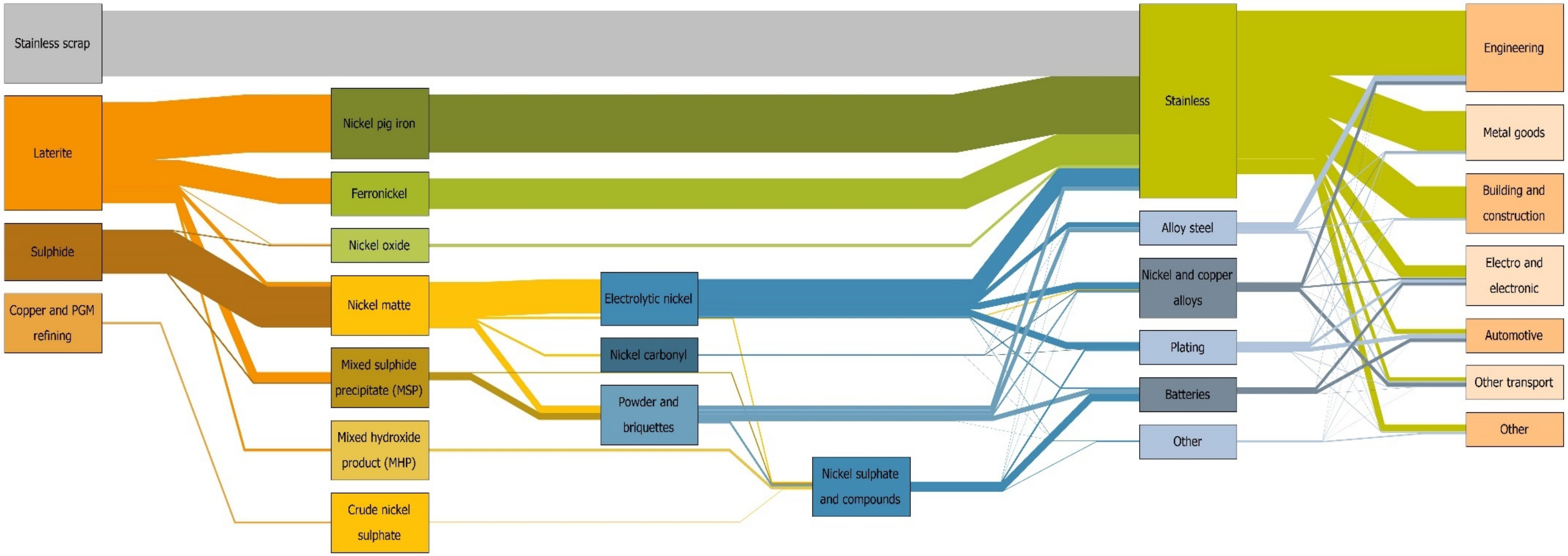
Figure 19: Refined nickel production by country, 2013-2019 (kt Ni)



Source: Roskill, 2020.

Outside of China and Indonesia, supply fell by 2.4% y-o-y in 2019 to 1.19Mt. This has become a familiar pattern for refined nickel supply outside these two countries, and the fall represented the fourth successive year that production declined. This can be explained not only by capacity closures, but also general variability of supply in these regions. Australian supply was down 6% y-o-y, explained by quadrennial maintenance at BHP Nickel West's Kwinana refinery. Other countries to record notable falls through 2019 were Brazil, Canada and New Caledonia. As a result of the disruption caused by the COVID-19 pandemic, supply outside of Indonesia is expected to fall y-o-y.

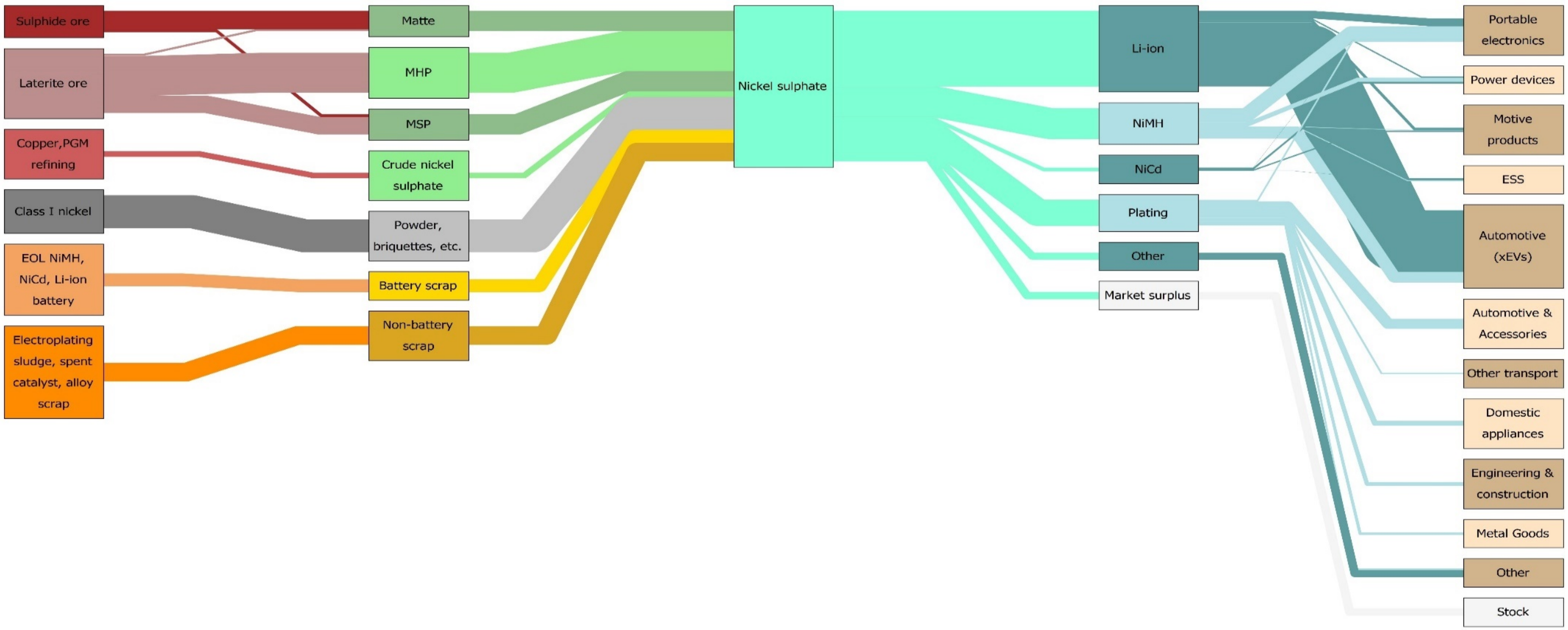
Figure 20: Nickel market flowchart, 2019



Source: Roskill, 2020.

Nickel is produced primarily from laterite and sulphide ores, although a small amount is also produced as a by-product of copper and platinum-group metals (PGM) refining. These raw materials are processed into a variety of intermediates (yellow/brown) and finished products. Low-grade products such as ferronickel, nickel pig iron (NPI) and oxide sinter (green) are used primarily in stainless steel, whereas higher-grade materials (blue) also find use in nickel's smaller applications.

Figure 21: Nickel sulphate flowchart, 2019



Source: Roskill, 2020.

Nickel sulphate is a refined chemical product produced from a variety of intermediate (green), finished nickel products (silver), as well as from secondary material (yellow), with the primary feedstock sources mainly originated from sulphide and laterite nickel ores (red) and secondary sources from end of life (EOL) batteries and plating scraps (orange). Nickel sulphate is used directly in the production of Li-ion precursors (blue) and plating (blue). It is also used to produce nickel hydroxide and other nickel compounds used in NiMH (blue) and NiCd (blue) batteries, and other applications (blue). End use of nickel sulphate is wide, with automotive and portable electronics being some of the main applications (brown).

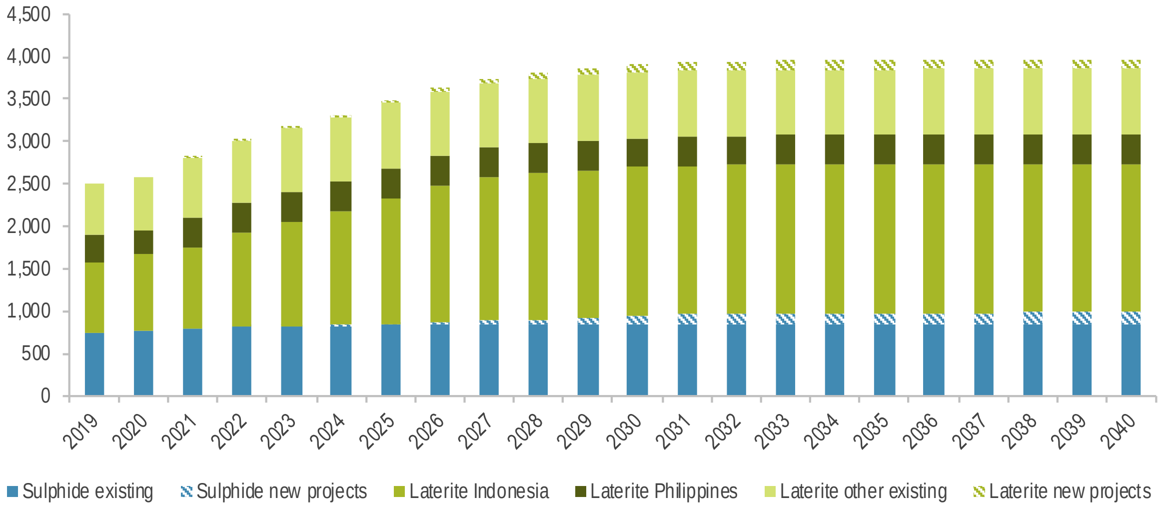
3.2 Global supply

3.2.1 Mined ore

This section provides a combined overview of the outlook for *mine* production of nickel through to 2040. Figure 22 shows a breakdown of forecast production by source of production. As indicated in the figure, there has been little growth in mine supply from sulphide deposits. Where little further growth is expected over the outlook period resulting from few new large-scale deposits having been discovered in recent years.

Within laterite mining, two distinct types of ore are mined, which are a function of the weathering profile in these sub-tropical to tropical regions. The first portion is a limonite cap (low Ni, Mg and Fe), which overlies a saprolite sequence (high Ni, Mg and Fe). These two types of laterite ore are often mined together despite being used in the production of different refined nickel products. Limonite is typically more suited to high-pressure acid leach processing to produce battery-grade nickel intermediates, where the lower Mg content reacts less with the concentrated sulphuric acid in the autoclave during leaching. Conversely, saprolite is almost exclusively used in the production of ferronickel and specifically, nickel pig iron (NPI) for use in stainless steel. Because of this association between mining of these laterite ore types, and difficulty in separating out the two, in this part of the study, Roskill has combined ore supply destined for Class I, II and battery-grade intermediate production.

Figure 22: Outlook for expected mine production by type[1], 2020-2040 (kt Ni)



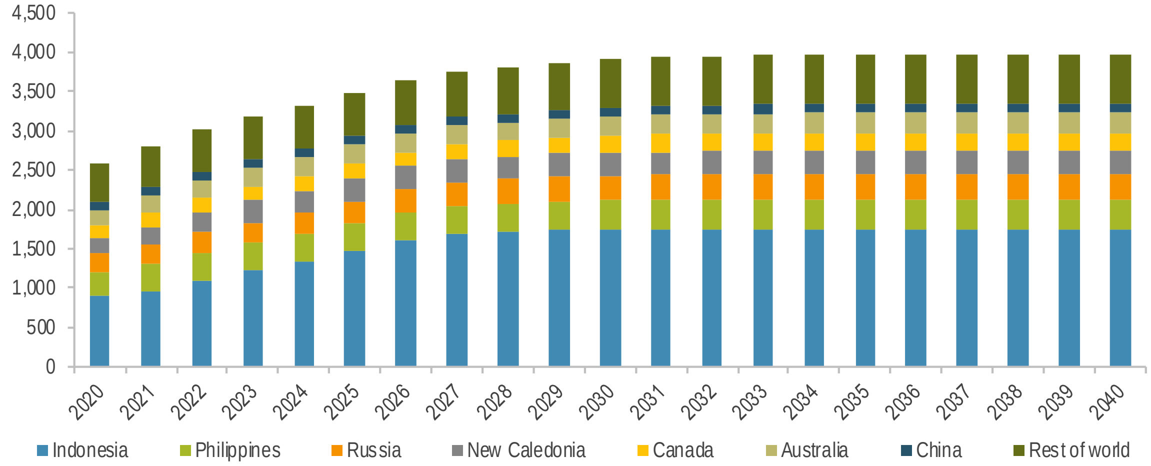
Source: Roskill, 2020.

([1]) Due to the fragmented small-scale mining of laterite ore in Indonesia, rising production has been accounted for by existing operations

We expect mine supply to rise at a CAGR of 4.7% between 2020 and 2030, with the majority of this growth to come from Indonesia to feed both NPI destined for the stainless steel industry and also battery-grade nickel intermediates suitable for processing to produce nickel sulphate. Indonesia is likely to see a growth rate of 6.7%py to 2030. Elsewhere, production in the Philippines is volatile, but assumed to be stable with a couple of projects expected to come online over the outlook period. Most laterite ore mined in the Philippines is exported to China for NPI production, but limonite is hydro-metallurgically processed in the country by Sumitomo Metal Mining (SMM) to produce mixed sulphide precipitate (MSP) for integrated nickel sulphate production in Japan. Some limited expansion is expected from other producers of laterite, from expansions by operations such as Ramu in PNG to produce mixed hydroxide product (MHP) and Gördes (MHP) in Turkey. Total expected mine production is estimated to increase to 4Mt Ni by 2030.

Figure 23 again shows the expected growth of mine production over the outlook period, this time on a country basis. By 2030, Indonesia will account for around 45% of global mine supply, feeding its domestic NPI and ferronickel smelters as well as battery-grade intermediate nickel plants.

Figure 23: Outlook for expected mine supply by country, 2020-2040 (kt Ni)



Source: Roskill, 2020.

It should be noted that the outlook presented in Figure 22 and Figure 23 represents the expected baseline forecast only and should be taken as indicative. In terms of production cost, the majority of cost is concentrated in the production of intermediate products, or in the case of Class II nickel, in the smelting of ores to produce NPI or ferronickel. Particularly in the case of laterite ore production in Indonesia, therefore, mine production is expected to be flexible and to be driven more by the development of downstream processing plants (both hydrometallurgical and pyrometallurgical), than by the availability of nickel deposits.

Mine production is generally in excess of refined production, owing to process losses. As such, the higher level of mine production than of forecast refined production does not necessarily indicate a large surplus or ore production. However, Roskill expects that the bottleneck in the production of nickel will be the production of intermediate and refined material, rather than mine production.

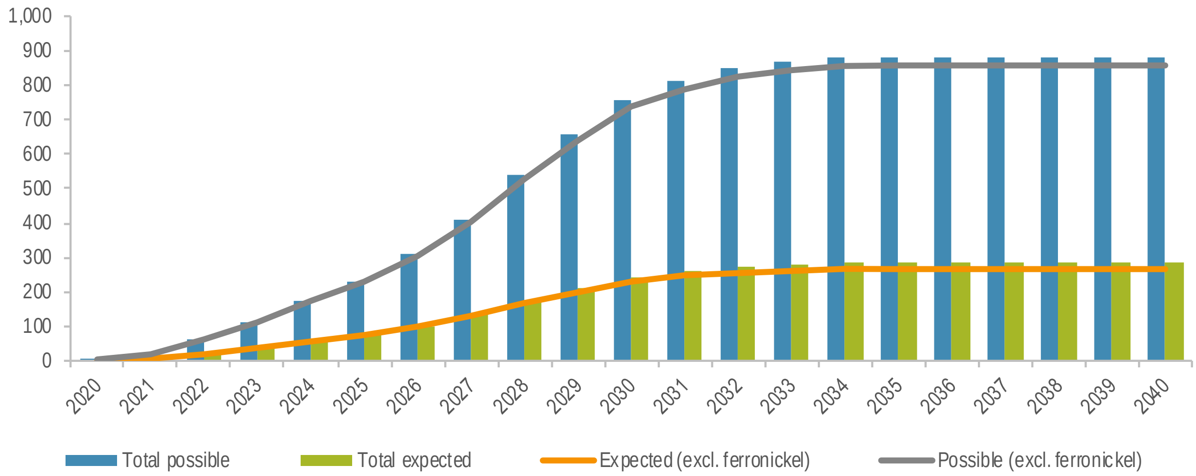
3.2.1.1 New mine supply

Over the outlook period, we expect that the most significant increase in mine capacity will take place in Indonesia, as previously discussed. However, a substantial amount of greenfield and brownfield nickel projects remain under development (at various stages) elsewhere. A number of these greenfield and brownfield projects are located in Australia, so that by 2030 Australia is expected to account for a little over a quarter of new mined supply coming online. Brazil and Canada are host to several projects at various stages of development and are each expected to represent 15% of new supply coming online by 2030.

Figure 24 provides an illustration of the expected contribution to mine supply by such new projects. It also shows slightly lower figures for expected mine production, once those projects that are targeting ferronickel and NPI are excluded. This analysis is of particular relevance to the outlook for Class I nickel and salts, and the market balance for such material. Horizonte Minerals' Araguaia project is targeting class II stainless feed. Once this project is excluded, possible new mine production is forecast at 736kt Ni by 2030 and 857kt Ni by 2040.

Expected mine supply appears to be considerably lower than expected production of intermediate and refined nickel. This is because rising mine output from Indonesia is not considered greenfield production, rather brownfield expansions of existing capacity by existing producers. Due to the nature of nickel laterite mining in Indonesia, pinpointing where mining is taking place is challenging. It is important to note that the development of intermediate and refined projects in Indonesia is a function of the availability of ore.

Figure 24: Expected supply from new mining projects, outside of Indonesia, 2020-2040 (kt Ni)

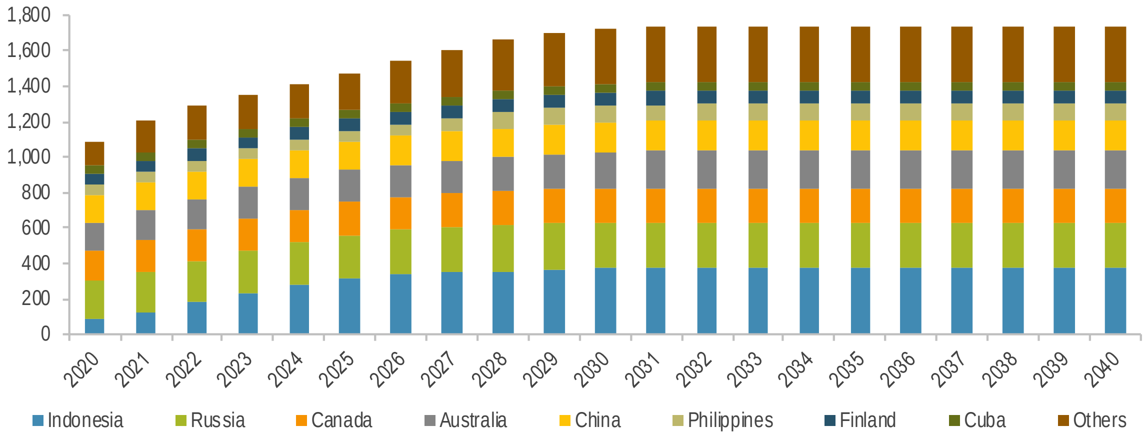


Source: Roskill, 2020

3.2.2 Intermediates

Figure 25 shows the outlook for expected intermediate production by country. Nickel intermediates are expected to total 1.7Mt nickel by 2040 rising at 2.2%py from 1.1Mt in 2020. Indonesian output is expected to account for the majority of this growth, rising by 7.5%py over the outlook period as a number of battery-grade HPAL plants producing MHP are forecast to be brought online. In achieving this growth rate, by 2023, Indonesia would overtake Russia as the world's largest producer of intermediates. Russian nickel matte output will rise over the outlook period as Nornickel boosts capacity at its integrated operations. Output from Canada, Australia and China are expected to remain relatively flat in comparison.

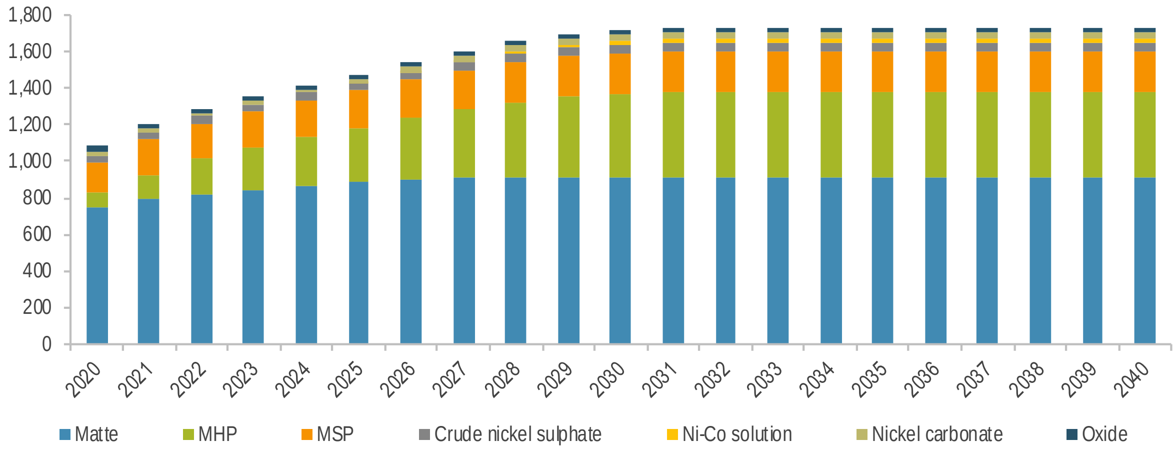
Figure 25: Total intermediate production by country, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Over the outlook period to 2040, we forecast production of intermediates to increase owing to output of new hydrometallurgical intermediates from Indonesia, as well as potential production from other greenfield projects in Australia, Brazil, and elsewhere, some of which are targeting direct-from-concentrate production of nickel sulphate.

Figure 26: Total intermediate production by product, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Figure 26 shows intermediate production over the outlook period on a product basis. Matte output expected to rise to 2028 as a result of rising output from Nornickel in Russia as well as increased capacity at PT Vale Indonesia's Sorowako operation. New matte is also expected to come from two projects at Weda Bay in Indonesia, Chengtun, Tsingshan and Huayou's subsidiary *PT Youshan Nickel Indonesia* and *PT Huake Nickel* (70% owned by Huayou).

3.2.2.1 Developments in Indonesia

We believe that Indonesia's large nickel reserves will be an increasingly important source of nickel for the battery industry. This is thanks to the availability of nickel ores and the government's eagerness to attract further processing in the country (following the re-implementation of the ban on unprocessed ores from January 2020). Producing battery-precursor material from lateritic ores will require hydrometallurgical processing, versus the pyrometallurgical route used for NPI. This could be achieved either through an atmospheric leaching process or, more likely, through a high-pressure acid leach (HPAL) process to produce an MHP or MSP suitable as feedstock for nickel sulphate production.

Such HPAL plants already operate in the Philippines (Coral Bay and Taganito) and in Papua New Guinea (Ramu). At the time of writing, there are several battery-grade intermediate HPAL plants in construction/planned in Indonesia, refer to Annexes for details.

Table 5: Indonesia: Details of intermediate and nickel sulphate projects

Producer	Name	Status	Products	Capacity (ktpy Ni)
PT Youshan Nickel Indonesia	Weda Bay	Construction	Matte	34.0
PT Huake Nickel	Weda Bay	Financing	Matte	45.0
PT QMB New Energy Materials	Morowali #1	Construction	MHP	50.0
PT QMB New Energy Materials	Morowali #1	Construction	NiSO4	33.0
PT Huaqi	Morowali #2	DFS underway	MHP	60.0
PT Halmahera Persada Lygend	Obi Island	Construction	MHP	37.0
PT Halmahera Persada Lygend	Obi Island	DFS underway	MHP	18.5
PT Halmahera Persada Lygend	Obi Island	Construction	NiSO4	35.0
Jinchuan WP	Obi Island	Pending FID	MHP	20.0
Jinchuan WP	Obi Island	Pending FID	NiSO4	20.0
Solway	Solway	Construction	MHP	30.0
Sumitomo Metal Mining / PT Vale	Pomalaa	Pending FID	MHP	41.7
Total			**Various**	**424.2**

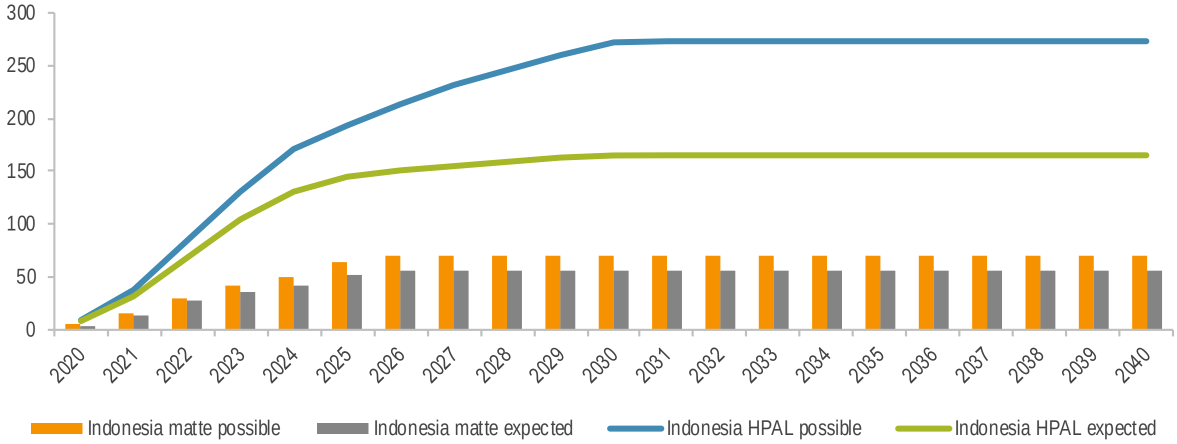
Source: Roskill and company filings, 2020.

There are a number of projects at various stages of development, targeting intermediate material destined for use in nickel sulphate production for the lithium-ion battery industry. Several of these are under construction, including the PT QMB New Energy Materials (GEM/Tsingshan) in Morowali and PT Halmahera Persada Lygend (Harita/Ningbo Lygend) on Obi Island. In March 2020, the Huayue JV (Huayou/CMOC/Tsingshan) began construction of the 60ktpy nickel-in-MHP project in Morowali. Nickel matte production is targeted at the PT Youshan Nickel Indonesia project, which forms part of the IWIP site at Weda Bay.

Figure 27 shows the possible amount of output that these various projects could contribute to production and the amount anticipated in Roskill's baseline case (accounting for delays and respective risks). This figure only includes production from projects that had been announced in Q3 2020. Therefore, actual production in future may be higher if further projects get developed, which Roskill considers a likely scenario.

Roskill believes that most MHP and nickel matte from these Indonesian projects will be exported for processing in China, Japan, or elsewhere in Asia. It is possible that a number of these projects will be integrated to produce nickel sulphate within Indonesia, as has been announced for the PT QMB New Energy Materials (GEM/Tsingshan) project in Morowali and the PT Halmahera Persada Lygend (Harita/Ningbo Lygend) JV on Obi Island.

Figure 27: Indonesia: Forecast production of hydrometallurgical intermediates and nickel matte, 2020-2040 (kt Ni)



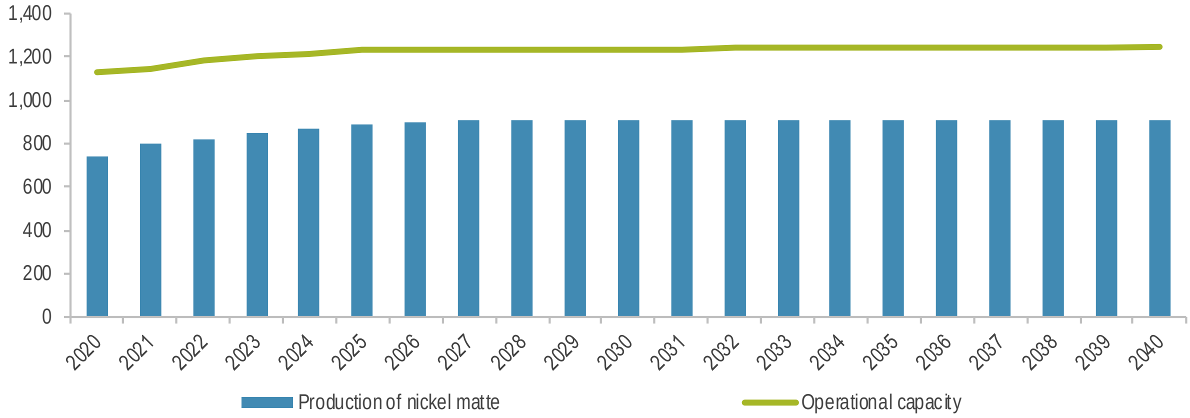
Source: Roskill, 2020.

3.2.2.2 New intermediate supply

Several projects listed in section 3.2.1 are targeting production of intermediate nickel products, mostly focusing on MHP and MSP, but also nickel matte. In total, these projects and restarts could contribute an additional 654kt Ni in intermediate production, compared to 2019. This compares to Roskill's baseline expectations of increases in supply at 481kt Ni, owing to likely project delays, particularly among some of the more capital-intensive projects.

Other projects are intending to produce concentrates only or have not yet announced their intended product. However, many of these mines may seek to process their ores and concentrates on a tolling basis, or through an offtake agreement with existing nickel smelters and refineries. Figure 28 shows the expected gap between production capacity and actual output from existing smelters, with the gap between the two implying that substantial surplus capacity remains that would allow for such processing of additional, external material without the need for major new production capacity. This extra matte production would be available for processing to produce nickel sulphate for the battery industry.

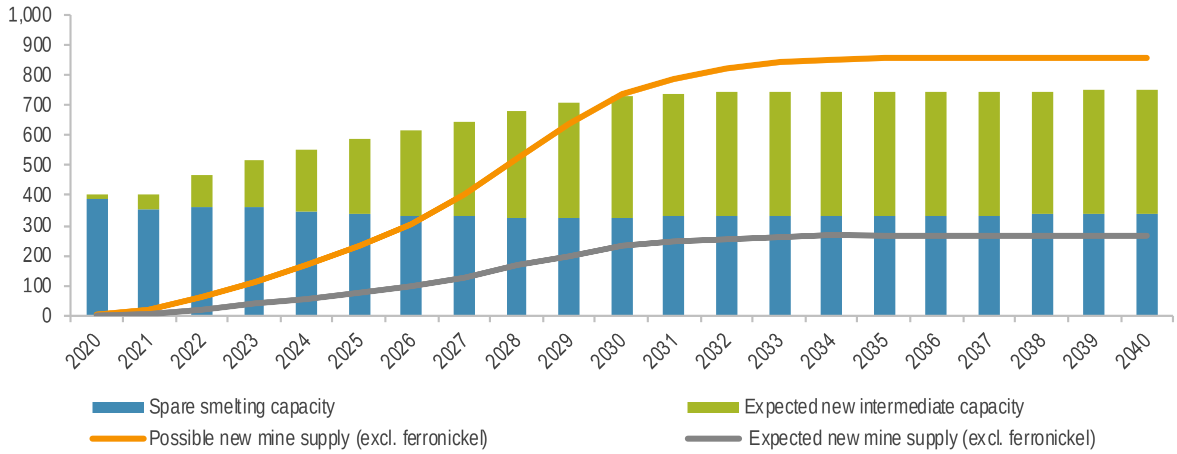
Figure 28: Capacity and production of nickel matte, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Figure 29 shows the total possible and expected increase in new mine production and compares this to both the spare smelting capacity for nickel matte, and the expected new intermediate capacity added by new projects. Mine supply that is destined for ferronickel and NPI production (Class II) has been excluded as this does not go through an intermediate stage. The figure highlights that Roskill forecast sufficient new and existing intermediate capacity to process the expected increase in mine supply, with some surplus capacity to absorb any higher-than-expected increases in mine production.

Figure 29: Comparison of spare intermediate processing capacity and new mine production, 2020-2040 (kt Ni)



Source: Roskill, 2020.

([1]) Forecast production by project displayed on a possible basis

([2]) Dumont, Sunrise and NiWest projects are targeting direct concentrate-to-sulphate routes, without an intermediate product. These projects have been included here nonetheless, as their production contributes in the same manner to the increased availability of feedstock for Class I nickel and salts. The Ni-Co solution that these projects would produce from the concentrate might also be considered an intermediate.

([3]) Forecast production from existing Ramu capacity excluded from total

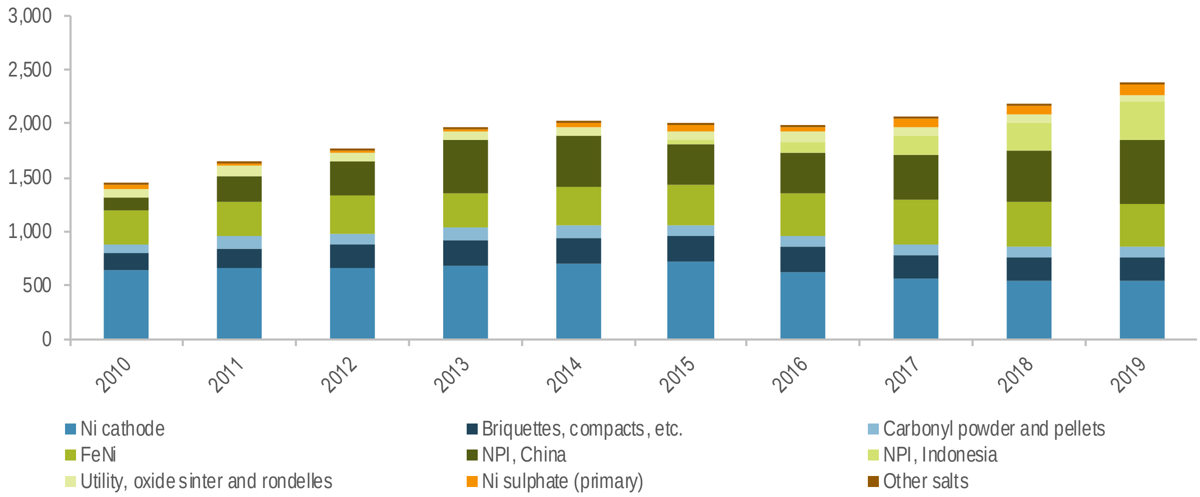
([4]) BRA = Brazil, TUR = Turkey, PNG = Papua New Guniea, AUS = Australia, CAN = Canada, IND = Indonesia, PHI = Phillipines, USA = United States of America, VIE = Vietnam. Forecast production from existing Ramu capacity excluded from total

3.2.3 Refined

Over time, the types of refined nickel being produced have changed not only to meet demand, but also due to the types of ore bodies being exploited. Electrolytic, high-purity nickel metal (a type of Class I metal) has long been the most common nickel product, as it has wide-raging applications. In 2012, electrolytic nickel cathode accounted for 38% of total nickel production including Class II, but this fell to 23% by 2019, owing to the rapid rise in NPI production.

Refined nickel supply outside of Indonesia and China has struggled, especially Class I metal, which has seen yearly declines since 2015 (Figure 30). Such decreases in output are not only explained by capacity closures but can be attributed to general variability of supply and to short-term production outages. In general, there have been no major sulphide discoveries in recent years with existing reserves declining following little investment into reserve build out. The success of Class II stainless steel feedstocks from abundant laterite ore resources, associated with low-cost mining, largely explains this.

Figure 30: Primary refined nickel supply[123], 2010-2019 (kt Ni)



Source: Roskill, 2020.

([1]) Blue shades denote Class I metal, whereas green shades denote Class II stainless feed products

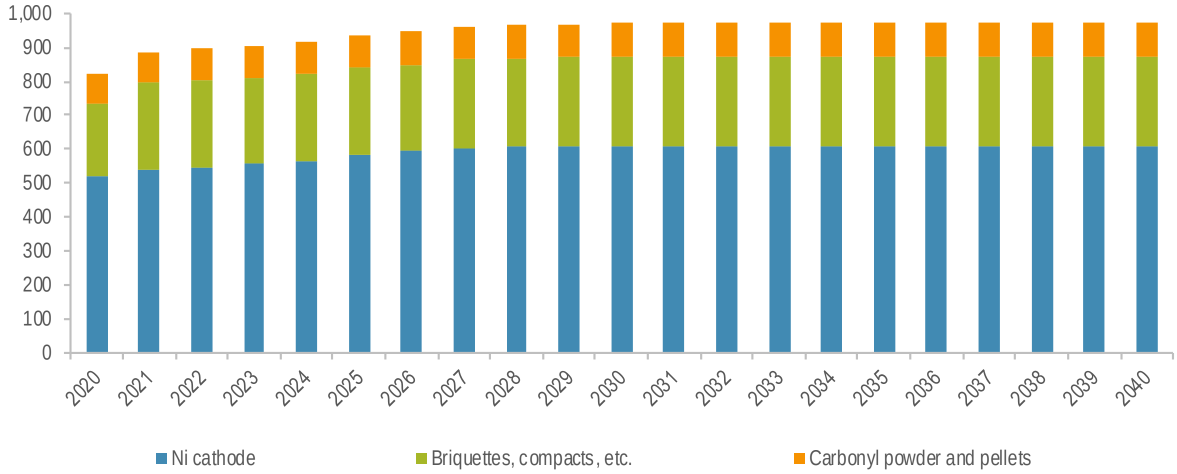
([2]) Primary nickel sulphate is the production of sulphate from *intermediates* (first product output). This is also included as a refined product, despite it having a nickel content of 22.3% Ni. This classification of nickel sulphate does not include additional production from Class I metal or recycled feedstocks. The inclusion of material from nickel metal would lead to double-counting, and recycling/secondary supply is not included in this analysis of the production of primary supplies of nickel. Class II nickel production including ferronickel and nickel pig iron (NPI), used as stainless steel feeds, are also excluded from the study, as they do not find use in the battery supply chain.

([3]) "Refined" nickel production here is used to refer to production of any finished nickel products, suitable for use in first-use applications. This is consistent with the definition maintained by the International Nickel Study Group, but is technically a slight misnomer, as products such as NPI and ferronickel (and nickel oxide) are produced in smelters that are not considered to be "refineries" and produce a product with significant impurities.

3.2.3.1 Class I metal

Class I metal in this study relates to production of nickel metal products containing a minimum of 99.8% Ni and priced using the LME reference standard. Class I products include, but are not limited to, electrolytic cathode, briquettes and powder, and carbonyl powder & pellets. When compared to full suite of nickel products over the forecast horizon, the forecast for Class I metal is likely to experience the lowest production growth rate.

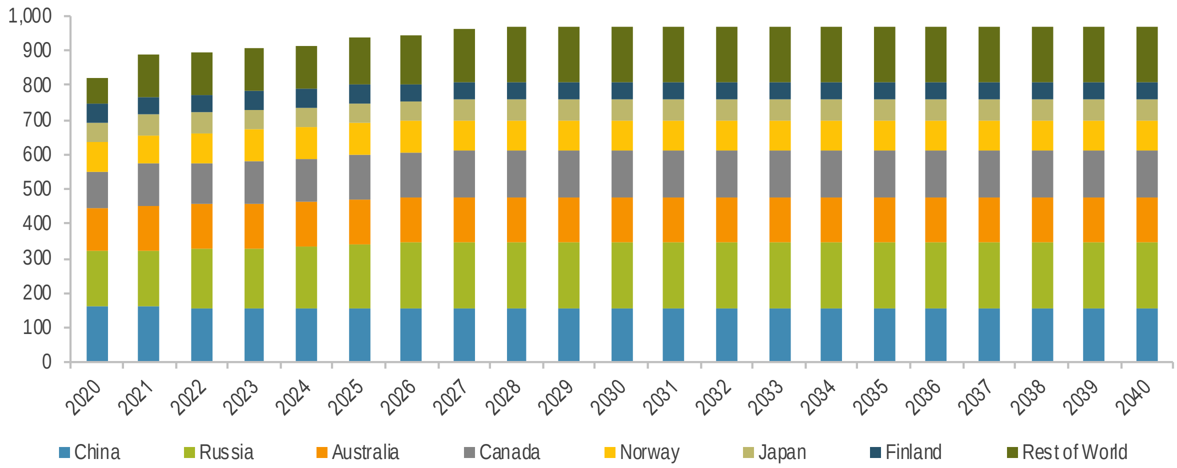
Figure 31: Class I metal supply, by type 2020-2040 (kt Ni)



Source: Roskill, 2020.

Roskill forecast Class I nickel production to total 0.82Mt Ni in 2020, down by 4% y-o-y from 0.86Mt in 2019. This is a direct result of COVID-19 disruptions to operations worldwide. The Ambatovy operation in Madagascar, which produces nickel briquettes, was suspended in late March 2020 due to a national lockdown and has remained on care and maintenance into September. This resulted in the loss of an estimated 23kt Ni-in-Class I metal.

Figure 32: Class I metal supply, by country 2020-2040 (kt Ni)



Source: Roskill, 2020.

Over the outlook period, Class I supply is forecast to grow by 0.8% compound annual growth rate (CAGR), whereas between 2020 and 2030 supply is forecast to grow by 1.6% CAGR (Figure 31). This growth is in part a reflection of an expected recovery in Class I supply in 2021 following the downturn in 2020. In addition, there are several capacity expansions at Class I refining operations globally.

Firstly, Russian nickel producer Nornickel aims to boost capacity at its Monchegorsk cathode refining operation. It is currently upgrading the second tank house at the Monchegorsk refinery, which should boost the plant's capacity from 120ktpy Ni to 145ktpy Ni. The work involves the introduction of chlorine leach technology that will help achieve the highest purity metal. As a result, Russia displays the largest rise in forecast Class I nickel supply between 2020 and 2030 of 2%py.

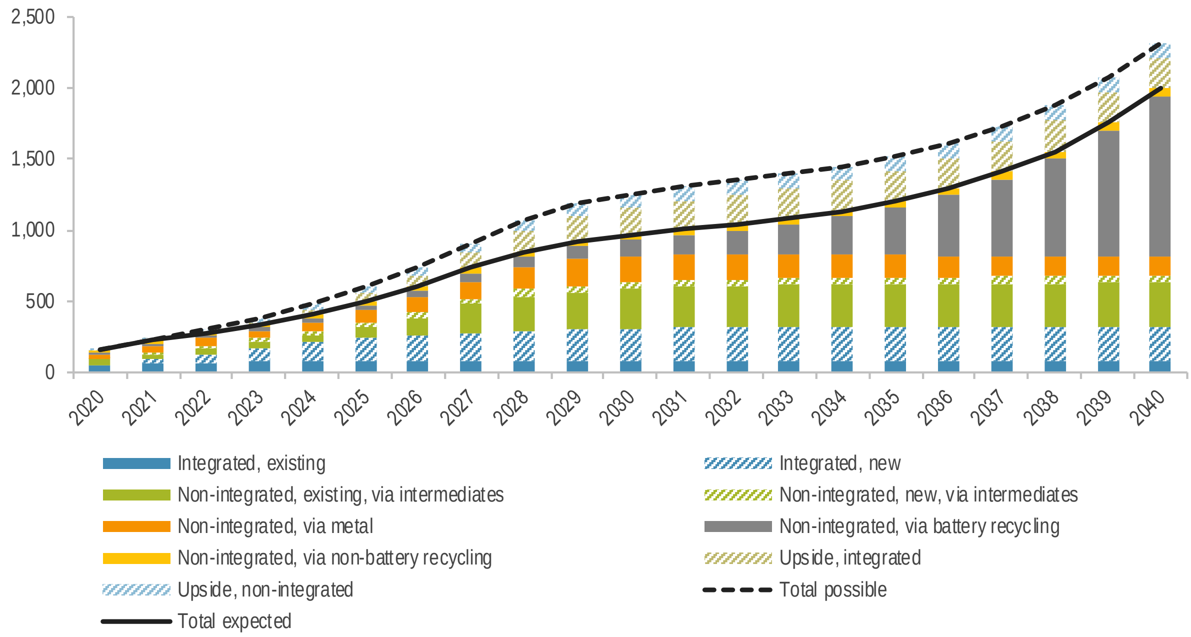
Cathode supply is also expected to increase from 2023 in Norway when new volumes of feedstock are realised from Glencore's Raglan Phase II and Onaping Depth mining operations. BHP Nickel West experienced a large drop in powder and briquette output in 2019 of 11% y-o-y to 66kt Ni, which was the result of major quadrennial maintenance activities at the refinery and Kalgoorlie smelter. With the battery sector offering high growth potential, BHP Billiton have opted to switch production toward nickel sulphate using its own nickel powder as feedstock. The company targets a nameplate capacity of 100ktpy of nickel sulphate (22kt Ni) from H1 2020, with the potential for a second phase expansion that would double production. If realised, the facility would consume 44kt of nickel powder. Roskill understands commissioning of the project has been delayed to H1 2021.

Despite these additions to supply, the global narrative for Class I metal remains of small growth over the outlook period. This reflects similarly low growth rates in demand from key Class I consuming first-use applications, including non-ferrous alloys, other alloys steels and castings as well as plating. As well as additional Class I supply, availability to meet demand from the battery industry will also potentially require substitution from the stainless steel industry (discussed further in Section 5.1.2).

3.2.4 Nickel sulphate

Under the baseline scenario, we expect total nickel sulphate production to reach approximately 2,000kt Ni by 2040 growing at 13.5%py, from 159kt in 2020. Figure 33 provides a combined overview of the production of nickel sulphate by type of production on both *expected* and *possible* basis. The figure also highlights the possible upside from *integrated* and *non-integrated* projects.

Figure 33: Outlook for nickel sulphate production, by type 2020-2040 (kt Ni)



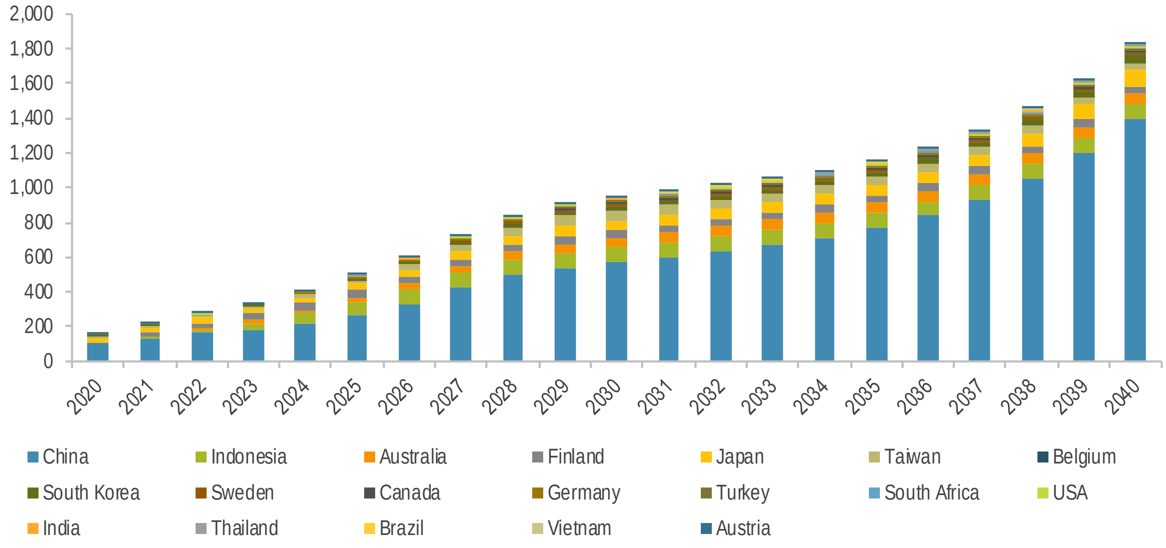
Source: Roskill, 2020.

Production from integrated producers is expected show the largest rise in output growing at 9.4%py to reach over 319kt by 2040, an increase from around 50kt in 2020. Output by 2030 is expected to reach 310kt, growing at 19.3%py. We expect to see significant growth in output, particularly in the next couple of years, as new projects are brought online, and existing producers ramp up production. In addition to the baseline scenario, more expansion plans could be likely announced over the forecast period. With some projects initially targeting intermediate products being likely to cast their focus toward integrating to sulphate production. This is particularly likely for projects in Indonesia, which may add more production in the near term. However, growth from integrated producers is expected to slow down towards the second half of the decade.

Production from non-integrated producers is expected to grow strongly at 14.8%py to 2040. We consider non-integrated producers to account for over half of total nickel sulphate output by 2030. Production from such refineries could potentially total 1,680kt by 2040, an increase from 106kt in 2020. Where the majority of growth is expected to come from intermediate and recycled battery material feedstocks. Production based on conversion of Class I nickel is likely to be constrained by expected tightness in supply of such material as the outlook period develops. However, more material may be possible should one or some of the below changes take place (albeit deemed unlikely by Roskill's baseline forecast):

- The stainless steel industry might be able to substitute more Class I with Class II (lower than 7% in the long term)
- More hidden metal stocks are released to the market
- New Class I nickel production capacity is built out
- Applications critically relying on Class I nickel, such as non-ferrous alloys, becoming able to substitute Class I nickel with other materials

Figure 34: Outlook for nickel sulphate production, by country 2020-2040 (kt Ni)

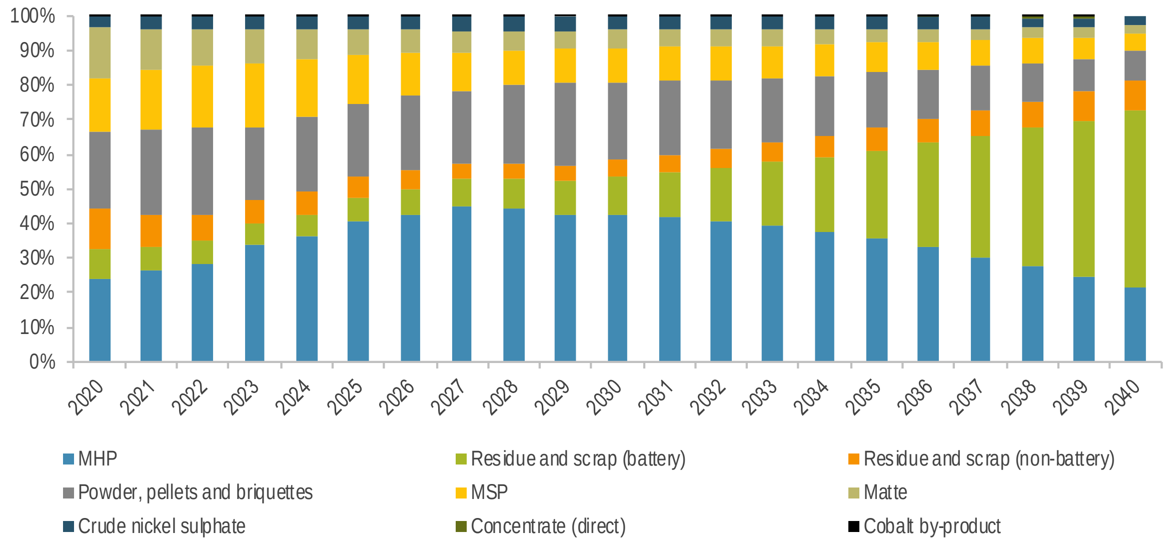


Source: Roskill, 2020.

Figure 34 and Figure 35 summarise the production outlook by country and feedstock type. We expect China to remain the largest producer of nickel sulphate throughout the outlook horizon. This is owing to expansions from existing producers as well as new projects, with the expected growth mainly coming from non-integrated producers. Indonesia, Finland and Australia are likely to overtake Japan and Taiwan in the near-term to become the next largest producers. However, Japan could return to being the second largest nickel sulphate producer by 2040 as a result of recycled feedstock availability by such time.

Feedstock wise, the share of nickel sulphate production from MHP is expected to increase considerably, from 24% in 2020 to over 42% in 2030. This is the expected result of the commissioning of new integrated projects as well as expansions from non-integrated producers in the next decade. However, post-2030 forecast this share to decline to 21% by 2040 as battery recycling feedstock availability begins to reach critical mass. By such time, nickel sulphate produced from battery scrap could account for exactly half of the nickel sulphate market. This is also partly due to the drop off in supply of forecast intermediate and Class I in the latter half of the forecast period. Overall, the share of production from other types of primary sources including nickel metal, MSP and matte is expected to decline as the outlook period develops, largely constrained by limited growth in supply of such materials.

Figure 35: Outlook for nickel sulphate production by feedstock, 2020-2040 (%)

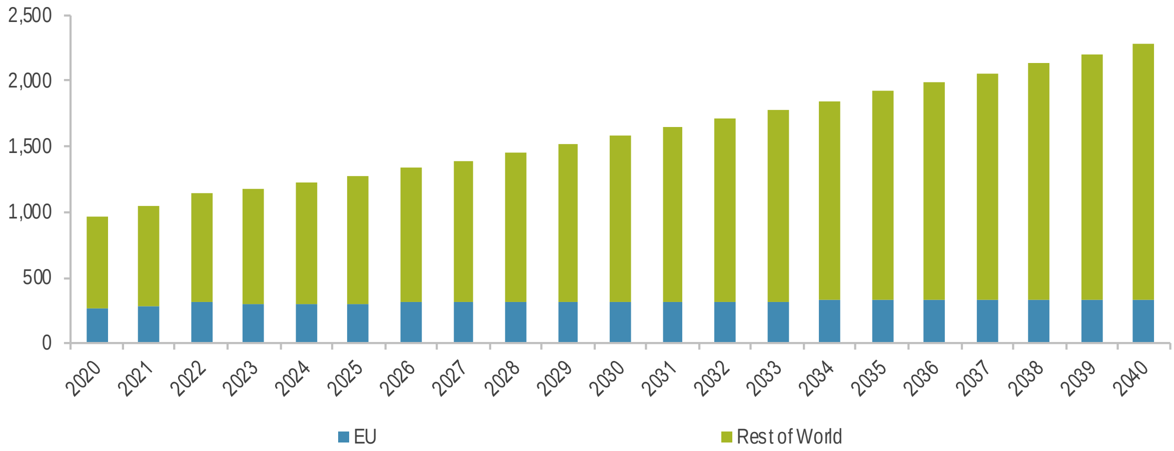


Source: Roskill, 2020.

3.2.5 Secondary (stainless steel scrap)

Between 2020 and 2040 forecast nickel in stainless steel scrap to increase by 5% CAGR. Representing an increase from 701kt Ni in 2020 to around 1,950kt Ni in 2040. There is a clear relationship between the use of stainless scrap (and Class II products), and Class I metal required in stainless steel production. If more stainless steel scrap/Class II is used by the mill, a lower quantity of Class I metal will be required. Although secondary supply of nickel from stainless steel recycling provides significant quantities of nickel for re-use, these units are locked into the stainless steel circular economy. Nickel units contained in stainless steel scrap are therefore unavailable or attainable for any future use other than stainless steel production. Nevertheless, the use of scrap by mills is of key importance for nickel availability by other primary nickel-consuming sectors. This comes as any increase in remelt scrap use by stainless steel mills will lower their requirements for primary material, thus making more primary units available to other first-use sectors. Such dynamics render mills the “swing” players in determining future availability of Class I units. This is discussed further in Section 5.1.2.

Figure 36: Nickel contained in stainless steel scrap, by region 2020-2040 (kt Ni)



Source: Roskill, 2020.

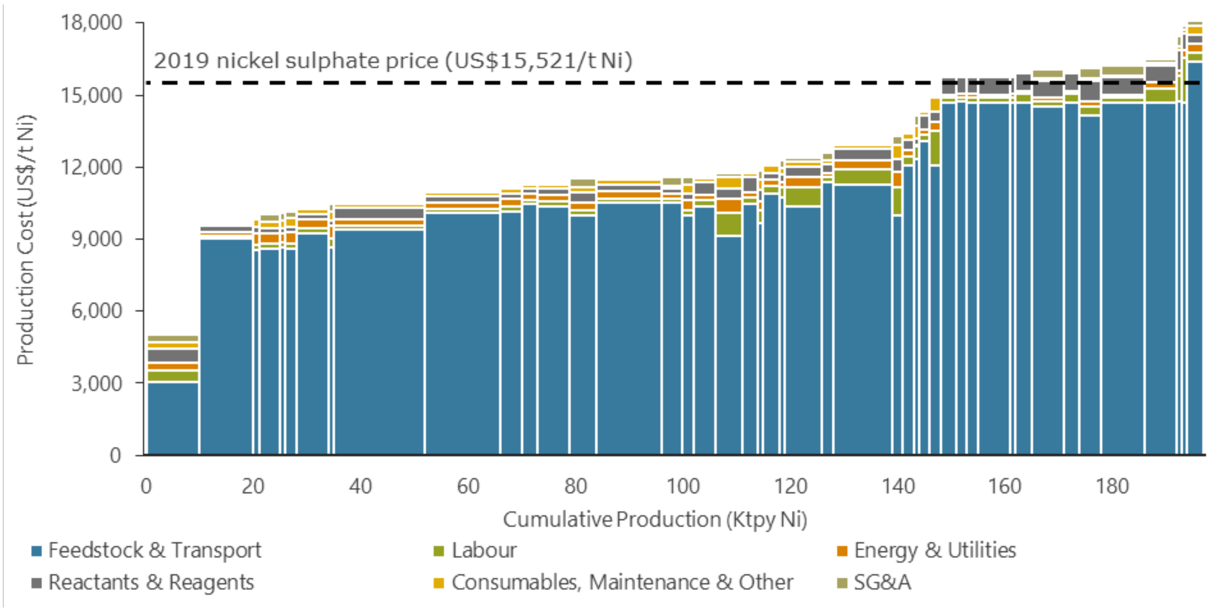
Many stainless steel producers obtain most of their nickel units from stainless steel scrap rather than from primary sources. Scrap availability can be affected by swings in the nickel price, however. For example, a period of low nickel prices acts as a disincentive for scrap collectors and processors to gather, sort and sell stainless steel scrap, which in turn forces mills to obtain a greater quantity of their nickel units from primary sources, such as ferronickel.

Taken as a whole, the EU-27 is usually a net importer of stainless steel (when stripping out intra-EU trade flows). Stainless steel producers such as Finland, Germany, Italy, Spain and Sweden are net importers of scrap, although Belgium's net trade position is likely skewed by the fact that the country is a trading hub through which this material transits before being exported to other countries. The Netherlands is a significant net importer of material (from outside the EU). Most of this material is subsequently re-exported to other stainless steel producing countries in the EU.

3.3 Nickel sulphate production cost drivers

Figure 37 shows a cost curve for nickel sulphate producers, breaking out the feedstock and the processing cost components. Also shown is the average nickel sulphate refined nickel price of US$15,521/t, which when plotted shows the marginal nature of the upper quartile of the cost curve in 2020. As shown by Figure 38, this region is dominated plants reprocessing refined nickel products into nickel sulphate.

Figure 37: Cost curve for nickel sulphate producers by cost item, 2020 (US$/t nickel contained)[1]

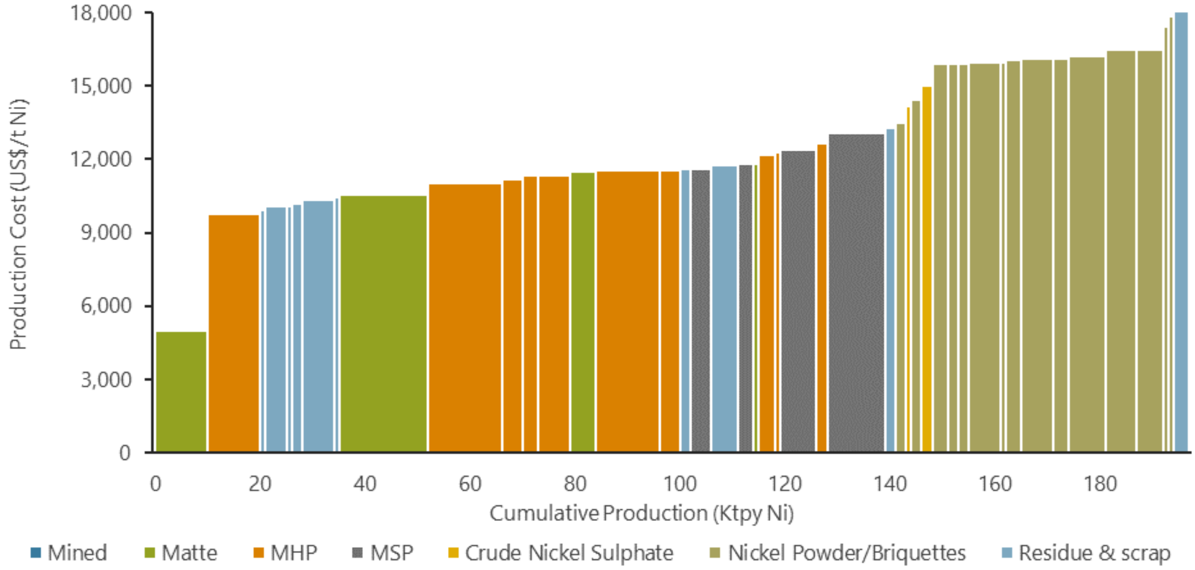


Source: Roskill, 2020.

([1]) The 2020 cost curve here is based on input costs in 2019$ dollar terms and 2019 average metal prices assumptions for nickel (US$13,932), cobalt (US$32,278/t) and copper (US$5,999/t)

The cost curve highlights the broad spread of production costs associated with the production of nickel sulphate. In general, the bottom quartiles of the cost curve are dominated by integrated producers which benefit from internal sources of feedstock. Most notably here, Nornickel benefits from its Russian feedstock supply, while Sumitomo's cost position is aided by its MSP feed from Coral Bay in the Philippines.

Figure 38: Cost curve for nickel sulphate by feedstock type, 2020 (US$/t nickel contained)[1]

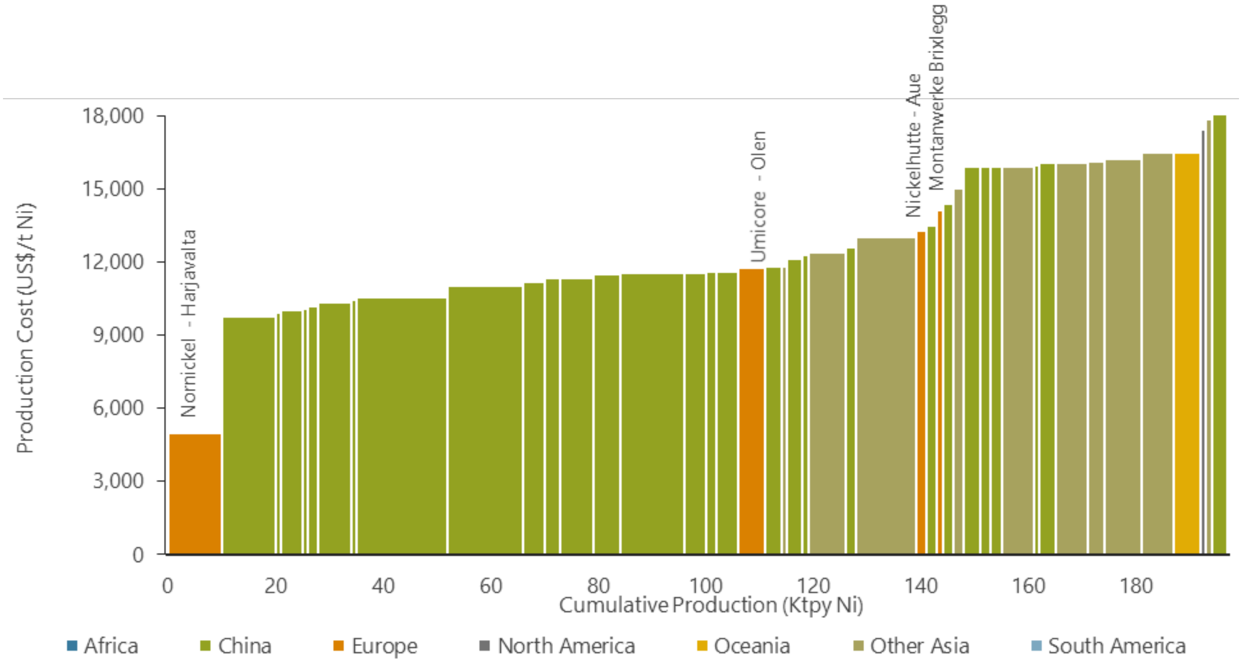


Source: Roskill, 2020.

([1]) The 2020 cost curve here is based on input costs in 2019$ dollar terms and 2019 average metal prices assumptions for nickel (US$13,932), cobalt (US$32,278/t) and copper (US$5,999/t)

One of the key drivers of nickel sulphate production costs is the feedstock type, along with the location and size of the plant. As shown by Figure 38 above, those producers processing MHP dominate the second quartile of the cost curve, while those producing nickel sulphate from already refined nickel feeds, such as Class I metal (e.g. powders and carbonyl), tend to occupy the upper quartile of the curve. That said, there is a trade-off here, and that is that plant processing/converting refined nickel feeds (such as nickel powders) into nickel sulphate generally come with a significantly reduced capital cost of construction owing to the simpler nature of the processing flowsheet.

Figure 39: Cost curve for nickel sulphate by region, 2020 (US$/t nickel contained)[1]

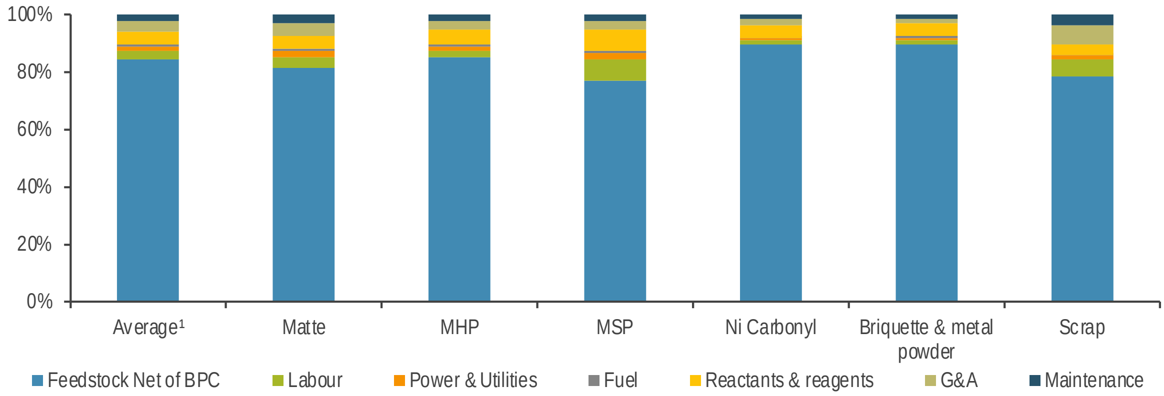


Source: Roskill, 2020.

([1]) The 2020 cost curve here is based on input costs in 2019$ dollar terms and 2019 average metal prices assumptions for nickel (US$13,932), cobalt (US$32,278/t) and copper (US$5,999/t)

As shown by Figure 40, the main cost component in the production of nickel sulphate is the feedstock cost, which in 2019 is estimated to have contributed around 85% of the average production cost. Within the processing cost (the remaining 15%), the main cost items include reagents, labour, electrical power, utilities and fuel. It highlights, the lower processing cost component of more refined nickel feedstocks such as nickel powders and carbonyl and the higher processing cost component of feedstock from secondary sources. Some regional differences for key input costs such as labour have inflated the processing cost position of plants producing nickel sulphate from MSP, which are significantly weighted towards Japanese operations.

Figure 40: Breakdown of nickel sulphate production costs[12], 2019e

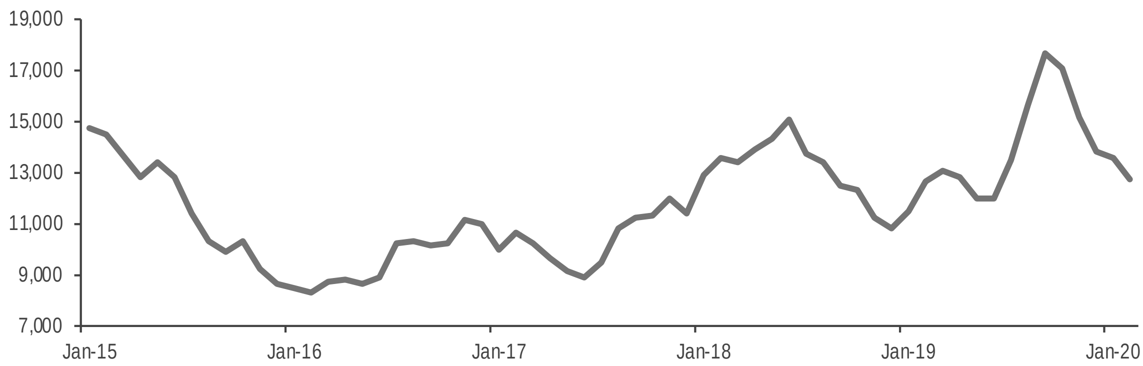


Source: Roskill, 2020.
([1]) Costs taken as averages from Roskill Nickel Sulphate Cost Model Service, and as such some of the processing cost differences are driven by regional variations in input cost and opposed to variations in the process flowsheets
([2]) Feedstock costs shown are based on the acquisition of intermediate feedstock at market rates, as opposed to from integrated sources

3.3.1.1 Feedstock cost trends

The main driver on the production cost of producing nickel sulphate is feedstock. For non-integrated producers, the cost of this will be dictated by the individual arrangements in place with mining companies, trading house or other intermediaries, and will either be in the form of short-term arrangements or longer-standing offtake agreements. In many instances, these will be linked to the nickel price, and as a result, the 6% increase in nickel prices y-on-y will have driven feedstock costs higher for many producers. And although there is a correlation between refined nickel and nickel sulphate prices, the contraction of the nickel sulphate premium to refined nickel in 2019 versus 2018 will have had an impact of producer margins in 2019.

Figure 41: Refined LME nickel price (US$/t)



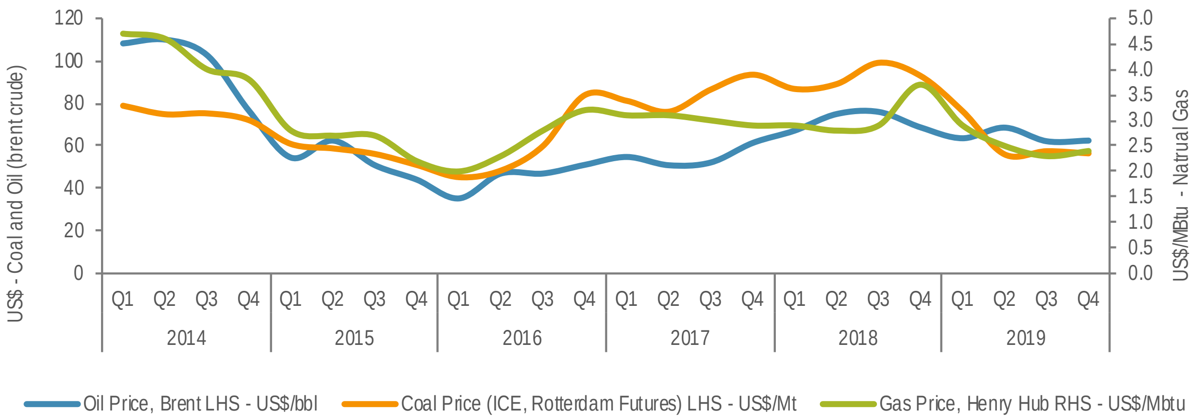
Source: Roskill, 2020. London Metal Exchange, 2020.

For integrated producers, there was a mix of factors impacting mined production costs in 2019 compared to a year earlier. One of the key drivers for mined production costs is revenue from by-product metals. Y-on-y Nornickel benefited from an increase in PGM prices, most notably palladium for which it is the biggest producer in the world. For many other nickel mines, and in particular laterite operations, cobalt represents an important by-product, and the 55% reduction y-on-y in refined cobalt metals prices will have impacted the economics of their operations to some extent in 2019.

3.3.1.2 Power, utilities and fuel costs

Another major input cost for nickel sulphate refiners is power and fuel costs. The decline in fuel cost in 2019 has provided some support for nickel miners, although the strong drop in market prices versus 2018 might not instantly be enjoyed by all nickel sulphate producers. This is due to the domestic pricing structure for inputs such as natural gas and electricity, were domestics policy, taxes and tariffs linked to climate targets can often smooth volatile market moves.

Figure 42: Brent crude oil price, coal price and natural gas price, 2014-2019

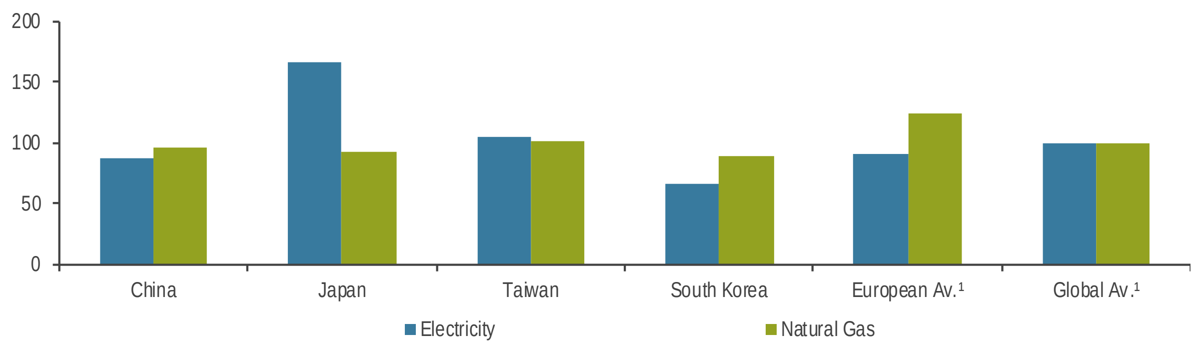


Source: Roskill, 2020. U.S. Energy Administration and Information, 2020.

The crude oil price gradually rose in 2018 before starting to fall back towards the end of 2018. There was a brief uptick in prices in Q2.19 before falling again and remaining around US$60-65/bbl in H2.19. Similarly, natural gas prices dropped significantly by 37% from Q4.18 to Q4.19, while coal prices have fallen since peaking at the end of 2018.

As shown by Figure 43, the price for key energy input such as electricity and natural gas can vary significantly between countries and even regionally within major nickel sulphate producing countries such as China.

Figure 43: Comparison of industrial electricity and natural gas costs within key nickel sulphate producing countries and provinces in 2019[1], Global average=100

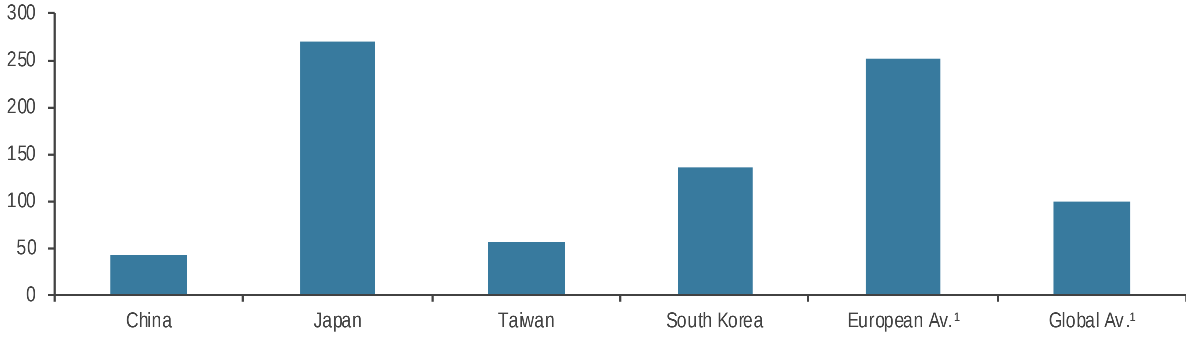


Source: Roskill, 2020.
([1]) Weighted average based on nickel sulphate production in 2019

3.3.1.3 Labour costs

Labour forms another significant cost component in the production of nickel sulphate, and in 2019 is estimated to have accounted for 25-30% of the average processing cost component. However, this proportion does vary significantly from plant-to-plant, driven by the level of automation and regional factors which can have a significant bearing on labour rates as shown by Figure 44.

Figure 44: Comparison of labour costs within key nickel sulphate producing countries and provinces within China in 2019[1], Global average=100



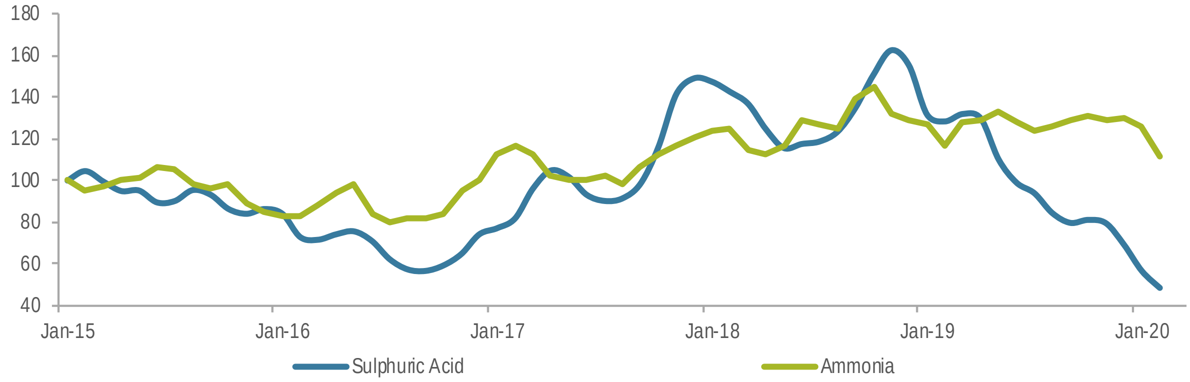
Source: Roskill, 2020.
([1]) Weighted average based on nickel sulphate production in 2019

Labour costs fall across the production chain and are mainly fixed and not directly linked to the production process, particularly in areas such as overheads, marketing costs, management costs and research and development. As a result, labour costs can go through sharp variations on a per tonne basis if production volumes fluctuate. In particular, if a plant decides to lower production temporarily without cutting staffing levels, the labour cost per tonne of output can rise significantly.

3.3.1.4 Reagent costs

Chemical reagents form a significant cost component in the production of nickel sulphate, and in 2019 are estimated to have accounted for 30% of the processing cost component on average. Two of the key chemicals are sulphuric acid and ammonia, which, depending on the process flowsheet, can be used in the dissolution of feedstock products, the production of ammonium sulphate by-products and the sulphurisation of nickel to produce a nickel sulphate product.

Figure 45: Key reagent prices in China, Jan-15=100

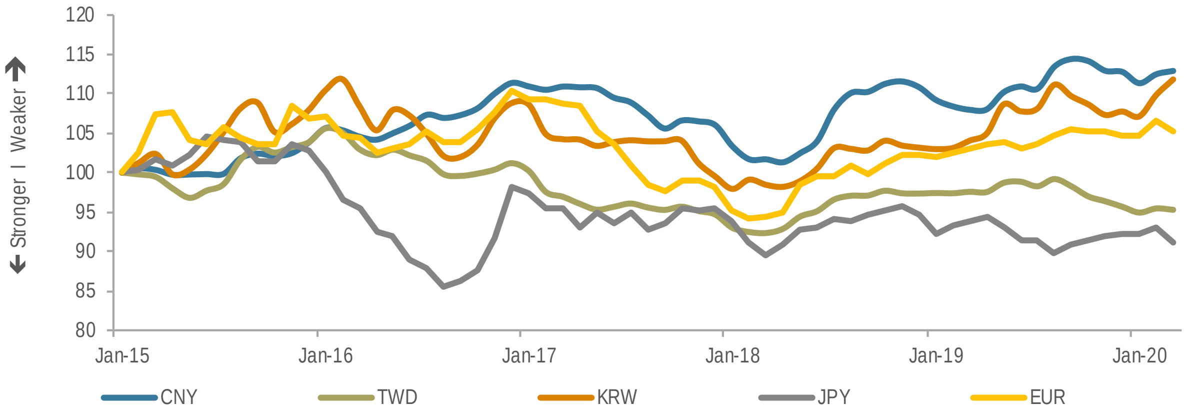


Source: Roskill, 2020.

3.3.1.5 Exchange rates

Another key factor that affects production costs is the local exchange rate. Figure 46 shows that local currencies for most nickel sulphate producing countries have continued to lose value against the US dollar in 2019 helping to reduce production costs on a US$ dollar basis. Although it is worth noting that this weakening has been less severe than in previous years.

Figure 46: US$ exchange rates of major refined nickel sulphate producing countries, Jan-15=100



Source: Roskill, 2020.

Of note, the Chinese Yuan (CNY) weakened by 1% y-on-y against the dollar, while the South Korean won (KRW) and the Euro (EUR) both depreciated by around 2%. The Japanese yen was flat versus 2018, while in contrast to the yuan, won and euro, the New Taiwanese dollar (TWD) strengthened by 2.5% y-on-y.

4 Nickel demand: effect of competing sectors

Chapter Summary

Demand status quo: Nickel demand is predominantly driven by the stainless steel industry, which accounts for 70% of total primary nickel consumption. In 2019, primary nickel consumption was 2.41Mt, which was a 4.4% increase on the 2018 level. Other demand drivers for nickel include non-ferrous alloys, alloy steels and castings, and plating, which individually account for less than 10% of primary nickel consumption. Despite only accounting for 5% of primary nickel consumption in 2019, the batteries sector is forecast to see the highest level of demand growth of all the first-uses of nickel. Li-ion batteries with increasingly nickel-rich cathode chemistries will find use in the rapidly growing EV market. The main primary nickel consuming country is China, which represented 55% of global consumption in 2019.

Batteries: Nickel demand across all battery applications if forecast to total 2.86Mt Ni by 2040, of which automotive powertrain applications will constitute 95%. Four main scenarios underpin our forecast for nickel use within batteries, where we expect both global and EU27 markets to focus on high-nickel cells in the long-term. Gigafactory capacity is expected to increase significantly between 2020 and 2040, and so too their demand for nickel. At a global level nickel demand from Gigafactories is forecast to reach 2.28Mt Ni by 2040. Respective OEM nickel demand varies significantly owing to overall production scale and announced EV model plans to date. In 2020, Tesla is estimated to be the largest OEM consumer of nickel globally at 10kt Ni, whereas by 2040 we forecast VW to be the largest, requiring 149kt Ni by such time.

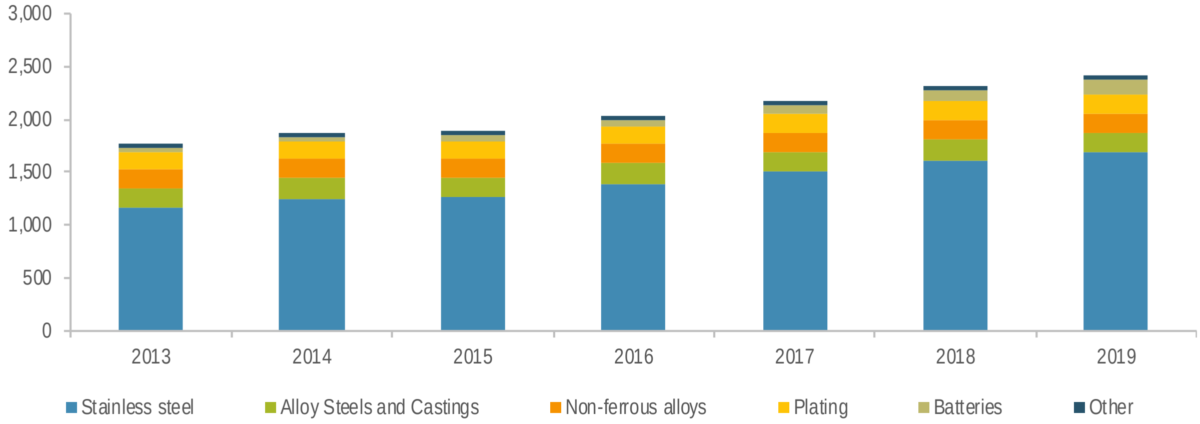
Within the EU27, demand is clearly segmented by end-use (EV sales) and first-use (precursor/cathode maker) sectors. At the cathode maker level we forecast nickel demand from industry with reach 71kt Ni by 2030, before increasing to 76kt Ni in 2040. This could be higher during the 2030s as it is considered likely additional precursor/cathode capacity will be constructed as battery cell manufacturing in the continent matures.

Lithiun-ion batteries require a high purity chemical product in the form of nickel sulphate. Nickel sulphate demand growth is forecast to be almost completely driven by demand from the battery sector. Between 2020 and 2030, nickel sulphate demand is forecast to increase by 22% CAGR, totalling over 1,200kt Ni. Whilst over the full 20-year outlook horizon a growth rate of 33% CAGR is forecast to see demand reach just under 3,000kt Ni by 2040. Battery demand by 2040 is expected to account for 96% of total nickel sulphate demand globally, an increase from 55% in 2020.

4.1 Demand status quo

Primary nickel demand grew by 4.4% y-o-y to 2,407kt in 2019, slightly slower than the 6.0% growth reached in 2018, and indeed the 6% average annual growth rate over the previous decade. The main driver of this rise in demand was the stainless steel industry, mostly driven by a construction boom in China. In 2019, the global stainless steel industry accounted for 70% of total primary nickel consumption, a share that has been rising steadily in the past decade.

Figure 47: World demand for refined nickel by first use, 2013-2019 (kt Ni)

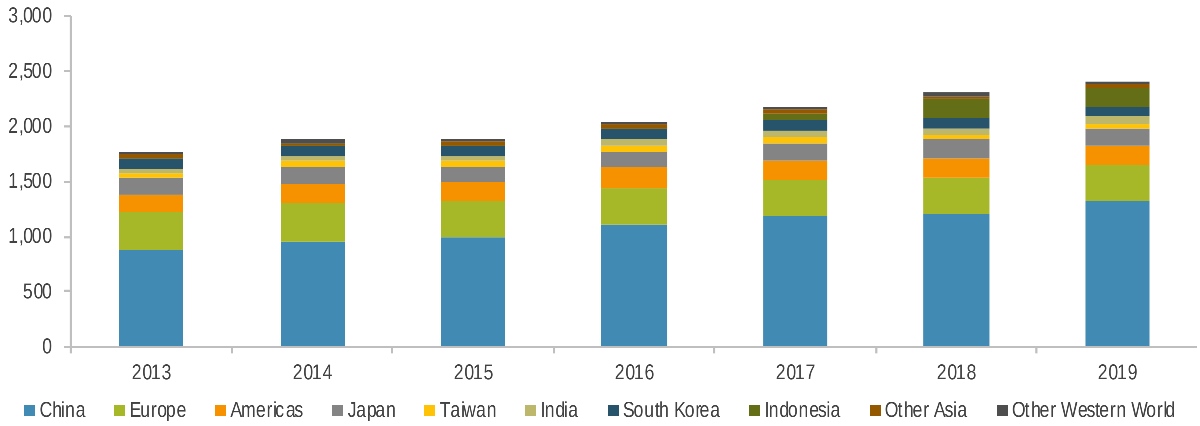


Source: Roskill, 2020.

After stainless steel, there are several other sectors that consume relatively similar quantities of primary nickel. The alloy steels and castings industries consumed 190kt of primary nickel in 2019, making it the second-largest consumer. Whilst non-ferrous alloys consumed 187kt (equivalent to 8% of global consumption), making it the third-largest consumer. The next-largest consumer of primary nickel is the plating industry, which also accounted for 8% of total nickel usage, or 182kt. Batteries, which consumed 125kt of primary nickel in 2019, only accounts for 5% of global primary nickel consumption. Nickel has been used by the battery industry for a long time, but only in recent years has usage started to grow as EVs have begun increasingly penetrating the automotive sector. Although this sector is among the smallest consumers of primary nickel, it is the sector which, along with stainless steel, is expected to show the highest level of growth in future.

It is little surprise that China is the world's largest consumer of primary nickel. The country consumed 1,331kt in 2019, or 55% of global consumption. In the past decade, Chinese demand has grown by an average of 11.1%py. Europe is the second-largest consuming region, but its consumption in 2019 stood at 328kt, lower than in 2013, equivalent to an average annual drop of 0.3%. This was largely owing to stainless steel industry in this region increasing its use of scrap, thereby lowering its requirements for primary nickel units. We estimate that in 2019 Indonesia became the third-largest consumer of primary nickel, overtaking the Americas. In 2013, primary demand stood at only 1kt and this level of usage barely moved between then and 2016.

Figure 48: World demand for refined nickel by region, 2013-2019 (kt Ni)

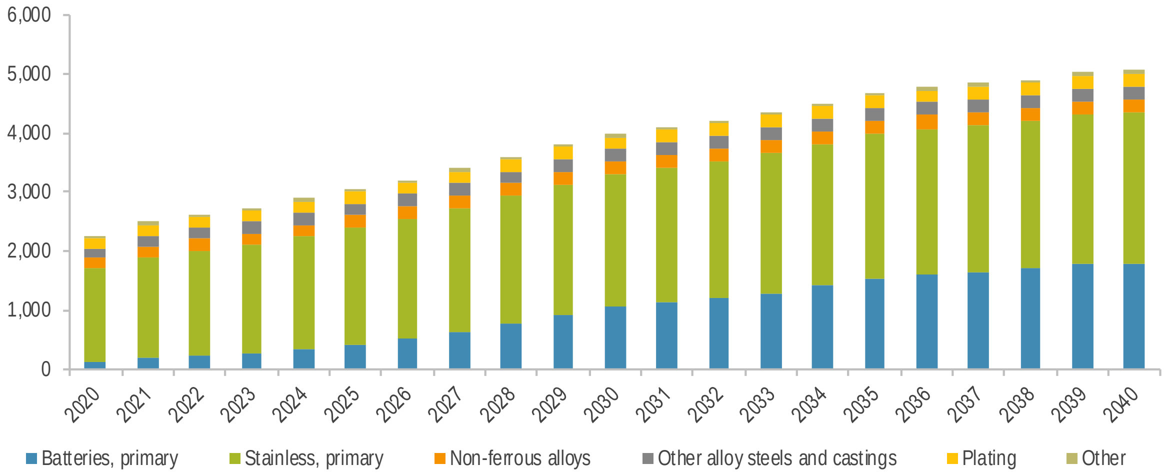


Source: Roskill, 2020.

4.2 Total market demand

In 2020, global primary nickel demand is forecast to reach around 2,250kt Ni. Roskill expects this to more than double over the 20-year forecast horizon totalling over 5,000kt Ni by 2040, representing a CAGR of 4.1%. The majority of nickel demand is currently accounted for by the stainless steel sector at around 1,550kt Ni in 2020. This compares to batteries which makes up a small portion of primary nickel demand estimated to total 143kt Ni in 2020. However, it is the battery sector that is forecast to become the most significant diver of nickel demand growth moving forward. Batteries are expected to increase by 13.5% CAGR to 2040, where demand from the sector could reach over 1,800kt Ni (see Figure 49).

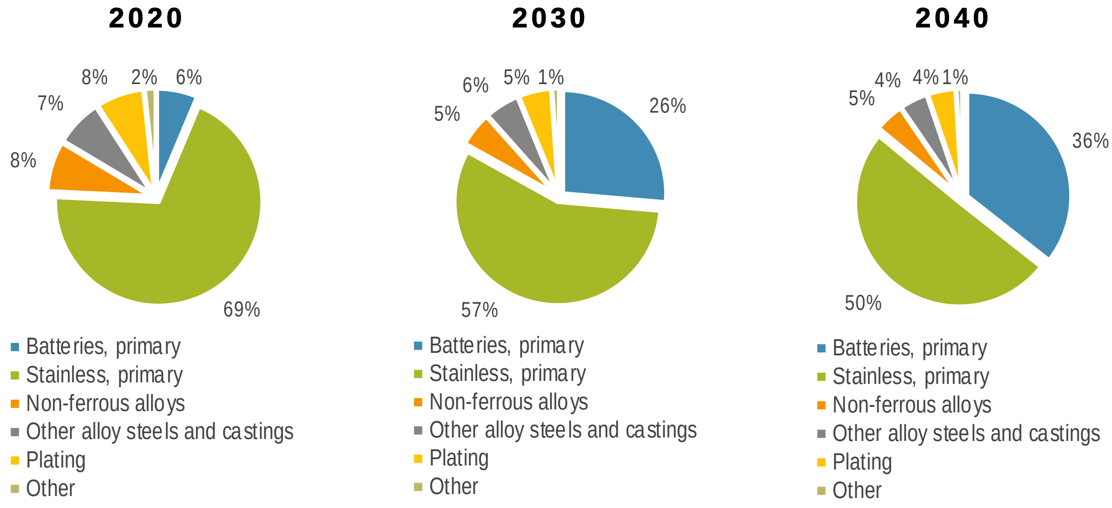
Figure 49: Total primary nickel market demand by first-use sector[1], 2020-2040 (kt Ni)



Source: Roskill, 2020.
([1]) Primary demand for batteries is net of secondary sales and inclusive of all nickel containing battery types

With respect to market shares, stainless steel demand current contributes around 70% of total market demand. This large position has been increasingly consolidated in recent decades off the back of economic stimulus in China driving a construction boom. Stainless steel is likely to remain the largest demand segment in 2040, although batteries may begin to rival stainless steel's dominance. We forecast the battery sector could potentially increase its demand share from 6% in 2020 to 36% in 2040, representing a six-fold increase.

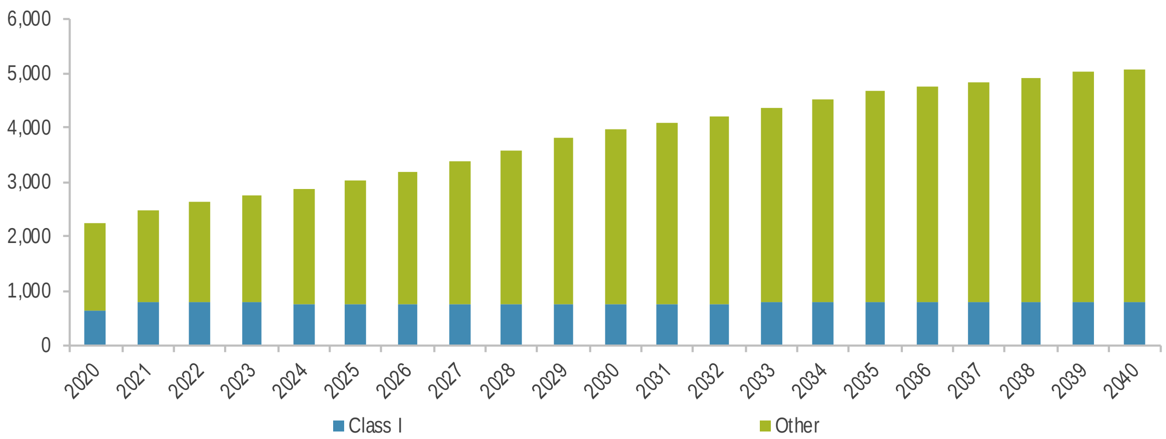
Figure 50: Nickel market demand share, by first-use sector



Source: Roskill, 2020.

On a product basis, demand for Class I nickel is forecast to total 640kt Ni in 2020. This compares to Class II and nickel salts ("other") demand over 1,600kt Ni, as shown in Figure 49. The vast majority of primary nickel demand growth over the outlook period is expected to come from Class II material used in stainless steel production. Whilst Class I demand is forecast to remain relatively flat increasing by a modest 1.2% CAGR.

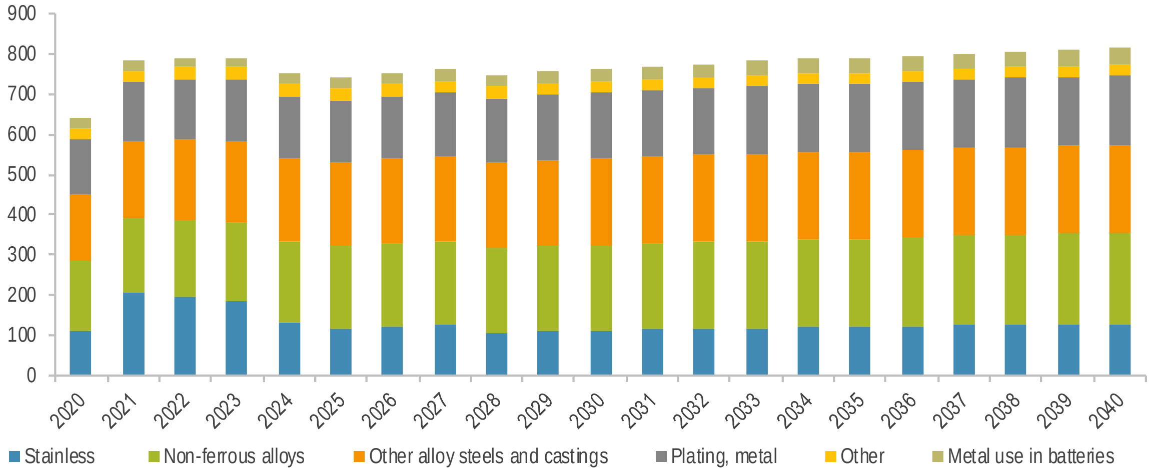
Figure 51: Class I nickel versus total primary market demand[1], 2020-2040 (kt Ni)



Source: Roskill, 2020.
([1]) Other includes all demand for non-Class I nickel products such as Class II, nickel salts etc.

An examination of Class I nickel demand by first-use sector indicates that the spread amongst the top four industries is relatively even. In 2020, demand from stainless steel mills is expected to be lower than 2019 as a result of the COVID-19 pandemic and increasing nickel prices. Although a recovery is expected in 2021, overall Class I demand from stainless steel is forecast to decrease over the 2030s and into the 2040s. This is underpinned by the expected 'thrifting' of Class I metal for scrap and Class II feedstocks (as discussed further in section 5.1.2).

Figure 52: Class I nickel demand competition by first-use sector[1], 2020-2040 (kt Ni)

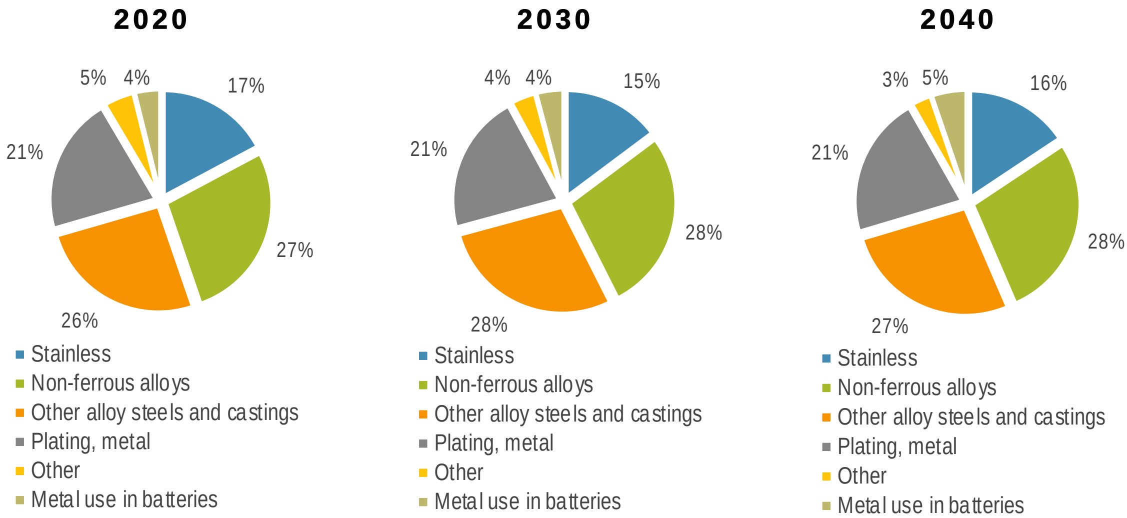


Source: Roskill, 2020.

([1]) Metal use in batteries is nickel metal directly used in battery production and does not include demand from nickel sulphate producers with lithium-ion end-user battery customer markets

Given the relatively even spread of demand of Class I demand amongst first-use industries, their respective proportional share of demand is not expected to experience significant change by 2040. This is shown in Figure 53. Importantly, volumes demanded from non-stainless sectors (also considered 'critical demand') are forecast to increase relatively in line with global and regional GDP growth rates. Collectively, this represents the total portion of Class I demand that cannot be substituted for other nickel products. These are therefore considered the main competing sectors for such units.

Figure 53: Class I market demand share, by first-use 2020-2040 (kt Ni)



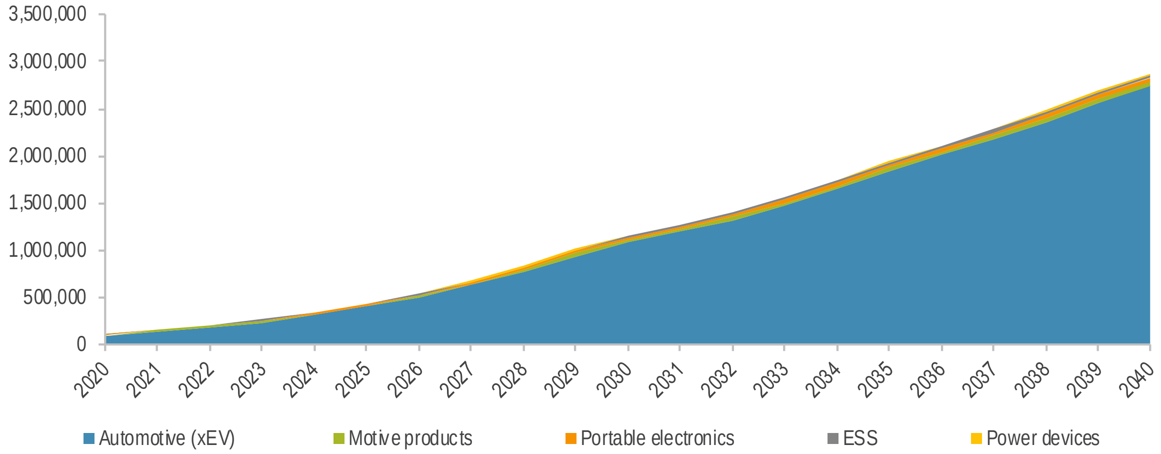
Source: Roskill, 2020.

4.3 Batteries – Global demand

4.3.1 Outlook for sold battery product demand

We forecast nickel demand across all battery applications to total 2.86Mt of nickel metal by 2040, of which automotive powertrain applications will constitute 95%. This represents a CAGR of 17.6% over the 20-year forecast horizon. Such demand growth is based on Roskill's forecast EV, portable electronics, niche transport applications, and ESS sales. These have then been crossed with their respective battery capacity and electrode chemistry.

Figure 54: Nickel demand by battery application, based on expected product sales, 2020-2040 (t Ni)



Source: Roskill, 2020.

Although demand from ESS devices is expected to grow accordingly, lithium-ion technology is not considered likely to be the dominant battery technology utilised within the sector. It is likely to be used in short duration grid applications whilst other ESS technologies (like flow batteries, hydrogen fuel cells or mechanical storage) are expected to provide the bulk of long duration storage. Furthermore, within the lithium-ion technology, nickel-based batteries are unlikely to be used due to:

1. Nickel supply constraints and cost
2. Procurement competition with automakers
3. Safety of LFP (less likely to experience a thermal runaway event)
4. Longer cycle life of LFP batteries; and
5. Lower cost on a levelized cost of ownership basis of LFP and flow batteries

4.3.1.1 Scenarios for nickel consumption in batteries

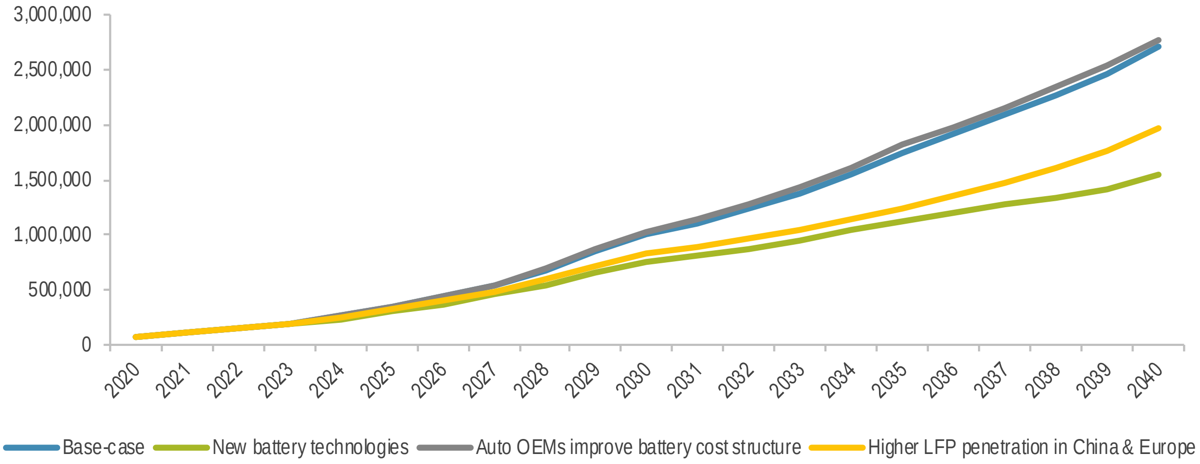
We have created three scenarios based on different technology parameters. This has modelled two low-case scenarios for nickel and one high-case. Roskill believes that a scenario in which automakers produce electric vehicles over the mandatory EV regulatory thresholds is unlikely due to the cost challenges in EV manufacturing and the uncertainty around consumers' attitude towards electric vehicles.

Main scenarios:

- China and Europe opt to use a higher share of LFP batteries (Low case)
- New battery technologies (Low case)

- Auto OEMs improve battery cost structure (High case)

Figure 55: Nickel in EV batteries scenarios, 2020-2040 (t Ni)



Source: Roskill, 2020.

Explanation of scenarios:

1. **China and Europe opt to use a higher share of LFP batteries:** this scenario assumes an estimated 30% penetration rate of LFP cathode material both in China and Europe by 2030. This rate is progressively phased-out by 2040. Most LFP is applied to urban small cars (A-C segment) and higher volumes of LFP are also applied to commercial vehicles. The result is an estimated 24% less nickel consumption on a cumulative basis during the period 2020 to 2040 in automotive powertrain batteries when compared to Roskill Base-case scenario.

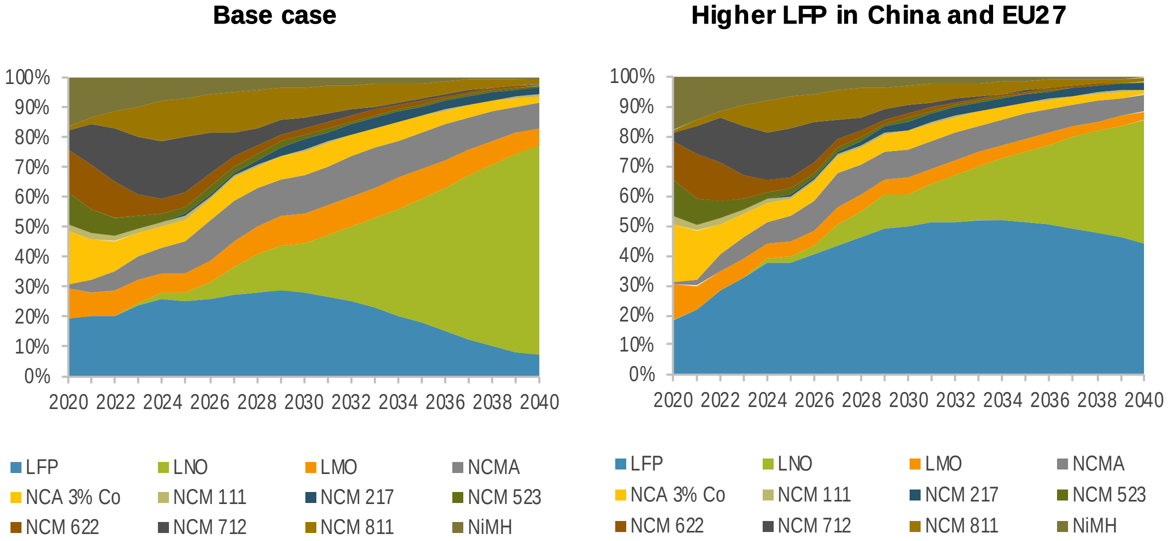
While the initial roadmap of most automakers is directed toward high nickel chemistries such as NCM 811, LNO, or NCMA, other alternative cathode chemistries like LFP was surprisingly adopted by Tesla in the lower range Model 3 for the Chinese market. Although this may seem a novel approach in high-end vehicles, other automakers have suggested to Roskill that LFP will always be a possibility if:

i. Cobalt and nickel prices become unsustainable

ii. Lower range city vehicles experience high demand

iii. A novel approach to cell packing allows for increases in energy density when using LFP (like CATL's Cell-to-Pack or BYD's "blade battery")

Figure 56: Higher LFP in China and Europe comparison to Base-case, 2020-2040 (% t of cathode material)



Source: Roskill, 2020.

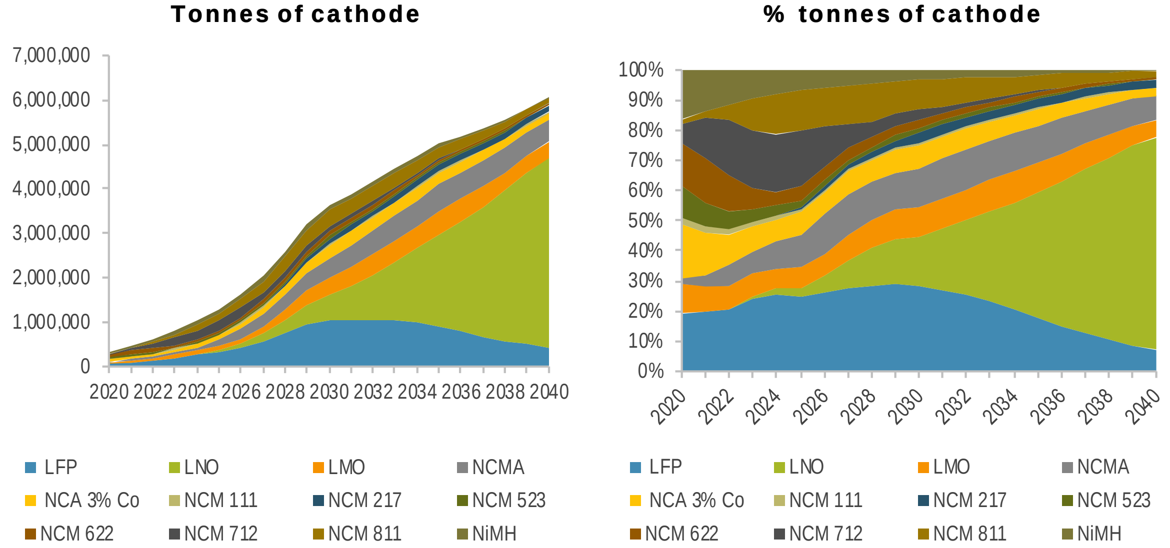
2. **New battery technologies scenario:** this scenario assumes a progressive phase-in of higher energy density battery technologies during the outlook period. The scenario assumes that in 2025 Li-ion batteries with Si-based anodes are fully introduced increasing average energy density by 15-30% compared to 2020. Later, higher energy density technologies like solid-state batteries start to be introduced increasing the average energy density by the end of the outlook period by 60-80%. The result is an estimated 33% less nickel consumption on a cumulative basis during the period 2020 to 2040 in automotive powertrain batteries when compared to Roskill's base-case scenario.

3. **Auto OEMs improve battery cost structure:** this scenario assumes aggressive improvements in battery costs with some automotive OEMs using fully dedicated e-platforms (reducing assembly times) and achieving ICE-BEV production cost parity as early as 2025 in some models of the A-D segments. The result is an estimated 2% more nickel consumption on a cumulative basis during the period 2020 to 2040 in automotive sectors when compared to Roskill's base-case scenario. As well as such automakers being expected to sell a larger number of vehicles, this scenario also assumes a slightly higher penetration of LFP-based batteries and other higher energy density new battery technologies that reduce overall nickel consumption.

4.3.1.2 Nickel demand by cathode type

We have forecast nickel demand by cathode technology, which utilises assumptions underpinned by engagements with leading industry players (such as cathode, cell and automotive manufactures).

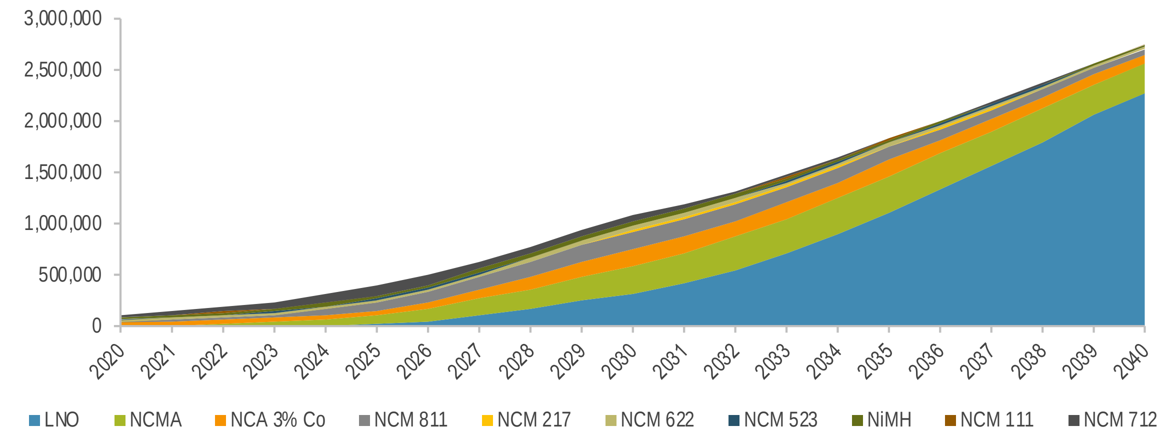
Figure 57: Base-case cathode demand in automotive powertrain batteries, 2020-2040 (% t of cathode material)



Source: Roskill, 2020.

Despite the challenges in the manufacturing and use of ultra-high-nickel batteries, significant R&D and industrial testing is underway to enable their mass adoption. Technologies like single-crystal cathodes, advanced cathode coatings, and electrolyte additives are expected to enable the widespread use of ultra-high nickel battery cells like those of NCMA or LNO. Consequently, in the base-case scenario we envision multiple families of NCM/NCA co-existing in the period to 2030. This is until ultra-high nickel chemistries like NCM 811, LNO, and NCMA become more widespread post-2030. On a contained nickel basis, chemistries like NCA 3%Co, NCM 811, NCMA, and LNO are expected to become the largest consumers of the metal by 2040.

Figure 58: Nickel demand by cathode material in automotive powertrain batteries, 2020-2040 (t Ni)



Source: Roskill, 2020.

For the base-case scenario, we have not included any disruptive battery technology beyond the existing liquid-electrolyte lithium-ion. This is due to the following considerations:

- Current liquid-electrolyte Li-ion batteries keep improving through new cathode coatings, electrolyte additives, addition of silicon to the anode, and sophisticated BMS (battery management systems) to control temperature, degradation, and performance.

- There will always be a trade-off of characteristics in an emerging battery technology. While energy density (Wh/Kg) may improve with new technologies like solid-state batteries, power density (W/Kg) may not. Similarly, cycle life (number of charge and discharge cycles) of such development technologies remains very limited and unfit for commercial deployment (e.g. Li-S technology).

- Supply chain difficulties are a major bottleneck. Most solid-state batteries rely on lithium metal anodes to increase energy density. However, production of ultra-thin lithium metal foil (<5 microns) remains a technical challenge. Additionally, ultra-thin lithium metal foil production capacity is non-existent despite new electro-deposition techniques.

- Most of the current battery supply chain is already geared towards the mass-manufacturing of existing Li-ion technologies. This means that any new battery technology needs to be compatible with todays' liquid electrolyte Li-ion battery manufacturing processes.

- In 2020, there is no commercial electric vehicle from a leading manufacturer using a non-liquid electrolyte lithium-ion battery.

4.3.1.3 Nickel demand from EV sales

Passenger vehicles are expected to be the largest consumers of nickel in the outlook period. Beyond the evident sales disparity between passenger and commercial vehicles (~70% of the global automotive sales correspond to passenger vehicles), not every commercial vehicle will be susceptible to electrification. Whereas light and/or urban commercial vehicles (e.g. buses, refuse collection vehicles etc.) are the best candidates for electrification, long-haul commercial trucks are less likely due to:

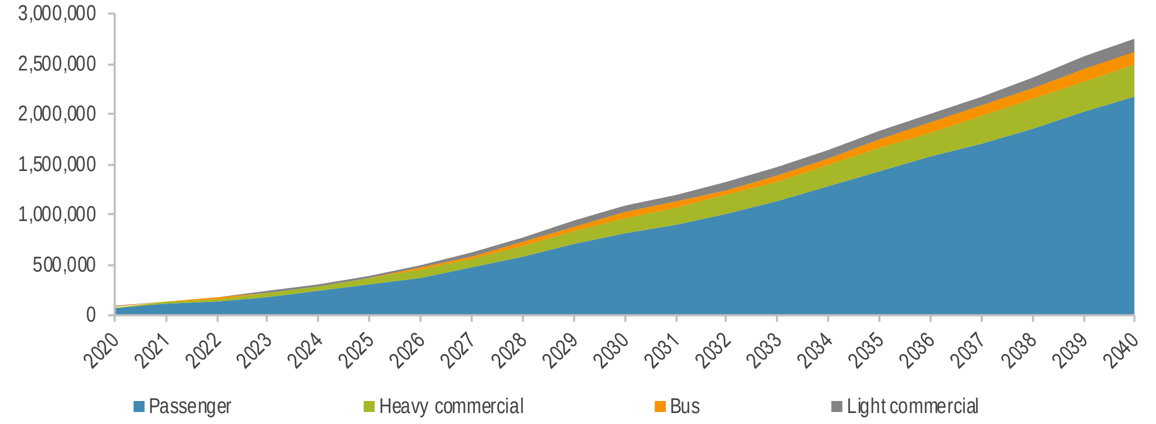
a) Annual driving distance is 6-7x more than a passenger vehicle. This will accelerate battery degradation as usage will be intensive.

b) Battery weight will be a problem as it will reduce the truck's "payload" (20-25% payload reduction).

c) Fast charging infrastructure for such battery packs (>1000kWh) may prove costly: an upgrade of local grids to allow ultra-fast charging speed in remote and uneconomical locations will be needed.

As a result, hydrogen fuel cell technology is probably the best powertrain technology for long-haul commercial vehicles. Nevertheless, we expect a considerable number of urban and inter-city commercial vehicles to be fully electrified.

Figure 59: Nickel consumed in automotive batteries by vehicle type, 2020-2040 (t Ni)

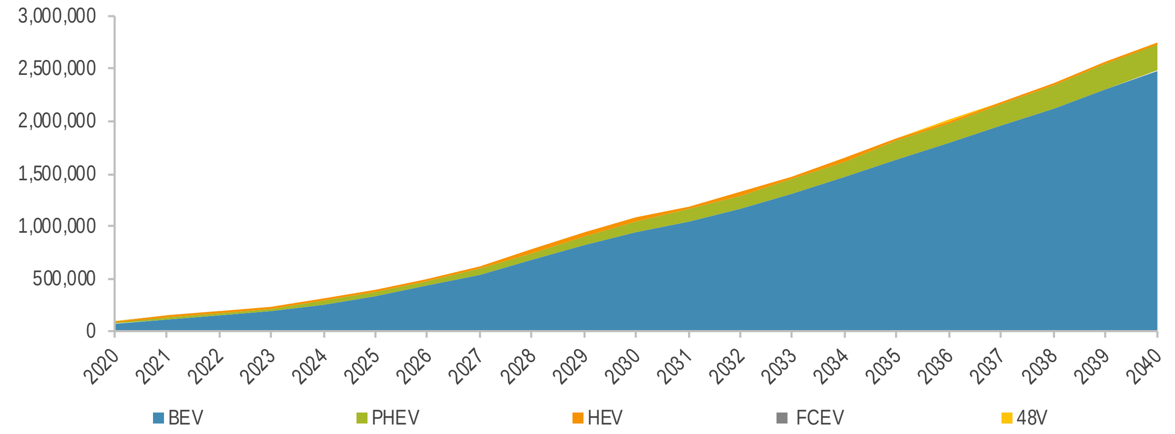


Source: Roskill, 2020.

Given the larger battery size (kWh) of fully electric vehicles (BEV), we expect this e-powertrain type to be the largest consumer of nickel in batteries. While end-consumers could initially prefer hybrid solutions like PHEV, HEV, or 48V, European and Chinese regulators are unlikely to favour these powertrains in the long-term due to the subjective environmental credentials these vehicles present (e.g. a PHEV drives in electric mode as long as the driver charges it).

On a regional basis, China is expected to remain as the largest nickel consumer from electric vehicle sales. Whilst the European market holds as the second largest automotive market globally, in comparison China has one of the lowest motorisation rates globally (vehicles per every 1,000 inhabitants) despite its growing economic status. For this reason, we expect China's automotive market to increase by 8-10M vehicles by 2040, whereas the European market could decrease by 2-5M vehicles in the same period. Even when assuming aggressive electrification rates in Europe, China is expected to sell a larger number of electric vehicles due to the larger size of its automotive market.

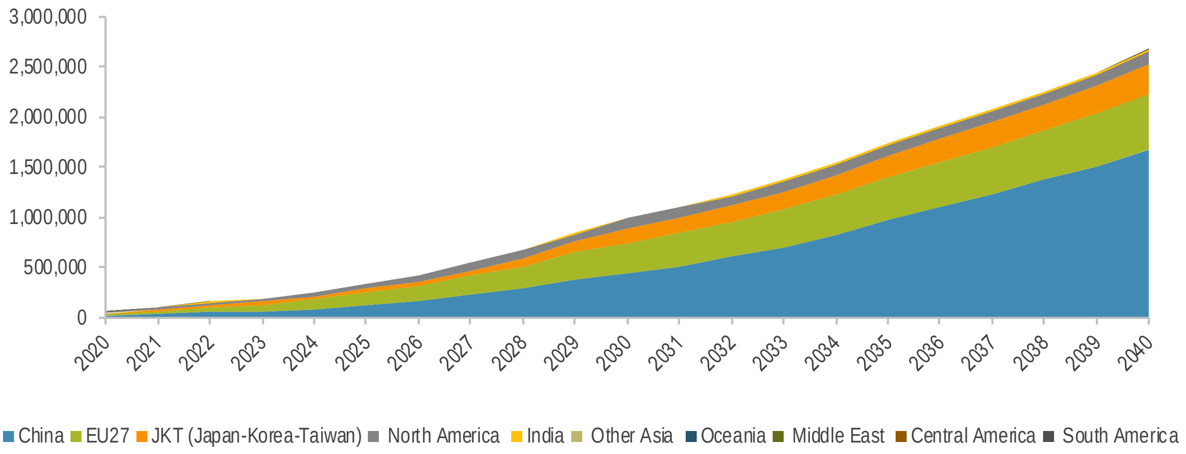
Figure 60: Nickel consumed in automotive batteries by e-powertrain type, 2020-2040 (t Ni)



Source: Roskill, 2020.

We forecast North America to be 4th largest EV market by 2040 behind that of JKT (Japan-Korea-Taiwan). This is predominantly due to the absence of clear EV and CO_2 emissions targets. This North American scenario is, however, likely to change during the outlook period. Conversely, we does not forecast other world regions like Africa and the Middle East to be aggressively electrified due to the lack of regulatory incentives, underinvested power grids, and overall lower consumer purchasing power.

Figure 61: Nickel consumed in automotive batteries by region, 2020-2040 (t Ni)

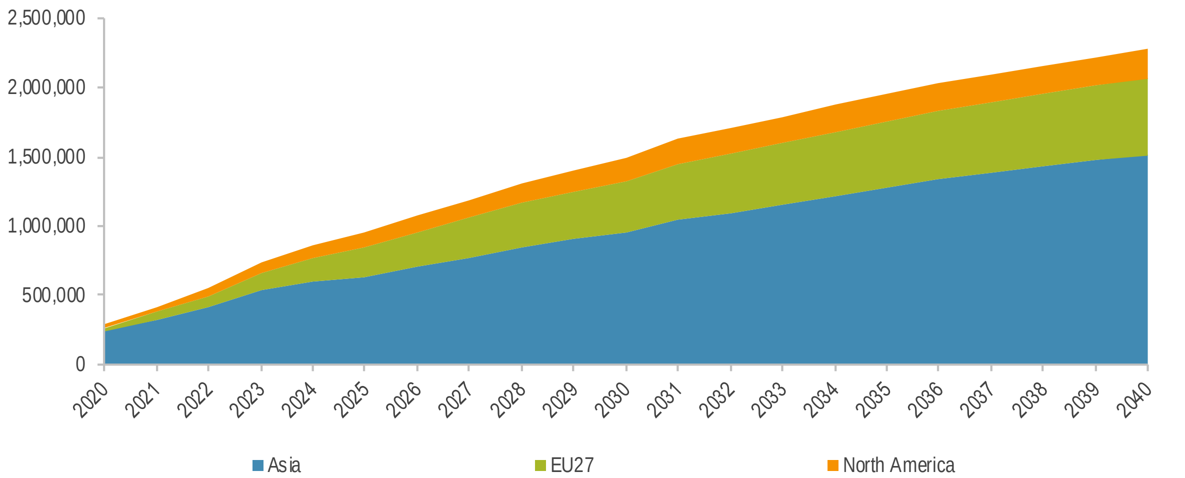


Source: Roskill, 2020.

4.3.2 Outlook for Gigafactory demand

Global installed manufacturing capacity for large-sized (automotive/ESS) lithium-ion battery cells is forecast to surpass 2,000GWh by 2030, around 4.5x times more than in 2019. This is forecast to reach 4,900GWh by 2040, around 11x times more than in 2019, if it is to meet the needs of demand. Most of these capacity expansions will be driven by transport electrification. China is expected to maintain its dominant position in battery manufacturing due to its large domestic automotive market and pre-existing upstream battery supply chain.

Figure 62: Nickel consumed by Gigafactories, by region, 2020-2040 (t Ni)

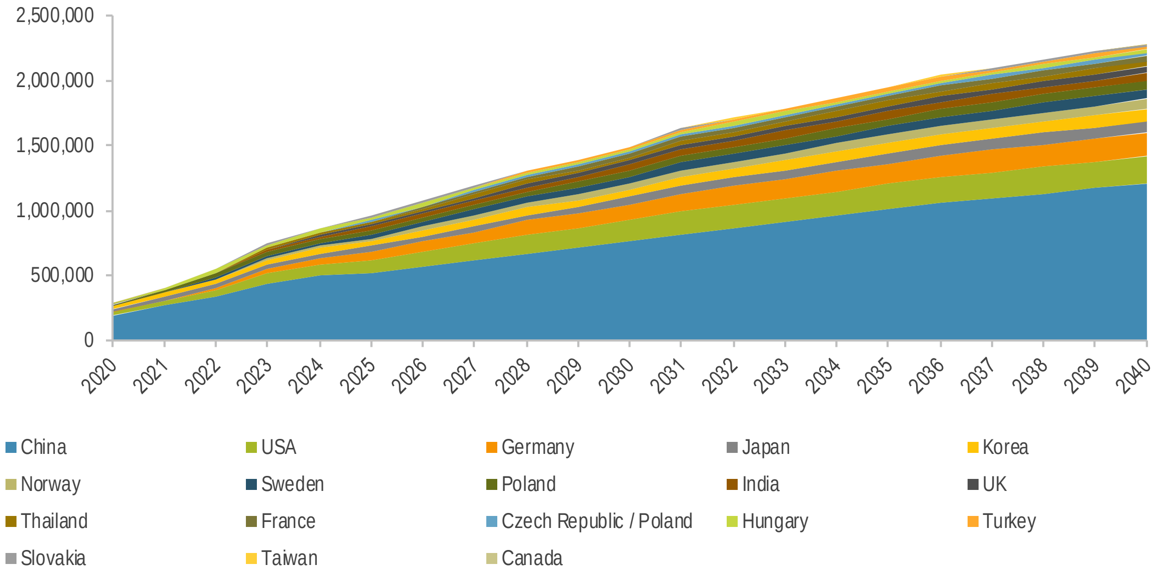


Source: Roskill, 2020.

Assuming these facilities operate at 80% capacity by 2030, Asian battery plants are expected to require 960kt of nickel metal alone, of which China will require around 770kt.

Despite significant levels of technological uncertainty around batteries in the period beyond 2030, China could potentially demand 1.2Mt of nickel metal by 2040 should ultra-high-nickel cathode technologies dominate the market. EU27 countries are expected to demand around half of that at around 553kt by 2040.

Figure 63: Nickel consumed by Gigafactories, by country, 2020-2040 (t Ni)



Source: Roskill, 2020.

To meet their respective future nickel demand, major downstream players have increased their activity in establishing agreements with upstream suppliers and/or future projects. Table 6 below shows examples of such engagements, noting significant variation in their respective grounds (e.g. MOU vs definitive offtake agreement) and current validity (i.e. current vs expired).

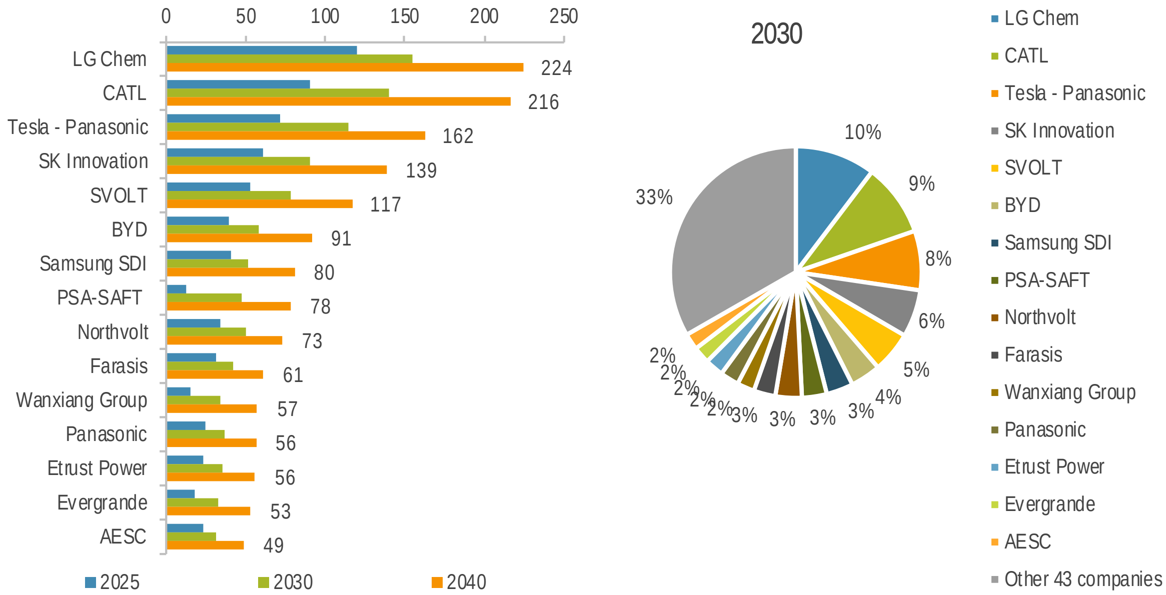
Table 6: Nickel supply engagements between battery supply chain participants and miners, 2017-2020

Deal type	Date	Buyer	Industry of buyer	Type of material	Seller company
Offtake	2017	Beijing Easpring	Cathode	Ni sulphate	Clean TeQ
Investment	2017	Trafigura	Trading	MSP/Ni sulphate	Terrafame Group
Offtake	2018	SK Innovation	Batteries	Ni sulphate	Australian Mines
Share purchase	2018	CATL Canada	Batteries	Ni sulphate	North American Nickel
Offtake	2018	Beijing Easpring	Cathode	Ni & Co sulphate	Pacific Rim Cobalt
Investment	2018	LG Chem	Batteries	Ni sulphate	Chemco
JV	2018	GEM/CATL	Precursor/Cathode	Ni sulphate	Tsingshan
JV	2018	BASF	Cathode	Ni sulphate	Nornickel
Offtake	2018	Ecopro	Cathode	Ni(OH)2 + NCA	GEM
Partnership	2018	BYD/Guoxuan	Auto/Batteries	NCM precursor	Minmetals (MCC)
JV	2019	Ecopro	Cathode	Ni sulphate	Blackstone Minerals
Offtake	2020	GEM	Precursor/Cathode	Ni MHP/sulphate	PT Halmahera HL

Source: Roskill, 2020.

A total of 63 companies are expected to operate in the large-cell battery market by the end of the coming decade, of which the top five are forecast to account for approximately 40% of total nickel demand. We consider it likely, however, that the large-cell battery industry will rather resemble 2010´s market structure, with no more than 15 companies competing. Sheer volume, cost efficiency and supply stability requirements of automakers underpin such projections. This is alike today's automotive parts supplier landscape (e.g. tyres, body stamping, engine components etc.), where suppliers are concentrated in 5-15 companies, albeit with some regional exceptions. Examples of such may occur in countries with government supported projects like Thailand's Energy Absolute project, Tukey's Vestel project, or the EU battery alliance with SAFT-PSA.

Figure 64: Nickel consumed by battery cell company, 2025-2040 (t Ni)



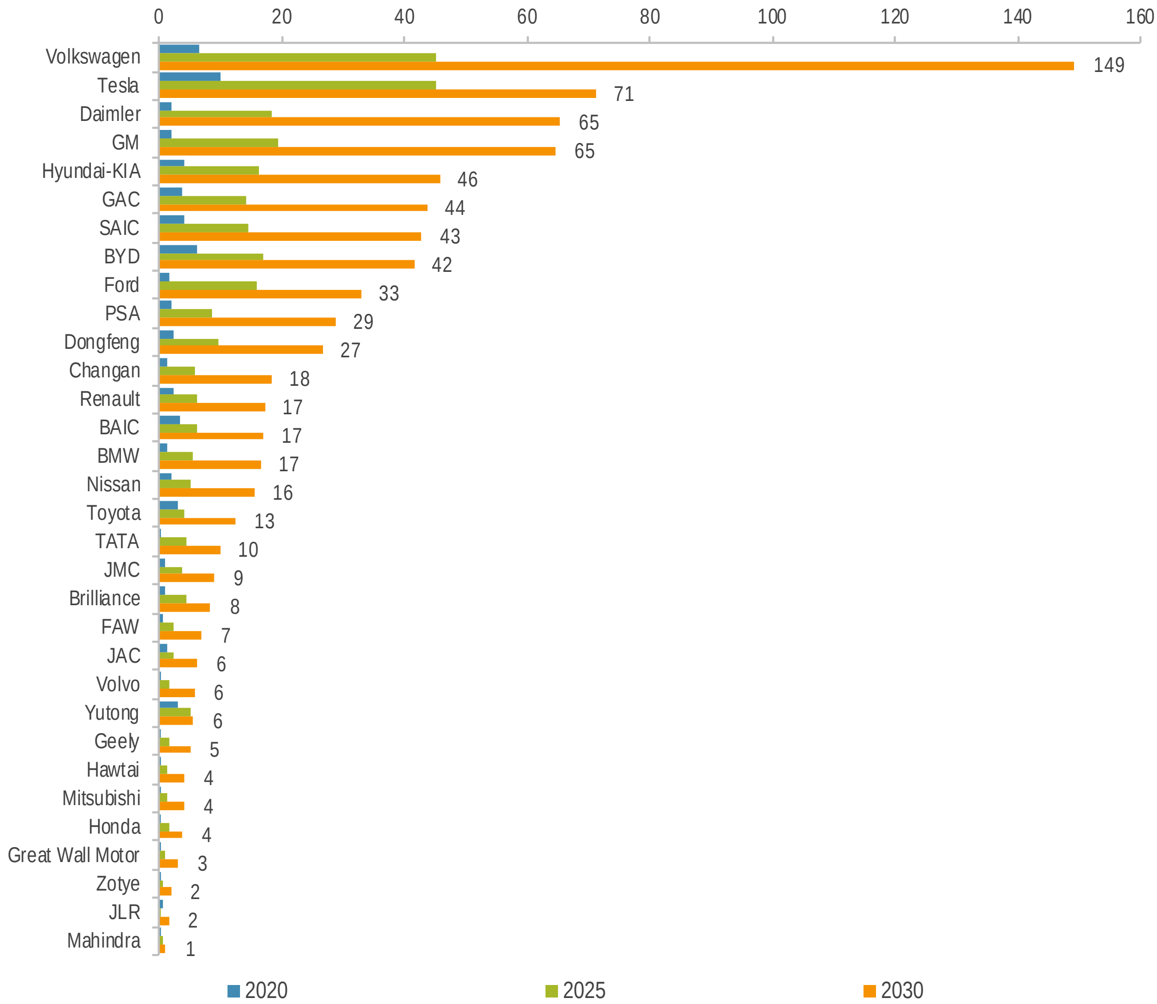
Source: Roskill, 2020.

4.3.3 Outlook for automaker demand

Similar to battery makers, automakers are increasingly wary of the significant growth in battery metals demand in the next decade. Most Asian and western automakers have or are establishing new procurement teams with focus on battery metals.

Importantly, not every automaker has chosen the same electrification strategy. While companies like Volkswagen group seem to be targeting fully electric vehicles (BEV) in the outlook period, other companies like Toyota, Volvo, or FCA are targeting hybrid powertrains like PHEV, HEV, and 48V. As a result, automotive groups targeting hybrid models in the outlook period may be less exposed to the availability of battery metals. But potentially more exposed to regulatory changes towards the CO_2 footprint attributed to hybrid powertrains or fleet average targets.

Figure 65: Global nickel demand by automotive group, passenger vehicles only, 2020-2030 (t Ni)



Source: Roskill, 2020.

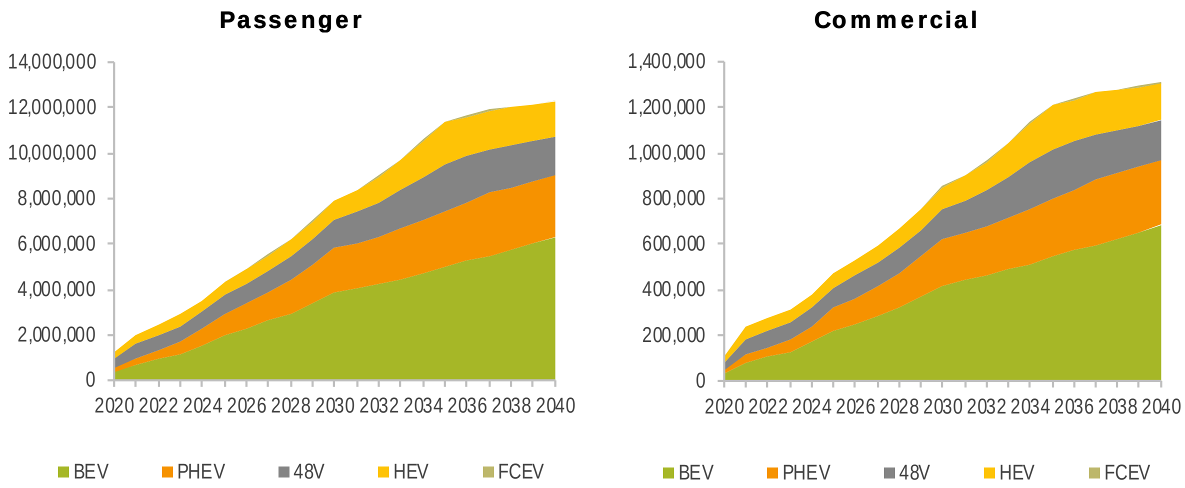
Based on current model announcements, Volkswagen Group (and its many Chinese joint ventures) is forecast to be the largest consumer of nickel by 2030, followed by Tesla, GM, Hyundai-KIA Group, and Chinese automakers GAC, SAIC, and BYD. It is important to note that strategy roadmaps of the analysed carmakers may change in the outlook period due to regulatory pressure or technology developments. In this sense, their attitude towards fully electric or hybrid powertrains may also vary which would have subsequent implications for nickel demand.

4.4 Batteries - European demand

4.4.1 Outlook for EV sales

On a regional basis, the EV penetration into the automotive market has followed highly uneven trajectories across different European markets. Differences in electrification have been the result both of varying levels of government support, consumer purchasing power, commitments to the development of charging infrastructure, and the market position of automakers in their respective markets. In 2020, Europe is expected to retain its positions as the world's second largest plug-in electric vehicle market. This trend is expected to continue as regulatory pressure on emissions limits are considered likely to increase over the forecast period to 2040.

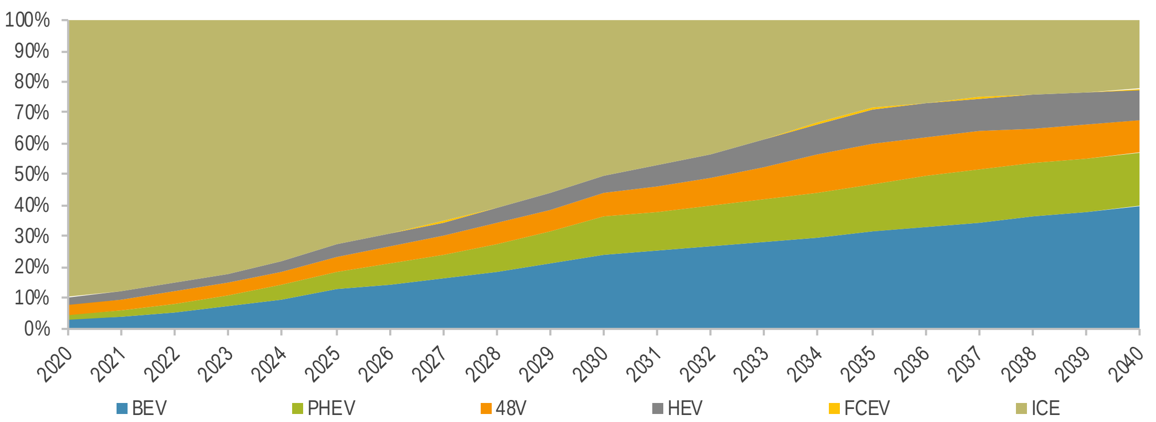
Figure 66: Outlook sales by e-powertrain type, 2020-2040 (Units sold)



Source: Roskill, 2020.

In the base-case scenario we estimate European fully electric and plug-in hybrid vehicle sales to total 6.4M (or 36% of sales) across both passenger and commercial applications. In comparison, the European Commission forecast 14% of vehicle sales to be either fully electric or plug-in hybrids by the same year. By 2040, we forecast European fully electric and plug-in hybrids sales of 10M, representing 57% of total vehicles sold within the passenger and commercial segment.

Figure 67: Passenger & Commercial vehicles: Penetration rate of electric vehicles over the total European automotive market, 2020-2040 (% unit sales)



Source: Roskill, 2020.

Table 7 below portrays the forecast European sales split across vehicle segment types. By 2040 around 22% of all vehicle sales are forecast to still have a purely ICE powertrain. When accounting purely for passenger cars this figure would be reduced to 19%.

Table 7: Passenger & Commercial vehicle sales by powertrain in Europe

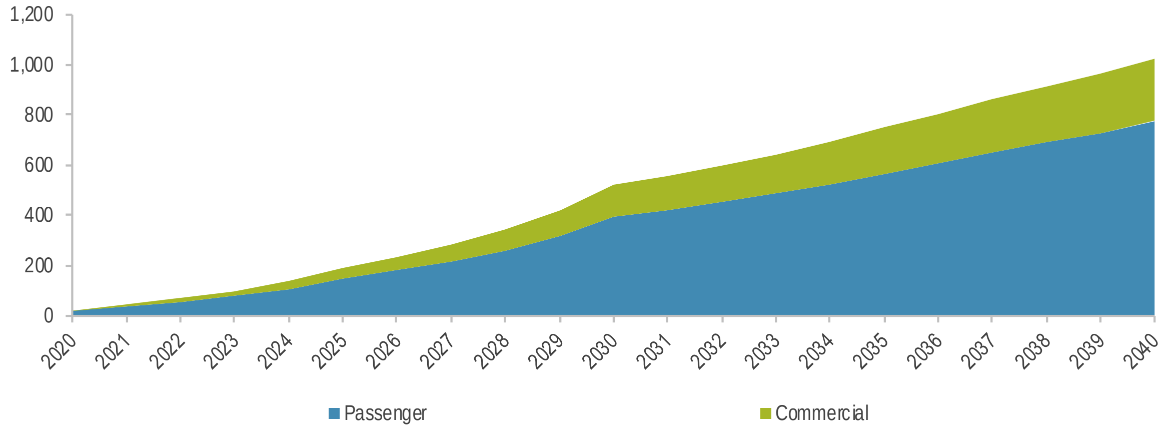
Type of powertrain	2030	2030 (% sales rate)	2040	2040 (% sales rate)
Plug-in (BEV, PHEV)	6,421,545	36%	10,007,112	57%
All electrified (BEV, PHEV, HEV, 48V, FCEV)	8,770,438	50%	13,620,966	78%
ICE	8,851,372	50%	3,927,286	22%
Total	17,621,810	100%	17,548,253	100%

Source: Roskill, 2020.

4.4.2 Outlook for cathode demand

Under the base-case scenario, we forecast that the resulting xEV sales across all e-powertrain types would total approximately 1,000GWh of battery capacity by 2040. This compares to an estimated 1,110GWh of installed European battery manufacturing capacity in the corresponding year.

Figure 68: Battery capacity across all electrified vehicles sold in EU27, 2020-2040 (GWh)

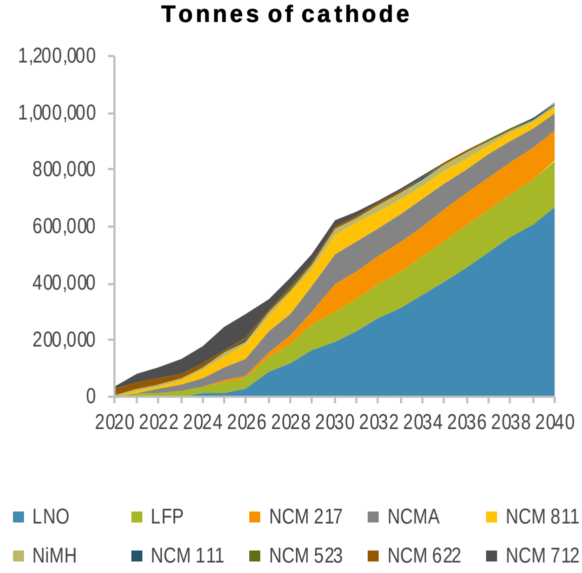


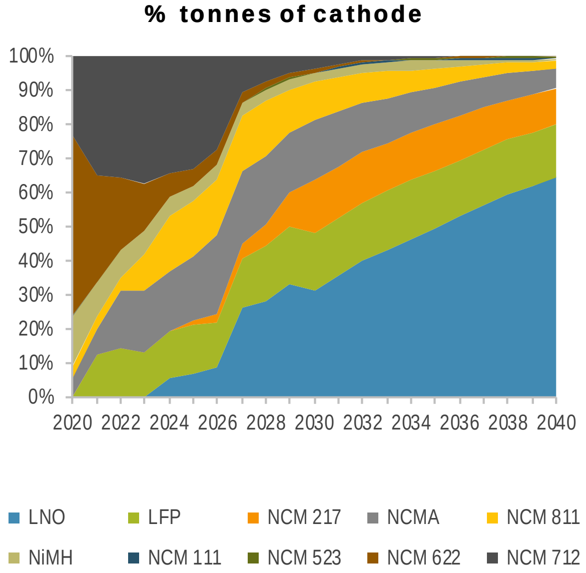
Source: Roskill, 2020.

To feed this battery demand around 1Mt of cathode materials is forecast to be required by cell makers domestically. Comparatively, the global lithium-ion battery industry required 382kt cathode materials in 2019 across all end-use sectors (Portable electronics, ESS, EVs etc). Representing around 38% of the total requirement forecast by the end of the outlook period in Europe alone.

By cathode type, Europe is forecast to utilise mostly ultra-high nickel cathode materials, as outlined in current auto and cell maker technology roadmaps. In 2020, however, some European cathode makers showed a degree of scepticism on the early adoption of these chemistries due to the difficulty of mass scale manufacturing and pack level management. Nevertheless, the entire EV battery supply chain ecosystem (including European companies) are working towards these types of high nickel cathodes. Formulations of such include LNO, NCMA, or NCM 811 as aforementioned. When compared to other regions like China, Europe is not expected to produce or demand LFP-based batteries. Albeit this could change during the outlook period.

Figure 69: European cathode demand in sold electric vehicles (passenger & commercial), 2020-2040





Source: Roskill, 2020.

We forecast these high-nickel based batteries to be first used in premium vehicle offerings (E-F and SUV segments) until large-sized cells can be safely manufactured and adopted for the mass market in an economic manner. Until such time, intermediate chemistries like NCM 712 are expected to be applied more commonly amongst mass market models.

Beyond 2030, we forecast ultra-high nickel chemistries like LNO and its variants with over 80% nickel content to increase in market share. This could be achieved either through standard liquid-electrolyte Li-ion batteries, cell designs using solid-electrolyte and advanced anodes using high silicon loadings or lithium metal foils. The reason for this is that LNO and its variants would involve minimal or no use of cobalt whilst delivering the highest possible energy density at pack level.

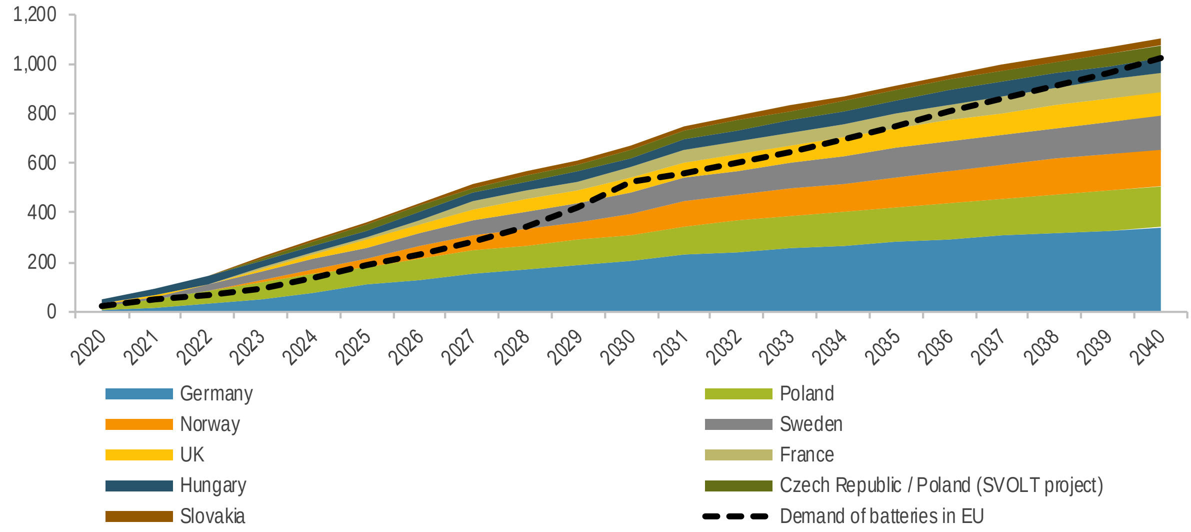
Some battery projects in Europe, like Moron Batteries or BritishVolt, envision the use of Li-S (Lithium-Sulphur) batteries. However, currently there is no commercial indicators that show Li-S batteries could be used for automotive applications. This is a result of their poor cycle life, high production cost, safety issues, and mass manufacturing complexities. Albeit it is reasonable to assume that new disruptive battery technologies beyond Li-ion could irrupt the European battery ecosystem in latter half of the outlook period.

4.4.3 Outlook for battery cell production

Over the next two decades, battery cell makers will expand their respective manufacturing capacities to match demand from the auto industry. A key transformation already underway by cell makers is the de-centralisation of battery production in Asia, where Europe is forecast to be a significant beneficiary of such. European institutions play a leading role in setting transport emissions standards in conjunction with region being forecast to become the world's second largest EV market. This, alongside the streamlined and quick nature of its automotive supply chain, will require battery companies to serve their automotive clients on a "just-in-time" basis. Such a business model requires battery companies and their upstream suppliers to move closer to regional automotive manufacturing hubs. As a result, Roskill estimates that Europe will increase its installed Li-ion battery manufacturing capacity from 48GWh in 2020 to 670GWh in 2030, before reaching 1,100GWh in 2040.

This “Gigafactories” capacity assessment has been based on the public announcements of incumbent battery companies. However, most of these public announcements focus on the period 2020 to 2030. To forecast Gigafactories capacity to 2040 Roskill has used regional growth assumptions based on its automotive model. Roskill has also adjusted the capacity of some of these plants to reflect the construction challenges that these companies face. Insight which has been corroborated with industry leading market participants.

Figure 70: Gigafactory capacity in Europe vs. European battery demand, 2020-2040 (by country GWh)

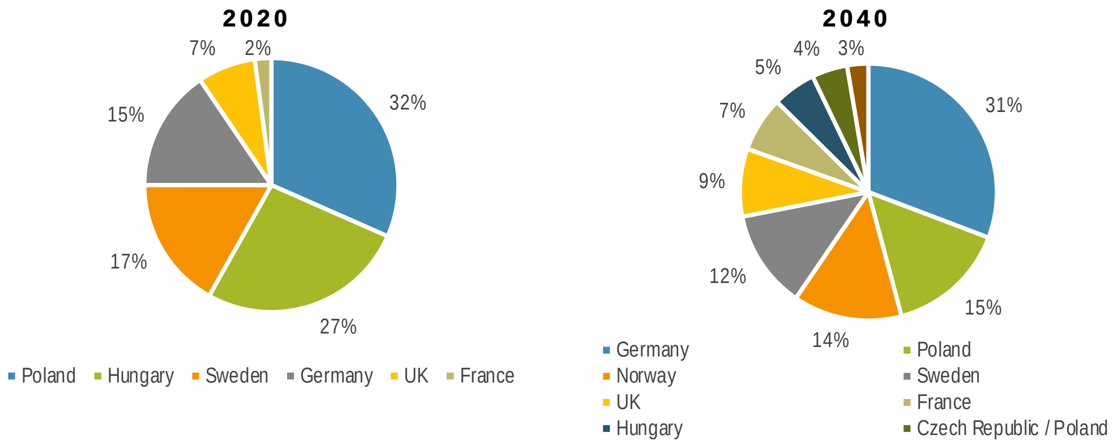


Source: Roskill, 2020.

Europe’s battery industry is considered most likely to develop in Germany and neighbouring countries such as Poland. While Asian companies are expected to continue to dominate the European market, a small number of European battery makers, such as Northvolt or the SAFT-PSA consortium, are expected to commission capacity supported by European policy. Projects including the European Battery Alliance are likely to support the creation of several consortiums led exclusively by domestic chemical and battery companies. An example of this are the two projects led by SAFT and PSA with Peugeot in France and Opel in Germany, with each targeting a 30GWh capacity.

Northvolt is, however, the most realistic developer to reach commercial status given the public support from the European Investment Bank alongside increasing battery orders from the private sector. Northvolt stated in December 2019 to have US$13Bn worth of pre-orders in hand, enough to cover its first five years of production. To fulfil these orders, the Swedish company is expected to create two plants based in Sweden and Germany. Where construction of such capacity is being supported by investments from the likes of Volkswagen, BMW, IKEA, Goldman Sachs, Vattenfall and Siemens.

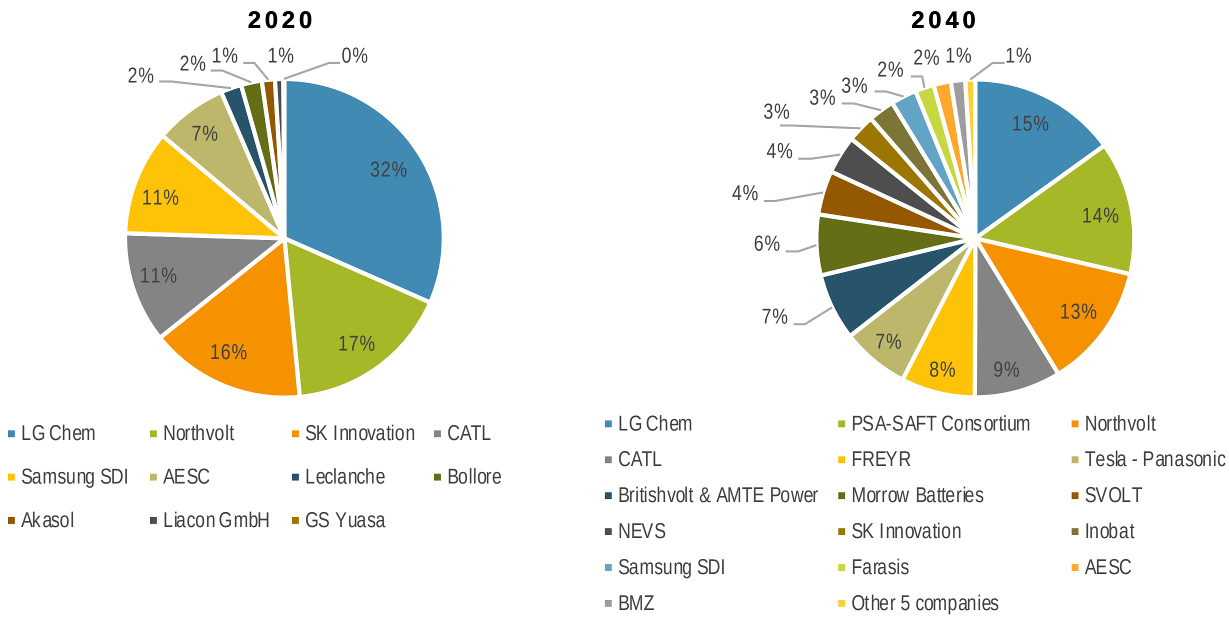
Figure 71: European Li-ion battery manufacturing capacity, 2020 & 2040 (% installed GWh)



Source: Roskill, 2020.

At a company level, Korean companies currently hold a dominant position in the European automotive battery market. A focus of building out manufacturing capacity abroad by both Korean and Japanese companies has been driven by the relatively low domestic EV production in their countries of origin. An example of this is Panasonic's joint venture with Tesla in the USA and LG Chem with its factories in both the USA and Poland. In 2020, both companies had more installed capacity abroad than in their home countries. Going forward, however, they will have to compete with Chinese companies (such as CATL and BYD) which are also expected to scale up manufacturing capacity in Europe. Chinese players are well established in their domestic market due to government support received since the early 2010's. Chinese companies are forecast to increase their capacity and market shares within Europe over the outlook horizon. Key Chinese players who have secured OEM supply contracts and target European production include CATL, Farasis, and NEVS.

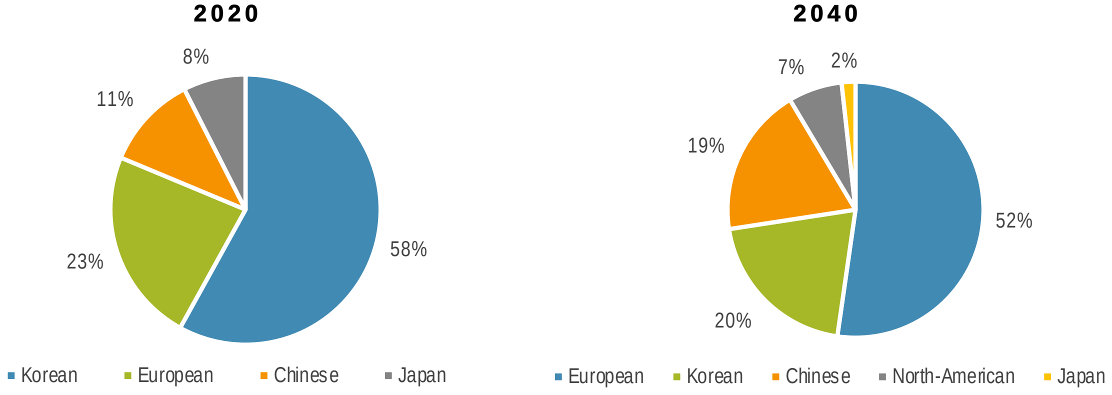
Figure 72: European Li-ion battery manufacturing capacity by battery cell company, 2020 & 2040 (% installed GWh)



Source: Roskill, 2020.

Despite efforts by European regulators and local upstream battery materials companies, around 50% of the installed battery manufacturing capacity by 2040 will be non-European. Market leaders are expected to be those companies already holding a dominant position in Europe in 2020 (such as LG Chem and Samsung SDI).

Figure 73: Origin of battery manufacturing companies in EU27, 2020-2040 (% by installed capacity GWh)



Source: Roskill, 2020.

When analysing the capacity plans of battery cell companies in Europe in the period 2020 to 2040, Roskill considers the following conclusions likely:

- Rapid industry growth to take place (x23 times more GWh installed capacity than in 2020)
- More competition and less market share per company is forecast (21 companies in 2040 vs. 10 companies in 2020)
- Larger average battery manufacturing plant capacity (x21 more GWh installed capacity per plant)
- Further delocalisation of battery production away from Asia (9 countries by 2040 vs. 6 countries in 2020)

Table 8: Market structure evolution, 2020–2040

Description	2020	2040	Multiplier
Number of existing companies	10	21	x2.1
Number of manufacturing plants	12	26	x2.2
Countries producing batteries	6	9	x1.5
Resulting GWh capacity	47	1,100	x23
GWh per plant	2	42	x21
Average market share per company	9.1%	4.8%	-47%

Source: Roskill, 2020.

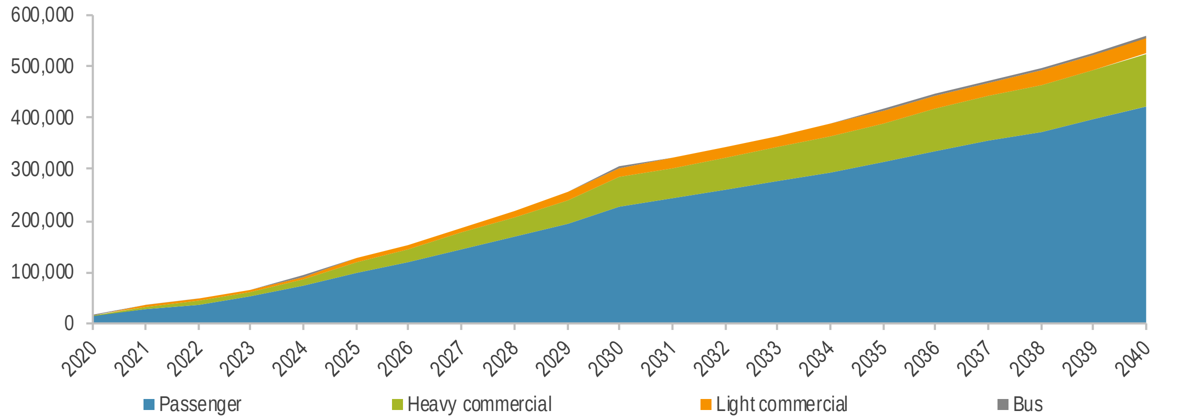
4.4.4 Outlook for nickel demand

4.4.4.1 EV sales: Base-case

The European EV transition is expected to demand considerable amounts of different raw, refined, and active battery materials. Among them, nickel is forecast to have one of the largest proportions of overall raw material demand from the EV sector and its focus on high-nickel chemistries. Roskill forecast Europe's nickel demand to total 304kt and 560kt of contained metal in batteries by 2030 and 2040 respectively, an increase from 17kt in 2020.

In the analysis of nickel demand different forecast methods lead to different results. For example, the nickel demanded by Gigafactories is somewhat different to the nickel required by cathode makers, or the nickel demanded by estimated EV sales. Such differences are the result of varied procurement strategies, diverse production routes, and different technology assumptions like those related to energy density or average battery capacity. Nevertheless, Roskill considers an increase in nickel demand between 30-40x times likely by the end of the outlook period should Li-ion batteries remain as the dominant e-powertrain storage technology.

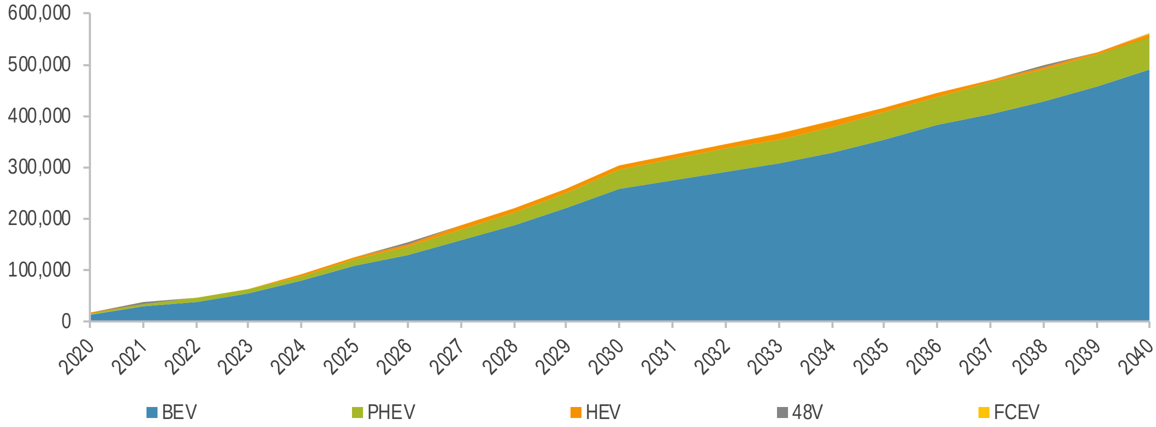
Figure 74: European nickel demand in electric vehicle sales by vehicle type, 2020-2040 (t Ni)



Source: Roskill, 2020.

On an e-powertrain basis, fully electric vehicles (BEV) are expected to be the largest nickel consumer alongside PHEV vehicles. While initially automakers may opt to produce hybrid powertrains, Roskill's European EV sales baseline and future stringent fleet average emissions limits suggest that BEVs are expected to dominate the market during the outlook period.

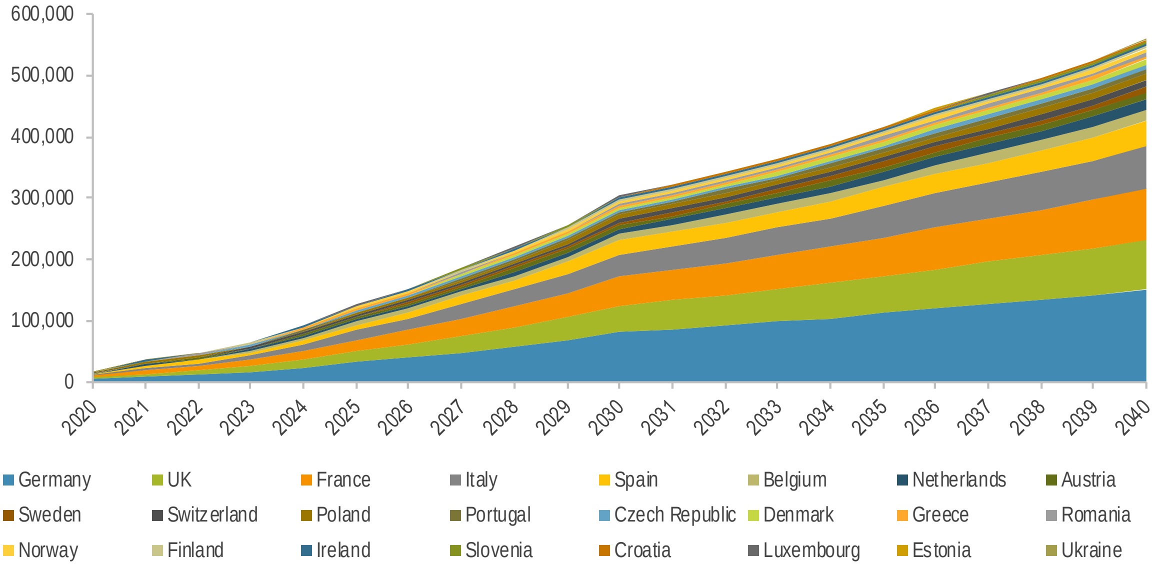
Figure 75: European nickel demand in electric vehicle sales by e-powertrain type, 2020-2040 (t Ni)



Source: Roskill, 2020.

Germany, UK, and France are expected to become the three largest nickel consumers on an EV sales basis. This not only aligns with the European EV sales baseline but also with these countries being the three largest automotive markets in Europe. Should European emissions limits be effectively implemented across the EU, Italy and Spain have the potential to become the fourth and fifth largest nickel consumers on an EV sales basis. This is despite the head start of smaller but wealthier European nations like the Netherlands or Sweden.

Figure 76: European nickel demand in electric vehicles sales by country, 2020-2040 (t Ni)



Source: Roskill, 2020.

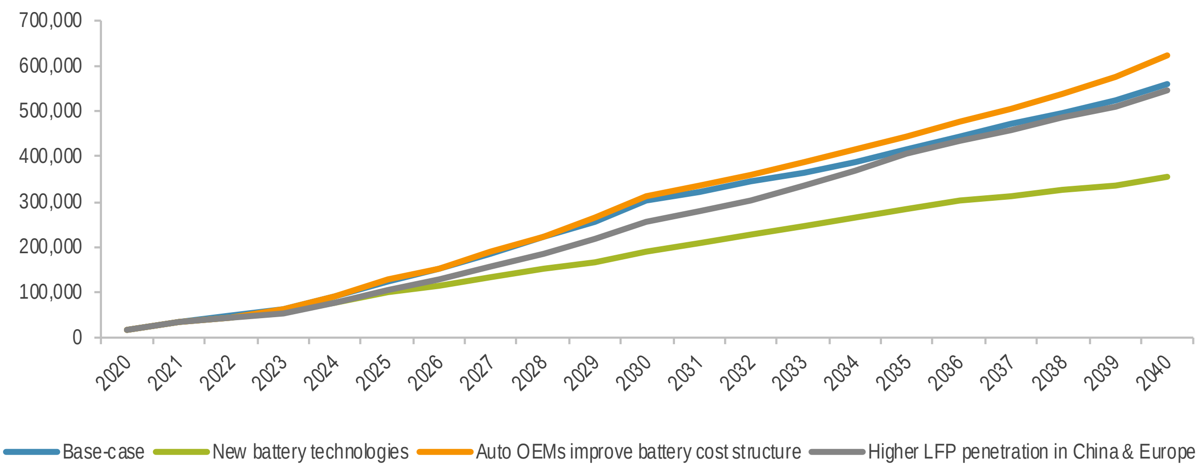
4.4.4.2 Scenarios for nickel in Europe

As in Section 4.2, Roskill has created three different European scenarios based on different technology parameters. Roskill has modelled two low-case and one high-case scenarios for nickel demand. Roskill considers a scenario in which automakers produce electric vehicles over and above the mandatory EV regulatory thresholds is unlikely. This is predominantly due to the cost challenges in EV manufacturing compared to ICE's and the uncertainty around consumers' attitude towards electric vehicles.

Main scenarios:

- Europe opt to use a higher share of LFP batteries (Low case)
- New battery technologies (Low case)
- Auto OEMs improve battery cost structure (High case)

Figure 77: Nickel in EV batteries scenarios, 2020-2040 (t Ni)

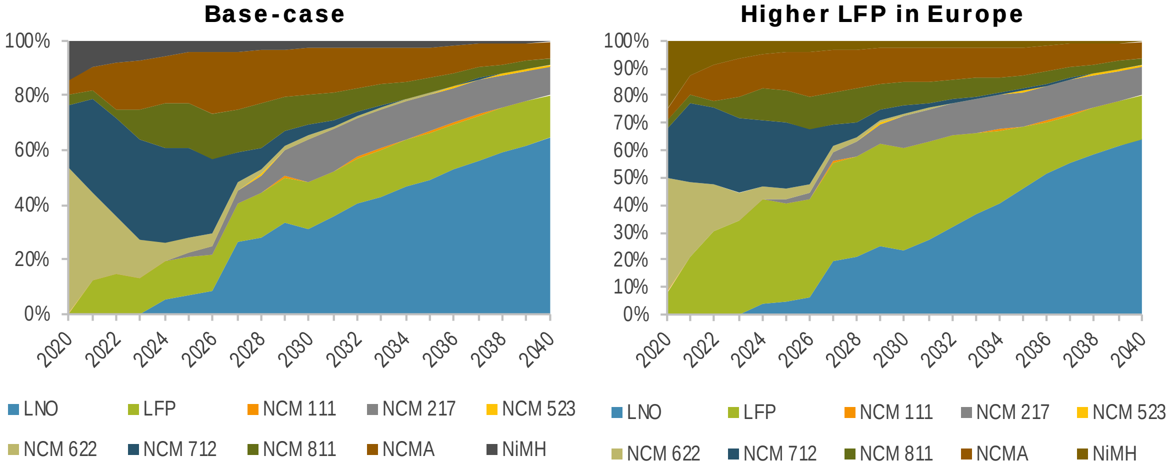


Source: Roskill, 2020.

Explanation of scenarios:

1. **Europe opt to use a higher share of LFP batteries:** this scenario assumes an estimated 30% penetration rate of LFP cathode material in Europe by 2030. This rate is progressively phased-out by 2040. Most LFP is applied to urban small cars (A-C segment) and higher volumes of LFP are also applied to commercial vehicles. The result is an estimated 8% less nickel consumption on a cumulative basis during the period 2020 to 2040 in automotive powertrain batteries when compared to Roskill Base-case scenario.

Figure 78: Higher LFP in Europe comparison to Base-case, 2020-2040 (% t of cathode material)



Source: Roskill, 2020.

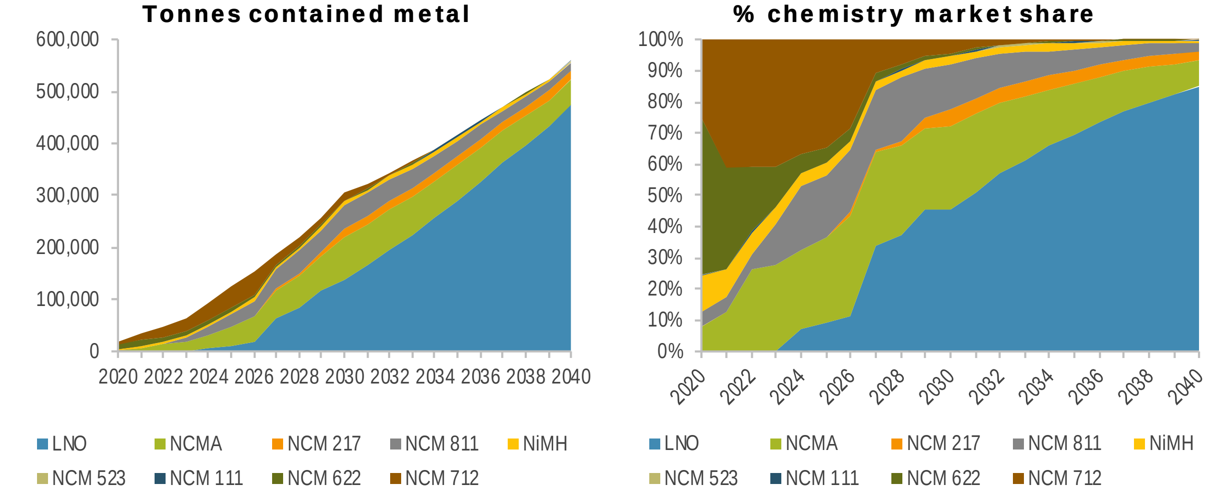
2. **New battery technologies scenario:** this scenario assumes a progressive phase-in of higher energy density battery technologies during the outlook period. The scenario assumes that in 2025 Li-ion batteries with Si-based anodes are fully introduced increasing average energy density by 15-30% compared to 2020. Later, higher energy density technologies like solid-state batteries start to be introduced increasing the average energy density in 2040 by 60-80% compared to 2020. The result is an estimated 33% less nickel consumption on a cumulative basis in automotive powertrain batteries when compared to Roskill's base-case scenario.

3. **Auto OEMs improve battery cost structure:** this scenario assumes aggressive improvements in battery costs with some automotive OEMs using with fully dedicated e-platforms (reducing assembly times) and achieving ICE-BEV production cost parity as early as 2025 in some models of the A-D segments. The result is an estimated 6% more nickel consumption on a cumulative basis in automotive powertrain batteries when compared to Roskill's base-case scenario. As well as such automakers being expected to sell a larger number of vehicles, this scenario also assumes a slightly higher penetration of LFP-based batteries and other higher energy density new battery technologies that reduce overall nickel consumption.

4.4.4.3 By cathode chemistry

European auto and cell maker industry are geared towards the use of high-nickel content batteries. This is reflected in the plans of major European cathode manufacturers like Umicore, Johnson Matthey, and BASF. Roskill forecast around 85% of nickel demand (or 264kt) in Europe to come from cathode chemistries using >80% nickel content in 2030. By 2040, such cathode chemistries could represent around 96% of nickel demand (or 537kt).

Figure 79: Nickel demand in Europe by cathode chemistry, 2020-2040



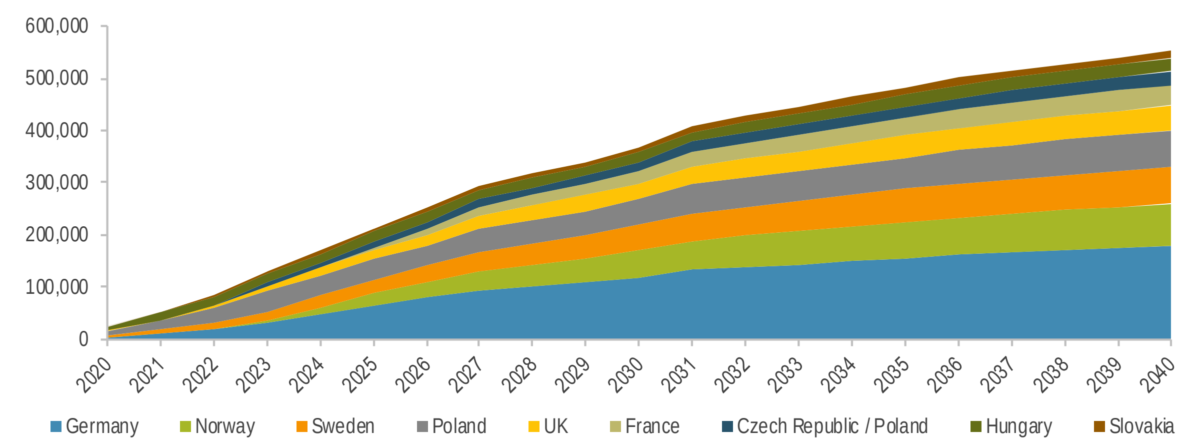
Source: Roskill, 2020.

Nevertheless, some cathode producers in 2020 have pointed out the criticality of nickel in the battery supply chain and launched several cathode R&D projects focused on reducing nickel contents whilst increasing manganese. Among these chemistries the most notable would be NCM 217 of BASF or the LNMO of Haldor Topsoe. But whilst these chemistries promise similar energy density specifications than their high-nickel peers via increased operating voltages (~4.7V vs. industry standard ~3.7V), several technical barriers like manganese dissolution and its subsequent impact on cycle life still need to be overcome. Roskill forecast nickel demand from such low nickel (high manganese) cathode chemistries could total 17kt by 2040.

4.4.4.4 European Gigafactories

As of 2020, nine countries (including Norway and the UK) are positioning themselves to be the main automotive powertrain battery manufacturers in the European region. Most of the Gigafactories present (or planned) in these countries largely intend to supply battery cells to automotive manufacturing hubs. Roskill forecast Germany and its neighbouring countries (Poland, Hungary, Czech Republic, and Slovakia) to account for 57% (553kt) of Europe's nickel demand by 2040. A direct result of the German automotive sector manufacturing concentration locally.

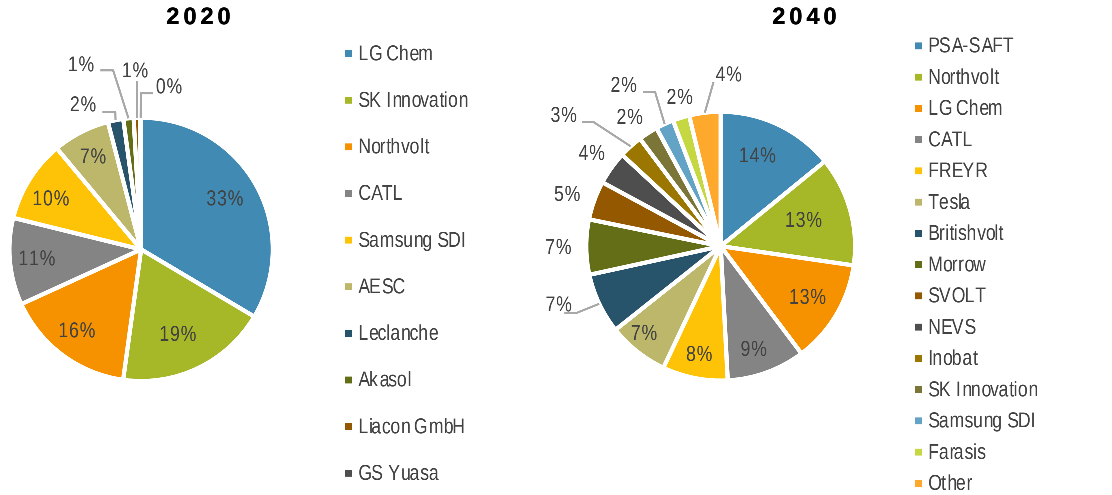
Figure 80: Nickel demand in European Gigafactories, 2020-2040 (t Ni)



Source: Roskill, 2020.

Out of the established cell makers in 2020, Korean companies are forecast to be the largest consumers of nickel in Europe, totalling almost 16kt. Conversely, by 2040 'home-grown' European battery plants could potentially dominate domestic nickel demand. Where if materialised home-grown companies could account for almost half of domestic battery production and subsequent nickel consumption. Among them, Northvolt, the PSA-SAFT consortium, Freyr, Britishvolt, Morrow, and Inobat would likely be the leaders and could potentially consume 290kt.

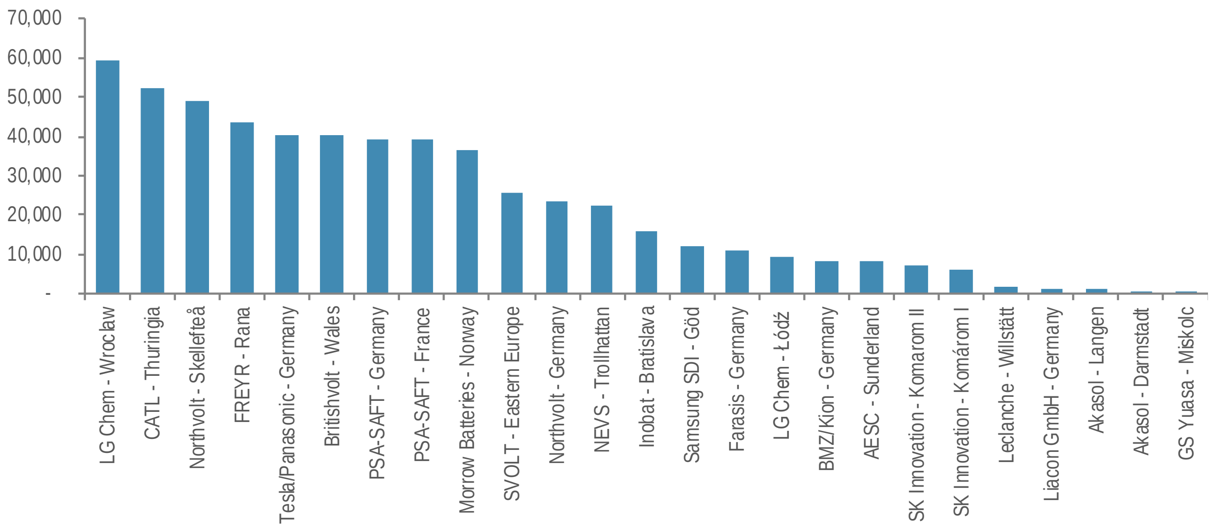
Figure 81: Nickel demand by battery maker in Europe, 2020-2040 (% t Ni)



Source: Roskill, 2020.

On a plant-by-plant basis, the top-five plants in Europe are forecast to demand around 45% (245kt metal) of the regions total by 2040. Within the top-five Gigafactories by consumption, two companies are European (Northvolt and FRER). Where the former is likely to establish commercial scale manufacturing in the next few years.

Figure 82: Nickel demand by European Gigafactory, 2040 (t Ni)



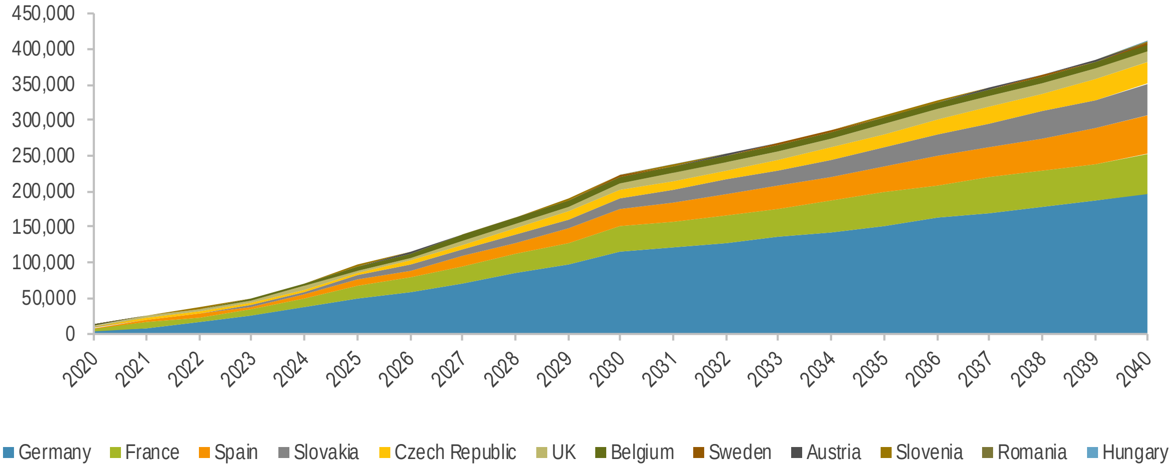
Source: Roskill, 2020.

4.4.4.5 By EV production plant

European OEM's have led the development of plug-in electric vehicles since the early 2010s. However, over the past decade such OEM's have not sufficiently scaled up their electric vehicle production for the upcoming fleet average emissions limits. This has allowed disruptive carmakers like Tesla to gain a major foothold in the European market, across unit sales, charging infrastructure networks, and now local EV and battery manufacturing plans. As a result of such competitive and regulatory pressures, European OEM's have progressed at an increasing rate since 2017. This has been seen in the announcements of Volvo stating to sell only electrified vehicles by 2019, Daimler announcing the launch of its electric EQ family in 2018, and the Volkswagen Group announcing its fleet electrification plans in both in Europe and China.

Roskill has forecast EV production, and its subsequent nickel requirements, by automotive manufacturing plant in Europe according to production plans of respective OEMs and available plant information. On a country basis, Germany, France, and Spain are forecast to be the largest consumers of nickel for EV batteries across the outlook period. These three countries are expected to account for around 72% (306kt) of nickel metal demand from European passenger car manufacturing.

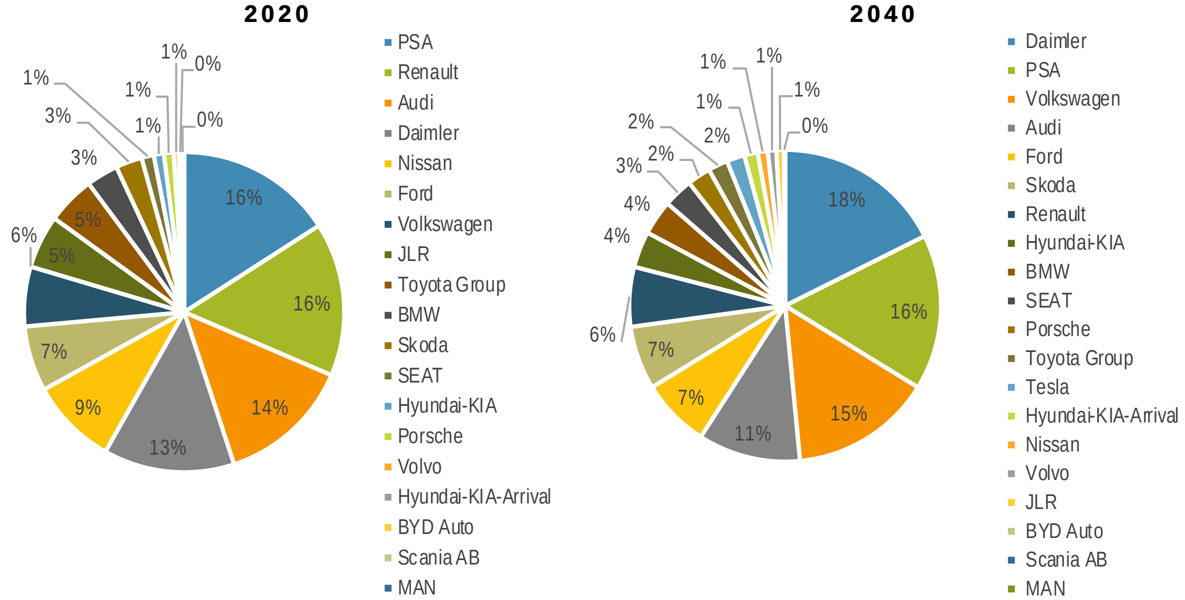
Figure 83: Nickel demand in EV passenger cars produced by European country, 2020-2040 (% t Ni)



Source: Roskill, 2020.

While initially automakers may opt to use hybrid powertrains as suggested by European carmakers BMW, Volvo, and PSA, the European baseline scenario suggests that BEVs are expected to dominate by the end of the outlook period. Furthermore, when analysing respective OEM plans in Europe by 2030, around 40% of production is expected to be dedicated to BEVs with a further 26% dedicated to PHEVs. Car makers with BEVs constituting over 40% of their total production include Daimler, PSA, VW Group (and its brands Audi, Skoda, Seat and Porsche), and Renault. These four carmakers are expected to consume 326kt of nickel metal, or around 77% of the total nickel demanded in European electric vehicles by 2040.

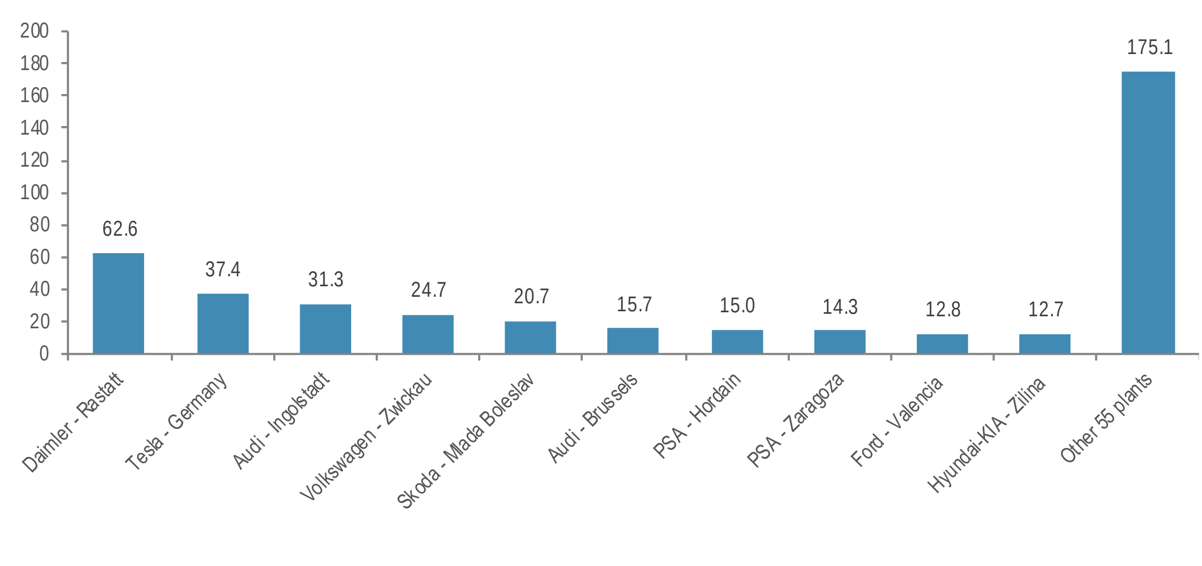
Figure 84: Nickel demand by EV passenger Auto OEM in Europe, 2020-2040 (% t Ni)



Source: Roskill, 2020.

On a production plant basis, the ten largest passenger EV manufacturing plants in Europe are forecast to consume 60% of the regions total EV nickel demand, or 247kt metal. This compares to the other 55 passenger EV production plants demanding the remaining 40%. Among the top ten EV production plants are the likes of Daimler, Volkswagen Group, and PSA.

Figure 85: Nickel demand by the top-10 EV passenger production plants in Europe, 2040 (Kt Ni)

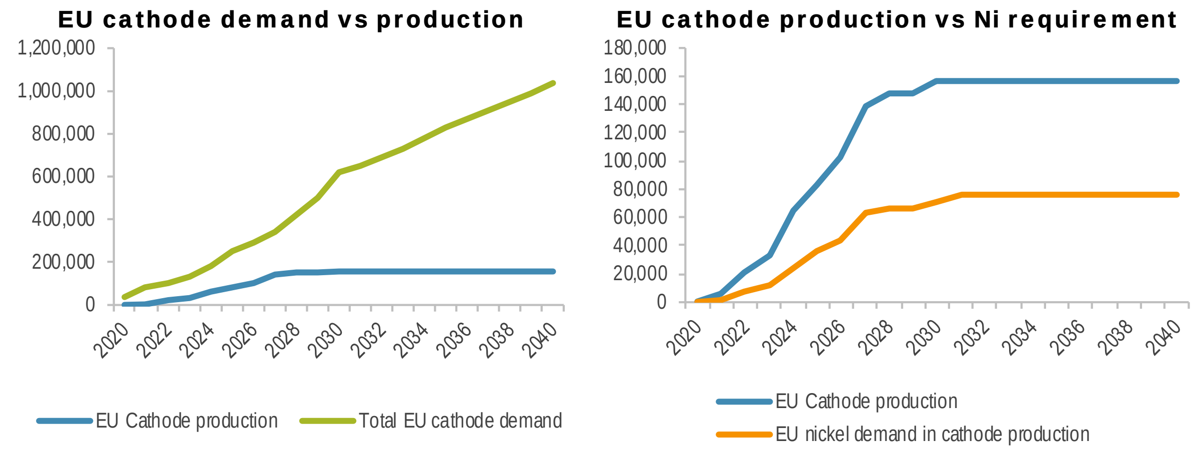


Source: Roskill, 2020.

4.4.5 Cathode manufacturing

Under the base-case scenario, Roskill forecast EU cathode demand to increase significantly over the coming two decades. A portion of this demand is expected to be served by domestic manufacturing capacity, albeit an increasingly smaller portion post 2030. The discrepancy between total forecast requirement and domestic manufacturing is shown in Figure 86 below. This highlights a constant need for domestic cell makers to rely on foreign sourced cathode supply for use within the EU. With Northvolt being the only exemption to such as it intends to provide its cell cathode requirements internally. Within EU cathode manufacturing, nickel demand is forecast to grow at 82% CAGR to 2030, reaching around 70kt Ni before flattening off throughout the 2030's. This is predominantly owing to the lack of visibility on new cathode capacity being constructed beyond the late 2020's.

Figure 86: EU cathode demand, production and contained nickel demand, 2020-2040



Source: Roskill, 2020.

In parallel to EU EV sales growth and Gigafactory capacity investment, domestic cathode manufacturing is now also beginning to see development. Albeit, at a slower rate to that of Gigafactory buildouts in the region. With only four key players targeting commercial production of cathode active materials in the EU, market shares are likely to be tightly held moving forward pending additional market entrants. It is also worth noting that all four of the current and future market participants are home-grown, originating from locally from the EU and United Kingdom.

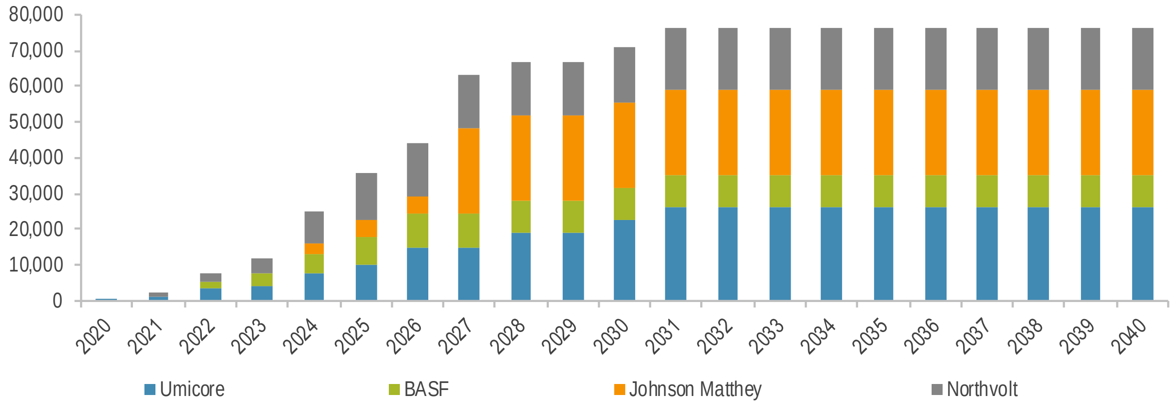
Table 9: EU current and future cathode manufacturers[1]

Company	Plant location	Forecast chemistry production
Umicore	Nysa	NCM 622, NCM 712, NCM 811
BASF	Schwarzheide	NCM 622, NCM 712
Johnson Matthey	Konin	eLNO 3% Co
Northvolt	Skellefteå	NCM 622, NCM 712, NCM 811

Source: Roskill, 2020.
([1]) Only includes commercial scale cathode production targeting lithium-ion EV batteries, does not include pilot plant scale manufacturing facilities

As aforementioned in previous sections, Roskill forecast the EU to predominantly focus on high-nickel cathode chemistries. As such, it is expected that local manufacturing will also focus on the high-nickel NCM and eLNO family variants. This has been witnessed in public announcements to date and known cell maker supply agreements. Under Roskill's base-case scenario, around 71kt Ni and 76kt Ni contained within nickel sulphate could be demanded from cathode makers in 2030 and 2040, respectively.

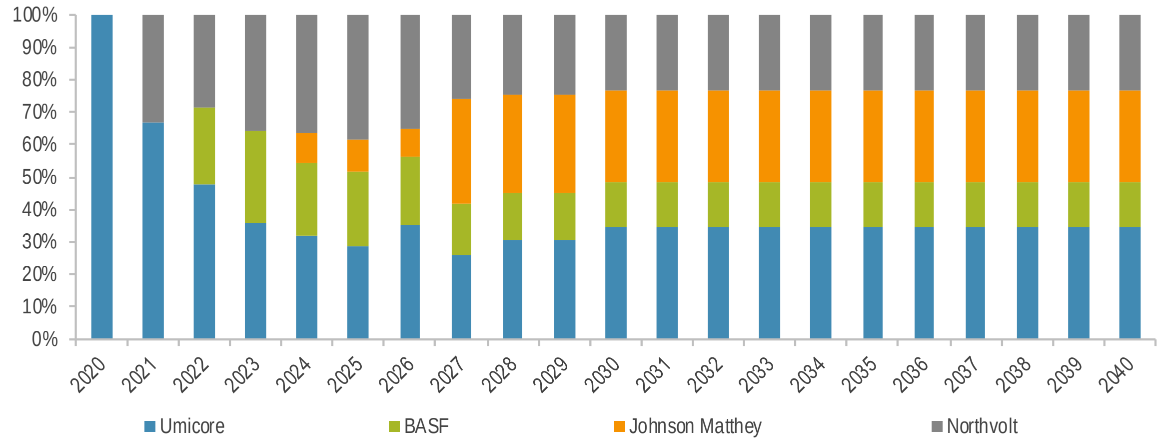
Figure 87: EU nickel in cathode demand, by producer 2020-2040 (t Ni in cathode)[1]



Source: Roskill, 2020.
([1]) Only includes commercial scale cathode production targeting lithium-ion EV batteries, does not include pilot plant scale manufacturing facilities

Of the forecast EU cathode makers Umicore is establish the largest market share in the domestic EV sector, totalling around 33% post-2030. New market incumbents, such as Johnson Matthey, BASF and Northvolt, are all forecast to reach commercial scale production by the mid-late 2020's. It should be noted that as the EU EV and cell manufacturing industry develops over time it is likely that additional market entrants may construct additional cathode capacity in the EU. Roskill considers such investment likely to come from foreign cell makers to bolster their in-house supply chains.

Figure 88: EU cathode producer market share[1], 2020-2040

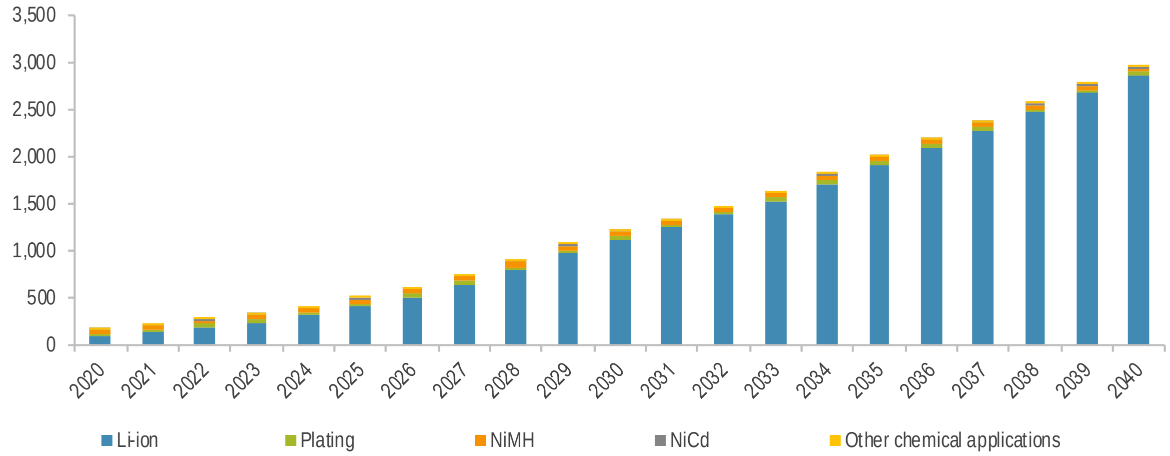


Source: Roskill, 2020.
([1]) Only includes commercial scale cathode production targeting lithium-ion EV batteries, does not include pilot plant scale manufacturing facilities

4.5 Nickel sulphate demand

In 2020, global nickel sulphate demand is forecast to total approximately 173kt Ni. As a refined sub-product of the overall nickel market, demand growth within the sector is forecast to see the largest increases moving forward. Between 2020 and 2030, nickel sulphate demand is forecast to increase by 22% CAGR, totalling over 1,200kt Ni. Whilst over the full 20-year outlook horizon a growth rate of 33% CAGR is forecast to see demand reach just under 3,000kt Ni by 2040.

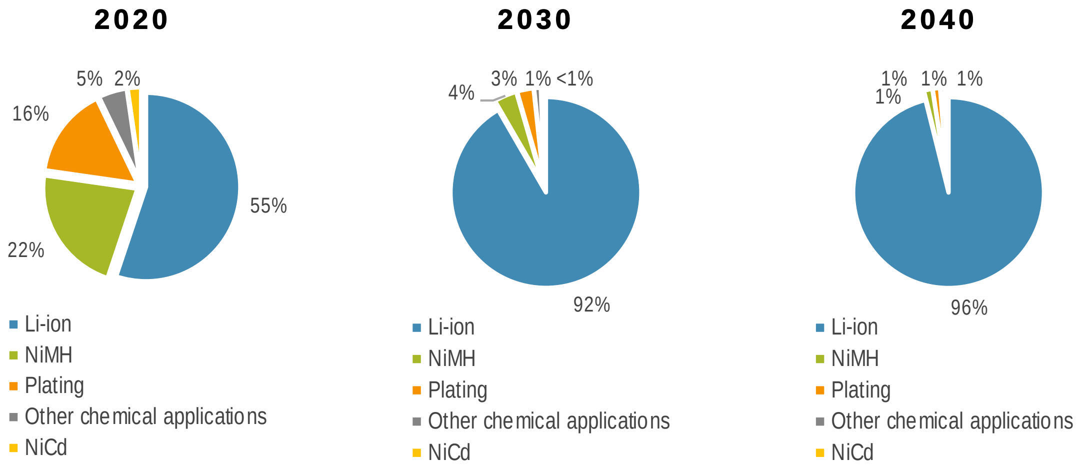
Figure 89: Nickel sulphate demand by first-use application, 2020-2040 (kt Ni)



Source: Roskill, 2020.

The significant demand growth expected for nickel sulphate is fundamentally driven by lithium-ion battery products and end-use applications. Without lithium-ion batteries, nickel sulphate would remain a relatively small and niche chemical market, as has historically been the case. However, the rise of lithium-ion batteries since the late 2000's has rapidly taken the majority of total demand, estimated at 55% in 2020. Roskill forecast this increase to over 90% of total demand share by 2030, where such will be consolidated with continued growth throughout the 2030's.

Figure 90: Nickel sulphate demand breakdown, by end-use sector, 2020-2040



Source: Roskill, 2020.

4.6 Main sources of uncertainty

4.6.1 Challenges for the European battery industry

The base case assumes 1,104 GWh could be installed in the EU27 by 2040, but there are significant risks and uncertainties over this forecast which will impact the production of batteries in the EU27 and demand for nickel. Should some of the downside risks occur this may hold back the development of the EV sector in the EU27 and the EU27 achieving its carbon reduction targets.

While some European battery manufacturing projects will be possible through government support and regulators aiming to protect domestic automotive manufacturing, many recent Gigafactory project announcements from new market participants may underestimate the challenges surrounding mass scale battery cell production and associated ramp up of greenfield capacity. Historically, it has taken 10-20 years for experienced battery makers to fine tune their operations to optimise production yields, standardise quality, develop competitive technologies, or reach profitability. As an example, Panasonic reported its first ever quarterly profit from its USA battery business with Tesla in Q1 2020 following a decade-long relationship with the EV maker.

Established giants like China's CATL needed considerable government support to become one of the global leaders in battery manufacturing. Founded in 2011, CATL's success was underpinned by one of the most supportive sets of industrial policies in the history of China. Regulators in China conditioned domestic automakers' getting access to a NEV subsidy program on them installing Chinese made batteries through a government list of "recommended battery suppliers". This policy favoured local battery companies, such as CATL and BYD, which greatly improved their technology and production capacity. Although this policy ended in December 2018, local industry had by then locked up large supply deals with OEMs operating in China.

While this policy created few domestic battery giants, it also attracted a myriad of non-battery related Chinese companies to the battery business. In 2015, there were around 240 power battery companies operating in China. Many of these since disappeared and by the end of 2019 there were only 95 companies still in operation. Such bankruptcies not only reflect the highly competitive market, but also the need for industry consolidation as large captive clients are necessary to reach economies of scale, achieve pricing power, and continuously invest in R&D.

Most of the bankruptcies in China resulted from cashflow problems and extreme price competition, with larger competitors often selling at loss. These extreme pricing strategies, originally motivated by the cost pressures demanded by OEMs, only allowed the largest and financially robust companies to survive. Once an automaker had selected a battery maker, it became captive of the tailored cell (and sometimes BMS) design created by the battery maker. In parallel, many of the smaller players expanded rapidly between 2010-2016 due to high demand expectations and low requirements to access the subsidy program. The downfall for many was in the actual order volumes versus expectations, where such that the industry only operated at a 30-40% plant utilisation rate over a 3-5-year period.

By 2040, Roskill forecast 63 battery companies could be operational globally, with 21 of these in the EU27. However, is considered likely that the cell maker supplier landscape will experience a degree of consolidation moving forward. This would see larger companies absorbing smaller ones or the smaller players simply disappearing before reaching commercial manufacturing status. This would be the case unless European regulators condition, like China did pre-2019, the grant of purchase subsidies to EV models installing European batteries to favour a range of domestic players. Given the cost, quality, and warranty pressures that OEMs face at present, implementation of such regulation may be unlikely.

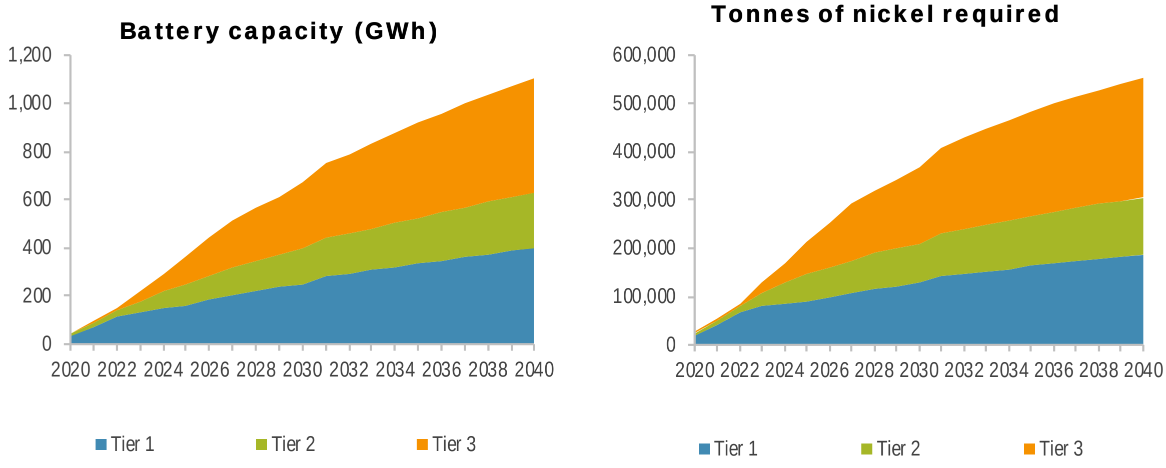
The possibility of smaller European battery companies disappearing from the market should be considered on two fronts. The first of which being the potential capacity void left in the market, and the second being the removal of subsequent nickel demand. To quantify these scenarios in its Gigafactories model, Roskill has included the "tiers" or relative market positioning of each battery company tracked. A tier system indicates the reliability or leadership of certain companies relative to their competitors:

- Tier 1 - "best in class"
- Tier 2 - "the market average"
- Tier 3 - "the followers" and most risky ventures.

Such classifications are based on a points system dependent on the following factors:

- Years of existence in the battery business
- Present battery production capacity
- Order backlog: existing orders with automakers
- Collaboration with carmakers: joint ventures or other co-production agreements
- Technology leadership: e.g. Ultra-high nickel chemistries
- Security of raw materials supply: deals with upstream and/or mining companies

Figure 91: European battery capacity and tonnes of nickel required by company tier



Source: Roskill, 2020.

Roskill forecast that tier 3 battery companies (see Annexes) are more likely to not fully complete their projects or will eventually disappear if not acquired by other larger players. As a result, an approximate 475GWh of planned cell capacity and 250kt of nickel demand could disappear from the European market.

Even large and reputed battery cell manufacturers may struggle in scaling battery operations, especially when manufacturing high-nickel cell chemistries. This has already been witnessed in LG Chem's scaling issues at its new plant in Poland. This could delay the ICE-BEV production cost parity which would ultimately affect the OEM's ability to profit from electric vehicles. Furthermore, this could drastically decrease nickel requirements if chemistries under 80% nickel are not phased out in the long run. European battery projects may be unable to compete with established Asian battery companies on cost unless European regulators level the playing field by subsidising local company cell production.

Another uncertainty that may affect demand for EVs and nickel on batteries is over the potential development of alternative powertrain technologies like hydrogen fuel cells, which could start to enter the mass market by 2030. This could reduce active materials requirements by the end of the outlook period. The technology transition towards fuel cell vehicles will, however, require a concerted effort to build vast refuelling infrastructure, and the upstream supply of blue and green hydrogen. In this regard, European OEMs including Volkswagen and Daimler stated in 2020 that they would end their passenger fuel cell programs as production cost and related infrastructure investments could not be met prior to 2030.

Finally, automakers could experience considerable cost challenges in the realisation of mass EV production. Demand uncertainty resulting from consumer attitudes is leading to underinvestment in e-mobility by some OEMs. In 2020, this was already delaying the adoption of dedicated manufacturing platforms that would simplify assembly, reduce production cost, and improve production specification. Strong signals need to be sent to European consumers over the necessary adoption of electric vehicles if underinvestment by incumbent carmakers is to be avoided.

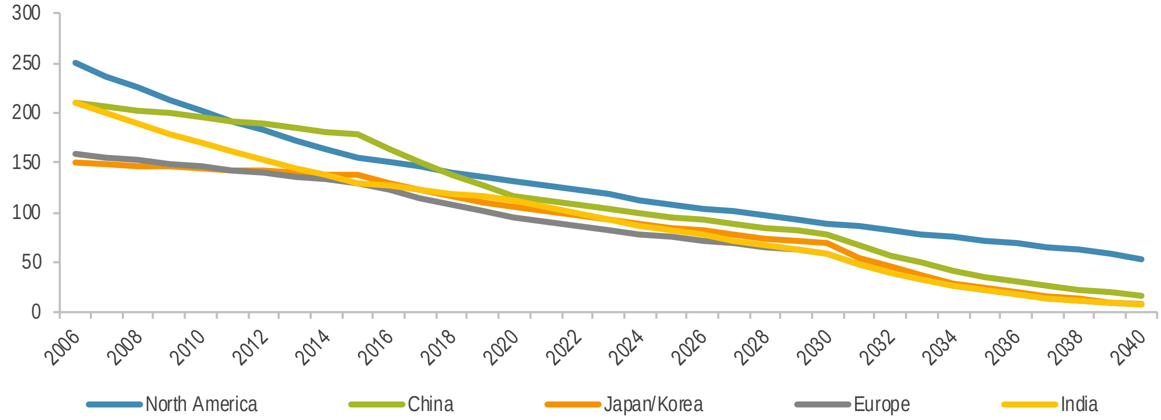
4.6.2 CO_2 emissions targets vs. EV targets in the study

This study does not underestimate the role of CO_2 emissions limits in the global push behind mass transport electrification. In its automotive forecast Roskill has used fleet average CO_2 emissions as a proportional proxy to assess future EV sales. While some countries or regions have clear emissions targets, others have emissions targets either misaligned with the requirements of reaching net-zero emissions by 2050 or have yet to establish emissions limits or an enforceable system to impose it.

In this regard, when more weight is added to the calculations based on emissions limits globally, fewer electric vehicles are sold. Conversely, when Roskill attributes a larger weight to the calculations based on EV sales targets in certain regions, overall forecast global EV sales were higher. While the forecasting model in which this study is based has been simplified to include the different factors and uncertainty surrounding EV and battery supply chains, a key takeaway is how flexible but somewhat ambiguous compliance systems like those based on CO_2 targets can actually delay the adoption of electric vehicles to meet climatic goals.

Nevertheless, other regulatory systems targeting the adoption of electric vehicles such as credit systems seem, at least in China and to some extend in Europe, to be clearer in nature (they attribute specific credits to BEV vs. PHEV or other hybrids) and appear more effective in practice.

Figure 92: CO_2 emissions targets by country/region (g CO_2/Km)[1]



Note: some values are estimates

Source: Roskill, 2020.
([1]) Estimates utilised within data set forecast

Furthermore, there are bans or prohibitions on ICE sales in place in some "EV-developed" countries. The legal instruments to effectively ban the sale of new ICE cars have, however, been vaguely discussed by the countries involved. They range from parliamentary resolutions/declarations, such as in Germany and Netherlands, to non-binding policy strategies such as in France. Other countries that initially proposed a total ban, such as Norway and Austria, now opt for less intrusive policies – such as heavy taxation on ICE cars. However, the long-term nature of these measures and the legal ambiguity around them does not necessarily encourage all automakers to take immediate steps towards a full EV scenario.

Table 10: Announced national/local ICE ban targets

Country	Term	Scope	Likelihood	Country
China	n/a	Ban of ICEs	High	China
Denmark	2050	CO2 Targets	Medium	Denmark
France	2040	Ban of ICEs; Paris by 2030	Medium	France
Germany	2030	Ban of ICEs	Medium	Germany
India	2030	Ban of ICEs	Low	India
Netherlands	2030	Ban of ICEs	High	Netherlands
Norway	2025	Ban of ICEs	High	Norway
South Korea	2020	EV target - 250,000 (30% market share 2017-2020)	High	South Korea
Spain	2020	Ban of ICEV in Madrid centre (car models pre-2000)	High	Spain
Sweden	2030	Ban of ICEs	High	Sweden
UK	2035	Ban of ICEs; Scotland by 2032	High	UK
California	2027-2030	Ban of ICEs	High	California

Source: Roskill, 2020.

5 Impact of batteries re-use on nickel demand and supply

Chapter Summary

Supply of nickel sulphate for lithium-ion batteries from non-integrated (third-party) producers is forecast to account for over half of production by 2030. As such, the availability of suitable feedstock for such nickel sulphate producers will be a key feature of nickel in the battery supply chain over the coming years. Intermediate nickel products are expected to be the main feedstock type utilised. Due to the bulk of intermediate nickel supply (in particular matte) being tied up in long-established integrated supply chains to produce Class I nickel, much will remain unavailable to the market. Conversely, mixed hydroxide product (MHP) is expected to be the main form available to the market over the next decade. This is subject to the successful commissioning of several high-pressure acid leach (HPAL) projects currently under construction in Indonesia. Alongside intermediates, another significant nickel sulphate feedstock is Class I nickel.

Class I nickel has increased in importance as a feedstock for nickel sulphate production in recent years, accounting for over 20% of total nickel sulphate supply by feedstock in 2019. However, future availability of Class I nickel supply over the outlook period is limited given that no new projects have been announced. Apart from being used as feedstock in nickel sulphate production, Class I nickel is widely consumed by the stainless steel sector as well as nickel's other smaller end-use sectors. Importantly for Class I's future availability, the stainless steel sector can be flexible in terms of type of nickel it consumes. The industry can substitute Class I nickel with Class II materials. The level of substitution that could take place will impact the volume of Class I units available to third-party processors of nickel sulphate. We believe that substitution of Class I out of stainless steel production will occur and therefore decline to between 3-10% of the sectors feedstock requirements. As a result, supply tightness for Class I nickel is forecast to decline over medium-term as increasing substitution takes.

Nickel available from recycling of spent Li-ion batteries are expected to become a sizeable feedstock source toward the late 2020s and in to the 2030s. Within the EU27 we forecast 21kt Ni and 228kt Ni would be available for recycling by 2030 and 2040, respectively. During this period, more batteries will reach their useful life limits and collection rates are likely to be maximised. We forecast recycled material available (battery and non-battery combined) to likely overtake Class I nickel by the end of the 2020s. In comparison to forecast available nickel units from intermediates and Class I nickel, recycled material represents the main supply growth area during the 2030s. Secondary sources of nickel sulphate feedstocks are expected to overtake primary sources by mid-2030s.

Global market balances: The global economy is forecast to recover from COVID-19 between 2021 and 2023. At the same time, market demand is expected to recover to reduce an expected 2020 supply surplus approximately balancing the market by the mid-2020s. We forecast the market to enter a structural deficit by 2028, initially representing a small requirement for additional capacity. Beyond 2030, growing annual market deficits reflect a combination of rising demand and a reduction in the visibility of new supply. As a result, such deficits are more appropriately considered an 'investment requirement' rather than what is likely to transpire. Roskill has assessed the cumulative investment requirement for additional units of new capacity in future years. This is underpinned by the market balance and highlights the cumulative annual cost of new capacity required to be brought online to bring the market back into balance. Under a base-case, US$30,000/t Ni project capital intensity, an investment of €9.5Bn is estimated to be required, increasing to over €34Bn by 2040.

We forecast the nickel sulphate market to remain in balance throughout the majority of the 2020s. This baseline scenario implies that a large quantity of new nickel sulphate capacity needs to be commissioned prior to 2028 from integrated and non-integrated producers. As with the total nickel market, large deficits are expected for nickel sulphate post-2028 should be considered as an ‘investment requirement’, for both primary nickel sulphate capacity and recycling capacity. Primary feedstocks alone will be unlikely to meet such high demand levels, even assuming all projects announced to date were to fully ramp up. In that case, higher nickel prices and/or nickel sulphate premia may be required to (1) incentivise additions of new feedstock and nickel sulphate projects, (2) encourage more displacements of Class I nickel demand by the stainless steel industry, and (3) crucially, encourage more recycling from both battery and non-battery sectors.

5.1 Outlook for available feedstock supply

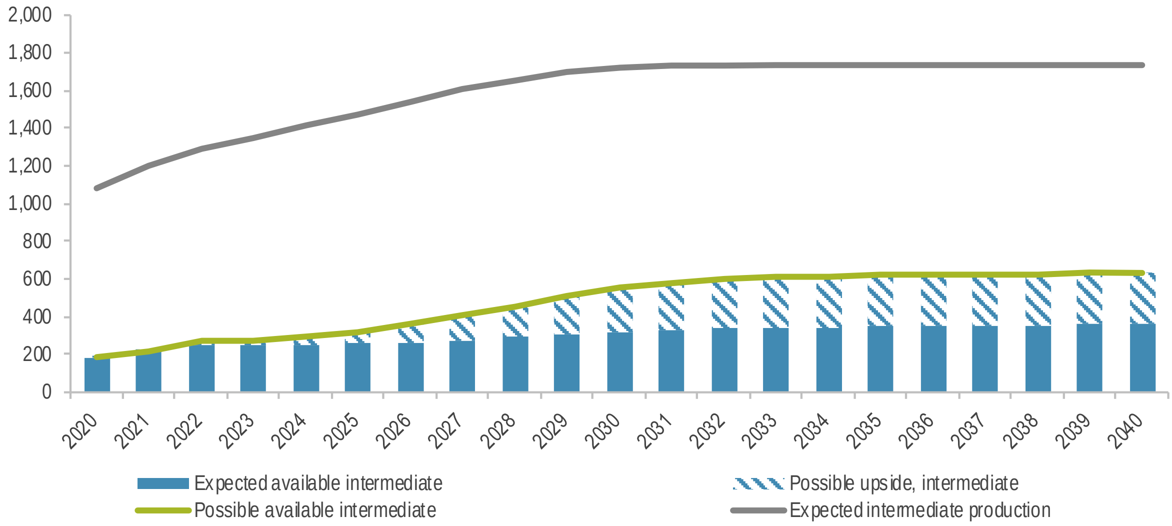
Building on the outlook for nickel intermediate and refined production (Sections 3.2.2/3.2.3), this section provides a detailed assessment on the availability of feedstocks for *non-integrated* nickel sulphate production through to 2040, focusing on primary and secondary sources. As Roskill believes nickel from secondary sources (recycled material) is of growing importance for future production of nickel sulphate, the future availability of recycled material from battery sectors will be discussed in the context of other feedstock types.

5.1.1 Intermediates

Intermediate products represented feedstock for nearly 60% of nickel sulphate supply in 2019. Benefitting from possible expansions from existing producers (e.g. Gördes and Ramu), restarts (e.g. Ravensthorpe) and commissioning of a number of projects (mainly in Indonesia), intermediate production is expected to grow at 4.2%py in the next decade. As a result, Roskill forecast more intermediate products to be available for processing into nickel sulphate.

Figure 93 shows the volume of intermediate Roskill expects to be available for *non-integrated* nickel sulphate production, which accounts for a small portion of the total supply of nickel intermediates. The main reason is that much of intermediate production is likely to remain locked into *integrated* production of refined Class I nickel metal products, especially in the case of matte to electrolytic nickel. Apart from operations and projects currently in advanced stages which target types of intermediate products suitable for nickel sulphate, a number of early-stage *sulphide* nickel mine projects are also included in this analysis as they could potentially support production of intermediate or Class I nickel in the longer term.

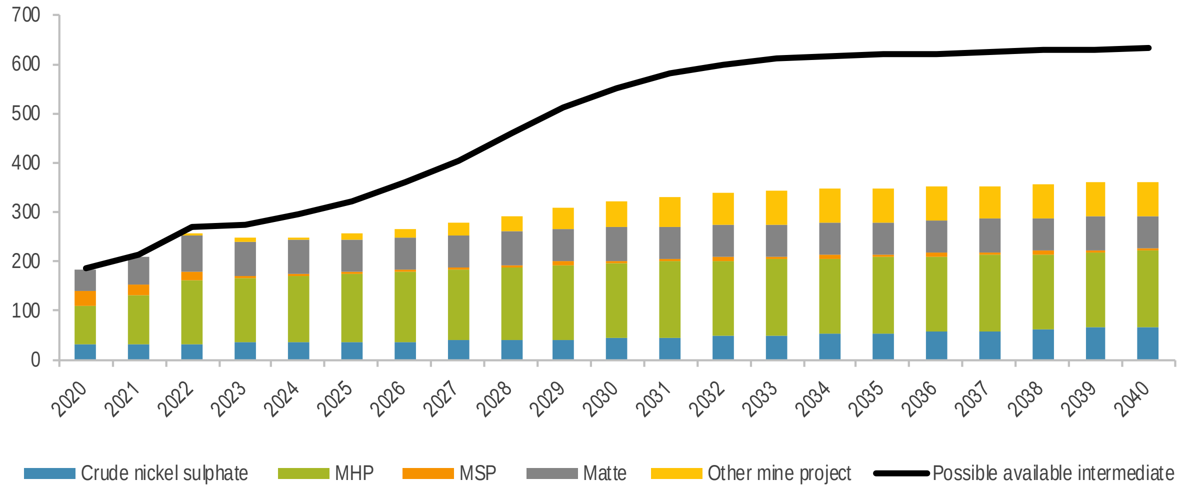
Figure 93: Forecast availability of intermediates for non-integrated nickel sulphate production versus total nickel intermediate supply, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Figure 94 shows *expected* available intermediate for non-integrated nickel sulphate producers by type. The difference between *expected* and *possible* scenarios can be largely attributed to potential project risks. In addition, less intermediate may be available than the expected scenario, as new downstream refining facilities could be further built by producers during the outlook period, most likely to happen for HPAL projects in Indonesia.

Figure 94: Expected available intermediate for non-integrated nickel sulphate production, by type, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Among all the intermediate types, MHP and matte are expected to contribute to most of the future growth in available feedstock, reliant on the successful commissioning of projects currently under construction. However, it is worth noting again that increasing amounts of MHP and matte from new projects are likely to be locked into integrated nickel sulphate production over the forecast period. Less MSP will be available for external processors as Terrafame's new nickel sulphate plant in Finland is set for commissioning in

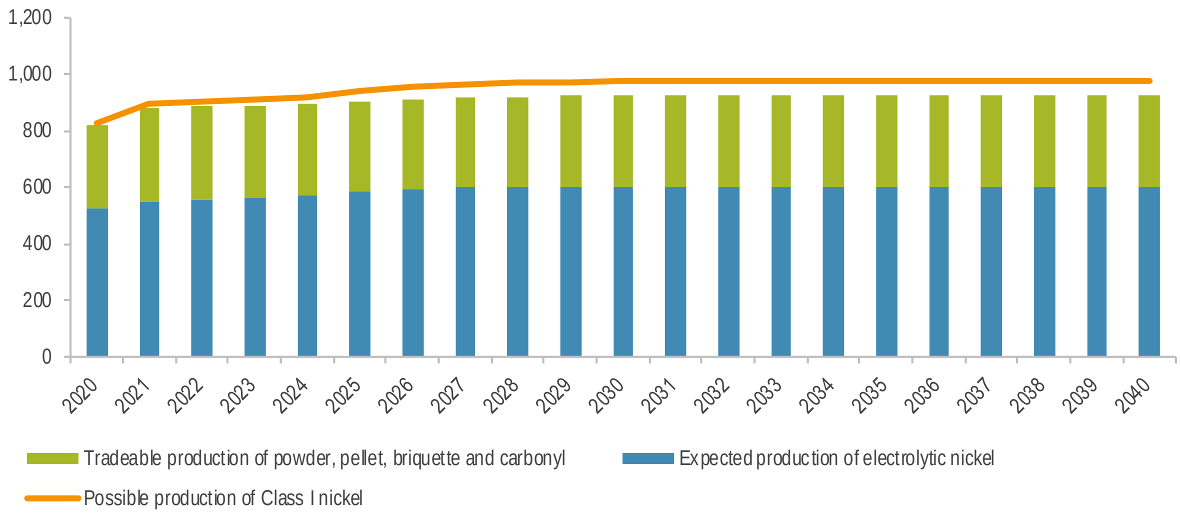
H1 2021, whilst the growth from crude nickel sulphate will be limited given its by-product nature.

5.1.2 Class I

Class I nickel has gained increasing importance as a feedstock for nickel sulphate production in recent years. Conversion from metal accounted for over 20% of total nickel sulphate supply in 2019. Underpinned by expected demand growth from electric vehicles and portable electronics, Roskill expects the battery industry to require more Class I nickel for conversion to nickel sulphate to meet increased demand from its end uses.

However, as shown in Figure 95, unlike intermediates, Class I has very limited supply upside. This is because only a few operations are likely to increase capacity and no new projects being announced, as of Q3 2020. Moreover, most of the growth is likely to come from supply of electrolytic nickel rather than powder and briquettes. Electrolytic nickel can theoretically be a feedstock for nickel sulphate, but this production route is not currently in large-scale commercial use. Whilst production of powder, pellet and briquettes, the most common forms of Class I feedstock in nickel sulphate production, are forecast to be flat. BHP plans to start its own nickel sulphate production using integrated powder and briquette at Kwinana in 2021. Given this, tradeable volume for such material is expected to decrease over the outlook period. Possible ramp up at Ambatovy could offset some supply loss. Although the growth is likely to be limited (as shown in the green bars in Figure 95) should no additional capacity be added.

Figure 95: Outlook for production of Class I nickel, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Apart from being used in the battery sector (both directly in battery cathode materials or indirectly as a feedstock for nickel sulphate production), nickel metal is also widely consumed by other non-battery applications (such as stainless steel, non-ferrous alloys etc.). Therefore, demand for Class I nickel from non-battery sectors is an important consideration to define how much Class I material may be potentially available for future nickel sulphate production. The stainless steel industry can be comparatively flexible and has the ability to substitute Class I nickel with Class II materials, whereas substitution for Class I metal's use in other applications is inextricable or technically challenging to achieve.

As such, there exist end uses sectors that are forced to compete for Class I supply. We believe demand for Class I nickel from such applications needs to be prioritised, which we define as *critical demand* for such material.

We provide three scenarios for Class I usage in stainless steel through to 2040, based on a reduction to 10%, 3% and an adjusted average in between, as shown in Figure 96. After subtracting the *critical demand* from other sectors and taking into account the change in stocks for Class I nickel in exchanges and off-warrant warehouses, Class I material available for nickel sulphate production under different stainless steel loading rates is shown below.

Figure 96: Scenarios for the reliance of stainless steel on Class I nickel, 2020-2040 (% Class I loading)

Source: Roskill, 2020.

Roskill considers there to be two key drivers influencing the use of Class I by stainless mills:

1. Domestic and international availability of stainless scrap and/or Class II feedstocks, where ratios of each varies regionally (e.g. China vs European stainless mills); and
2. Market prices for nickel metal

In a scenario where Class I usage in stainless steel gradually falls to 10%, no surplus units would be left available for processing into nickel sulphate by the mid-2020's (Figure 97). We consider this an unlikely outcome for two main reasons. Firstly, although we expect the loss of Class I feedstock to likely be offset by the upside potential from other feedstock sources (e.g. intermediates and recycling) it is unlikely to be compensated entirely. As a result, a foreseeable shortage in Class I nickel is likely to push the metal price higher, thus incentivising stainless steel producers to substitute more Class I with Class II. Secondly, many long-standing nickel sulphate producers (mainly in Taiwan and Japan) have their plants designed exclusively for metal conversion. With no available Class I nickel metal, production from such operations is likely to be suspended and cause supply disruptions for nickel sulphate in batteries.

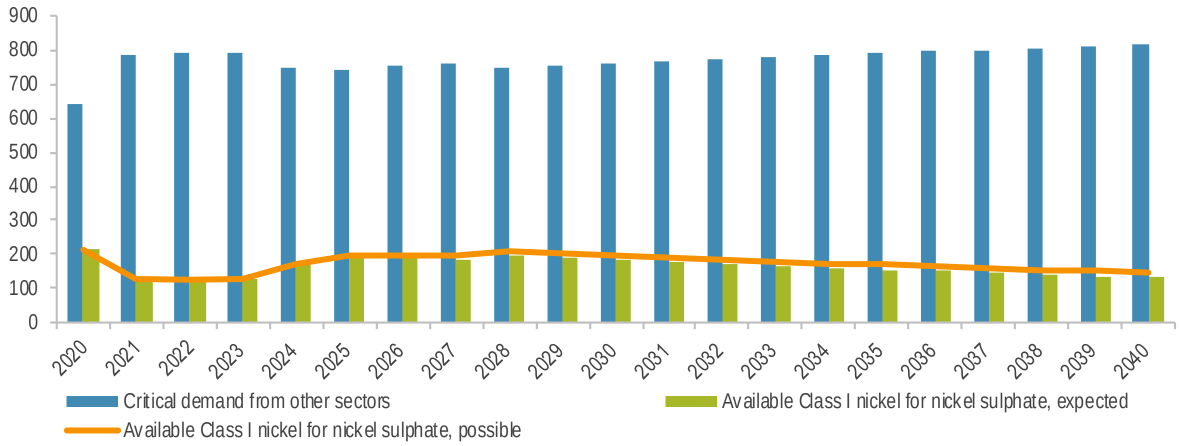
Under a 3% loading scenario, we forecast there would not be a significant shortage in Class I material for the battery industry. However, it would likely require substantial capital investment by stainless steel producers to re-engineer their mills to reduce Class I metal use such a level. Particularly in the US, Europe and Japan, where reliance on Class I nickel is higher. We believe such investments would only be contemplated if a large price differential between Class I and Class II nickel were to emerge. We consider this scenario less likely to materialise, albeit more likely than the 10% scenario.

Figure 97: Scenarios for Class I availability for nickel sulphate production, 2020-2040 (kt Ni)

Source: Roskill, 2020.

Roskill forecast a Class I loading rate to average between 3% and 10% as the most likely scenario for the stainless steel industry long-term. However, this can be only interpreted as indicative, as the actual usage is likely to fluctuate annually. Fluctuations will be dependent on various factors such as Class I metal demand from batteries and other sectors, Class II nickel supply and the nickel price over the outlook period.

Figure 98: Forecast availability for Class I nickel used in nickel sulphate production, 2020-2040 (kt Ni)



Source: Roskill, 2020.

The expected availability for Class I nickel is outlined in Figure 98, based on Roskill's three-case loading rate scenarios. Despite increasing requirements from the battery sector for nickel metal (for nickel sulphate production), the usage from other traditional applications combined will continue to dwarf the rest of the market over the next decade. In addition, the potential upside for metal availability is likely to be very limited, constrained by the supply outlook set out in Figure 95.

Given the supply outlook for Class I (limited new capacity is expected to be added), figures indicate that a shortage in Class I may emerge in early 2020s. With supply tightness likely easing gradually over time as the stainless steel sector substitutes Class I with Class II. This may create a peak in the mid-2020's for available Class I for nickel sulphate producers, before starting to diminish as stainless steel producers reach their Class I loading rate floor estimated at between 3% to 10%.

It is worth highlighting that the movement of Class I nickel stocks may also have an impact on the actual availability of such material, which Roskill has factored into the forecast. As an actively traded metal globally, considerable volumes of Class I nickel sit in exchanges such as LME and SHFE, as well as in producer warehouses as off-warrant material. This can theoretically offer a buffer when Class I nickel supply becomes tight, but on the other hand, could also be another hidden 'application' for Class I nickel when the material is more readily available in the market. This could effectively rebalance the market for Class I nickel and change its availability in an opposite way. As a result of adjustments from stocks, the available Class I nickel metal for nickel sulphate production may increase initially before remaining should prices incentivise the release of such units.

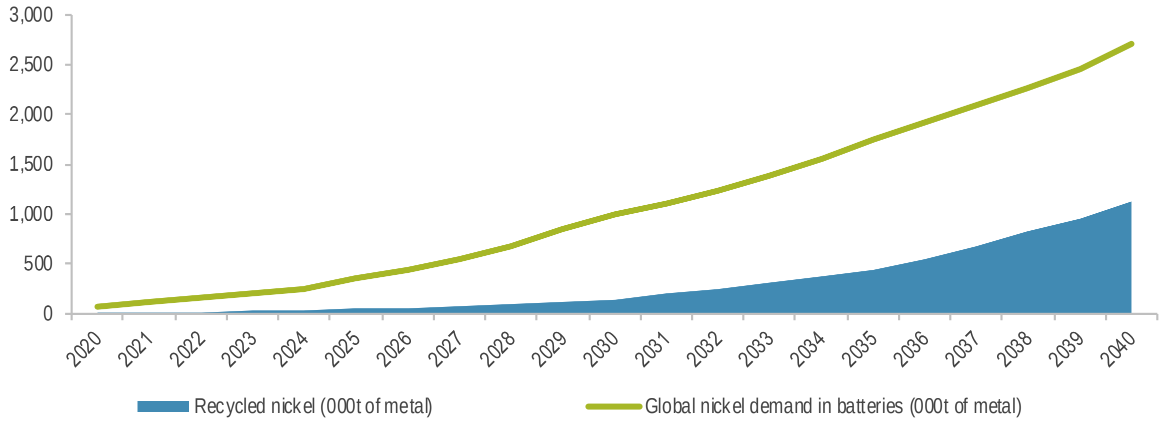
Additionally, the actual availability of Class I nickel metal for nickel sulphate production may fall even lower than estimated. The main reason can be that this forecast assumes nickel sulphate producers are indifferent among different forms of Class I material and will be willing to switch between one and another based on market conditions. Despite being technically feasible, we understand that change of feedstock can often increase the processing cost, in the case of electrolytic nickel or briquette in stock, or affect end product quality, which may disincentivise producers to do so.

5.1.3 Recycling (EOL batteries)

Recycled metals from spent Li-ion batteries are expected to form an increasingly important and sizeable source of nickel for the EV market. Furthermore, recycling is considered a strategic necessity in establishing a circular economy of nickel supply in future as part of OEMs' sustainability and ESG frameworks. We forecast that globally around 146kt Ni and 1,100kt Ni could be available for recycling in 2030 and 2040 respectively.

After batteries are discarded by the consumer, some will be degraded and rendered unfit for second-life applications, whilst others will be further re-used. Among second-life applications, used Li-ion batteries can be further sold in second-hand smartphones, laptop, power-banks, and ESS battery systems. After all primary and secondary batteries reach the end of their useful life, they will be collected, sorted, and available for recycling. End of Life (EOL) is a term to define those batteries that cannot be used further as the chemicals and other materials inside them have degraded because of usage.

Figure 99: Global nickel available from EOL batteries, all battery applications (kt Ni)

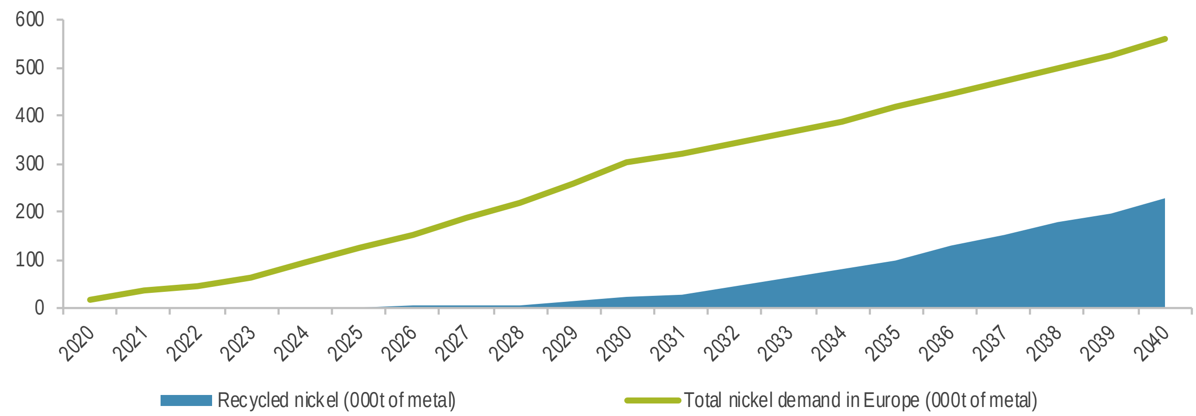


Source: Roskill, 2020.

We have modelled battery recycling assuming different EOL timeframes by battery application (portable electronics, ESS, EV), cathode chemistry, collection rates, and recycling rates based on the projected price of battery metal. It is important to note that this reflects the quantities of nickel metal theoretically available for recycling. Hence, to match forecast nickel demand, dedicated recycling facilities and collection networks need to be constructed in advance. New Li-ion battery improvements such as advanced electrolytes, cathode coatings, or BMS could prolong the useful life of automotive powertrain batteries beyond 10 years. In this case, volumes of spent batteries available for recycling could be considerably delayed. From this perspective there are two main challenges facing the development of an EOL recycling industry:

1. Achieving critical mass of EOL batteries to economically sustain large-scale recycling businesses; and
2. Effectively determining the timing of investment in recycling capacity to critical mass EOL cell availability

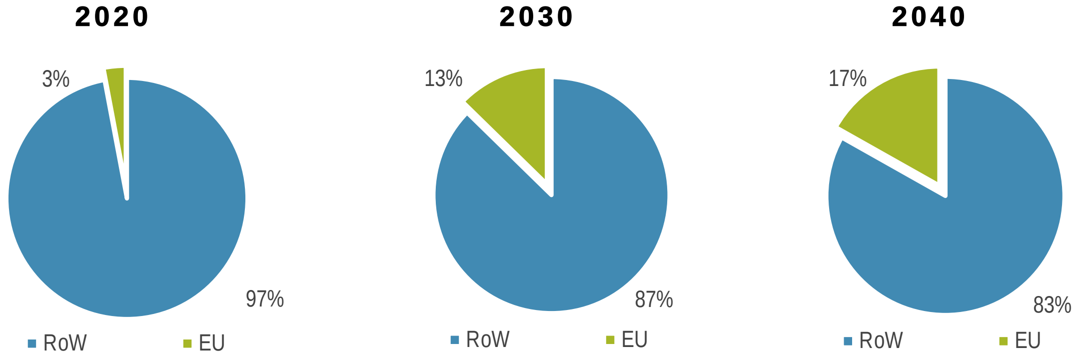
Figure 100: EU27 nickel available from EV EOL batteries (kt Ni)



Source: Roskill, 2020.

At the European level, we forecast around 21kt Ni and 228kt Ni would be available for recycling by 2030 and 2040, respectively. Where over the 20-year forecast horizon nickel available from European EOL batteries is set to account for an increasing portion of the global EOL market. Under the base-case scenario, nickel available from European EOL batteries would increase from 3% of global availability in 2020 to 17% by 2040.

Figure 101: Europe vs RoW available nickel from battery recycling



Source: Roskill, 2020.

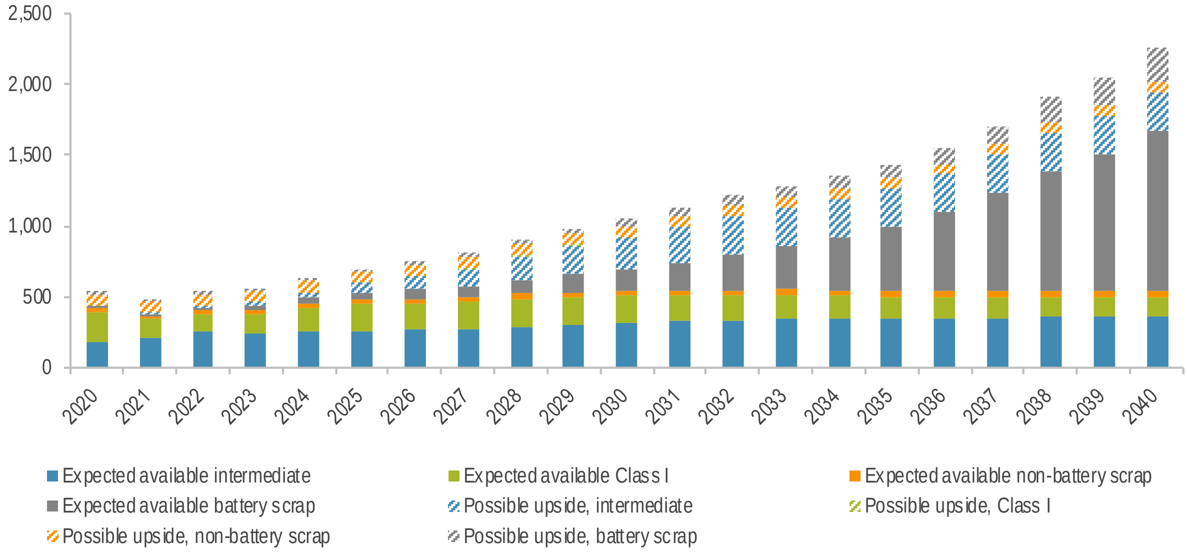
5.1.4 Combined outlook for feedstock availability

Figure 102 summarises the outlook for availability of different feedstocks suitable for processing into nickel sulphate and subsequent use in EV batteries. Feedstock availability is of particular importance to all the non-integrated nickel sulphate producers whose production is exclusively reliant on third-party sourced feedstock materials.

Roskill forecast over the coming decade, among all the feedstock types, intermediates are likely to be the largest feedstock source for non-integrated producers. Whilst also having the greatest upside potential for additional supply volumes. However, Roskill believes the availability of such material is likely to decline between 2025-2030 as more mine-integrated projects could move to construct nickel sulphate facilities. This would result in reduce units available for third-party refinery buyers.

Class I metal is forecast to be the second largest feedstock source to 2030. Although as previously discussed, Class I available for nickel sulphate production may be highly dependent on various factors. Such factors include *critical demand* from non-ferrous alloys and plating sectors, as well as usage from stainless steel and general stock levels. This in turn presents great uncertainty across the outlook of this feedstock, as described in Section 5.1.2. Roskill expects the availability of Class I nickel to increase initially, as the stainless steel industry may opt to substitute its use for Class II products instead. Given that new supply of Class I is considered to be limited, even if the stainless steel industry continues thrift out Class I units to half of today's consumption, supply tightness is still expected to emerge in the late 2020's. This may be compounded by some units becoming 'frozen' as stocks in exchanges or producer warehouses. As such, nickel sulphate producers relying on Class I metal are likely to face increasing processing costs moving forward if the forecast tightness promotes an increase in prices. Producers of this type may be forced to take less favourable metal feedstock types, such as electrolytic nickel, or supplement with intermediate or recycled feedstocks.

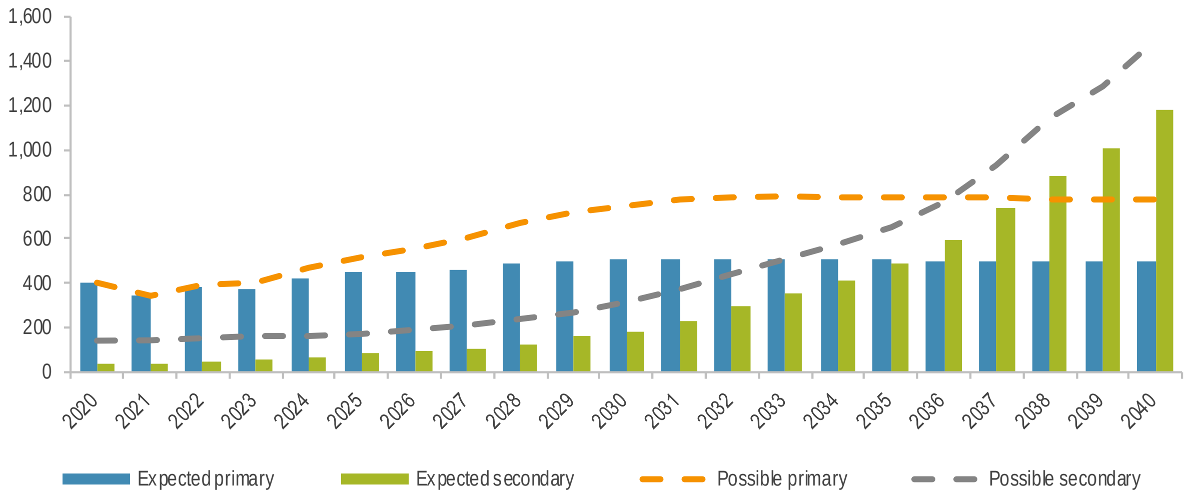
Figure 102: Outlook for feedstock availability, by feedstock type, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Recycled material from EOL batteries is expected to become a vital source of nickel by 2040. This is particularly so between 2030-2040 as more batteries reach their useful life limits and collection rates are maximised. Roskill forecast recycled material available (battery and non-battery combined) is likely to overtake Class I nickel by the end of the 2020s. When compared against the forecast available nickel units from intermediates and Class I recycled material represents the main supply growth area in the 2030's. The importance of this is strengthened by the challenges and risks associated with building out new primary supply sources as touched on in previous sections. Based on the above analysis, we expect recycled material to play an increasingly dynamic role in determining market balances moving forward.

Figure 103: Outlook for feedstock availability, primary versus secondary, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Figure 103 provides a comparison between the availability of *primary* and *secondary* feedstock sources. Roskill considers the majority of supply upside is likely to come from primary sources over the 2020's. This is underpinned by several new projects (mostly targeting intermediate products) being expected to enter production in the coming five years. However, primary feedstock available for non-integrated producers may reach its peak and even decrease as more producers could become downstream integrated to sulphate production. Despite starting from a low base, significant growth from secondary feedstocks are forecast to become increasingly important for non-integrated sulphate producers post-2030, particularly from EOL battery sources. Such feedstocks are expected to overtake primary sources by the mid-2030.

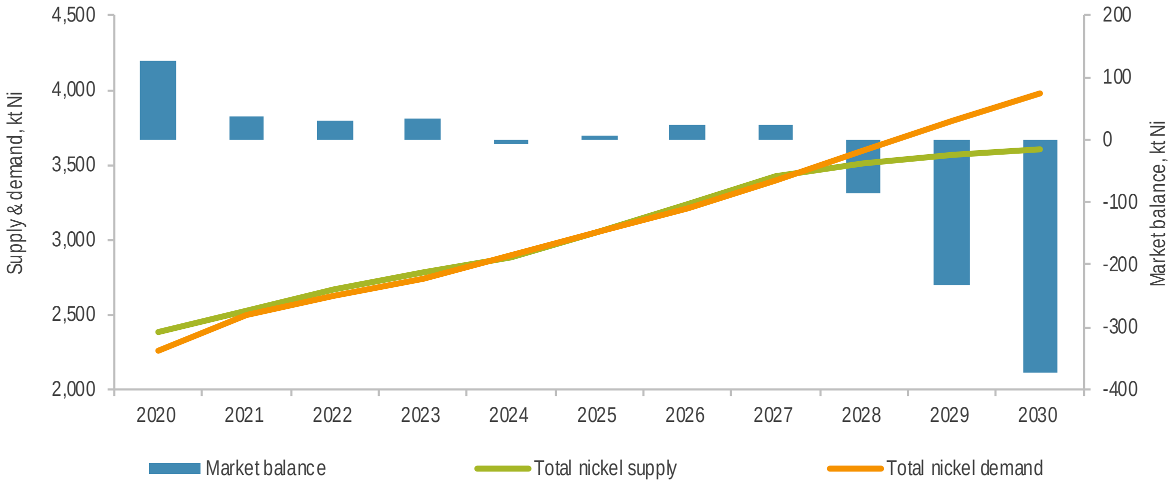
5.2 Global market balances

5.2.1 Total market

Roskill's outlook for the primary nickel market balance between 2020-2030 is shown in Figure 104 and 2030-2040 in Figure 105. The primary market was in surplus in 2020, due to COVID-19's larger impact on demand than disruption to global supply. This surplus ends a run of four consecutive years where the nickel market registered deficits.

Between 2021 and 2023, the global economy is forecast to recover from the effects of COVID-19. Market demand is expected to follow suit, resulting in a reduction of the supply surplus and generating an approximately balanced market by the mid-2020's. In the near-term, we forecast nickel supply to be met by large-scale NPI capacity buildouts in Indonesia, based on ample local availability of ores. This NPI supply will be used to feed domestic stainless steel mills, with excess supply exported to China to supply the stainless steel mills there. Supply growth is also forecast to come from primary nickel sulphate (using intermediate nickel feedstocks) to serve the battery market.

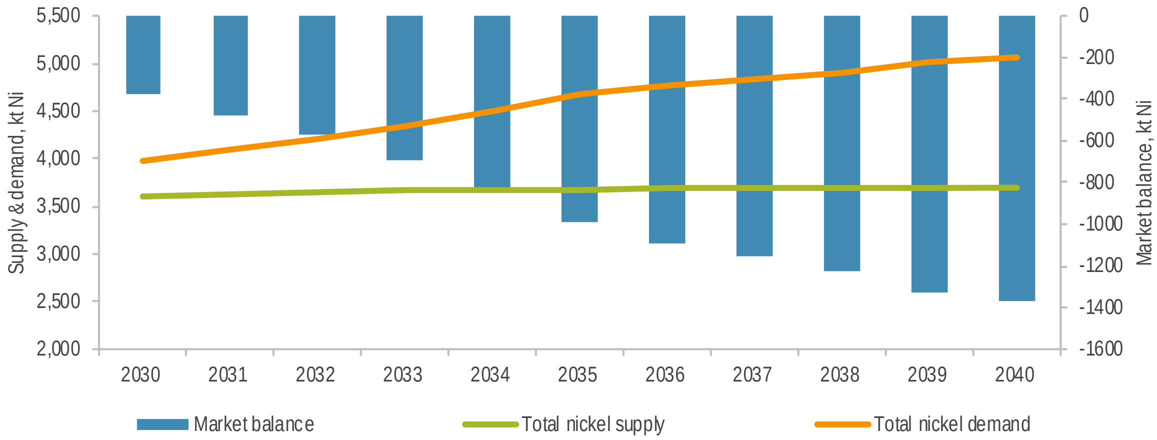
Figure 104: Outlook for primary nickel market balance, 2020-2030 (kt Ni)



Source: Roskill, 2020.

Roskill forecast the market to return to deficit by 2028. Initially, this represents a relatively small requirement for additional capacity to be added, especially when considering the speed with which new NPI capacity has been built in Indonesia in recent years. Although, by the late 2020's most of the demand growth is expected to come from the battery sector and so would require non-Class II forms of new capacity. Post 2030, the deficits forecast are due mostly to a lack of visibility on projects that far ahead. This means that supply growth will decline towards the end of the forecast period. Between 2020 and 2025, we expect supply growth to average 5.1%py, whilst between 2025 and 2030 supply growth slows to an average 3.4%py. This compares to an average of 0.3%py between 2030 and 2040.

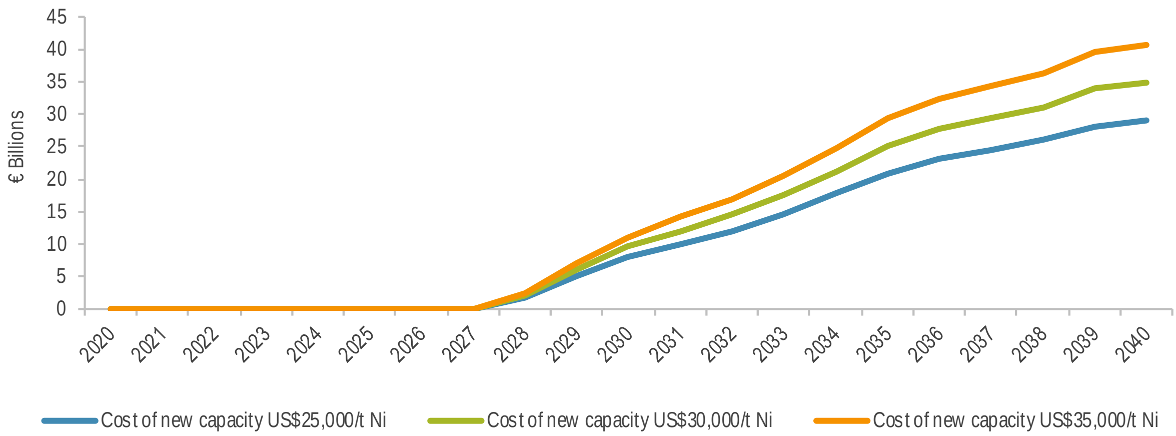
Figure 105: Outlook for primary nickel market balance, 2030-2040 (kt Ni)



Source: Roskill, 2020.

Beyond 2030, we forecast significant structural market deficits arising. Where the potential depth of such also highlights the need for increasing recycling to reduce pressure on primary supply to balance the market. However, it is salient not to view this period as purely from a market deficit quantification point of view. Conversely, Roskill considers these events to reflect the 'investment requirement' of supply rather than what is suggested to transpire. This is mostly due to the higher level of uncertainty and variables to account for later in the forecast period.

Figure 106: Global cumulative investment requirement for new nickel capacity[1234], 2020-2040 (€ Billions)



Source: Roskill, 2020.

([1]) Analysis is based off the total nickel market balance shown in Figure 104 and Figure 105

([2]) Assumes USD:EUR of 0.85

([3]) Cost of new capacity is also defined as the capital intensity of project development. The US$30,000/t Ni "base-case" represents the average requirement of existing global greenfields nickel projects, determined by Roskill's in-house analysis

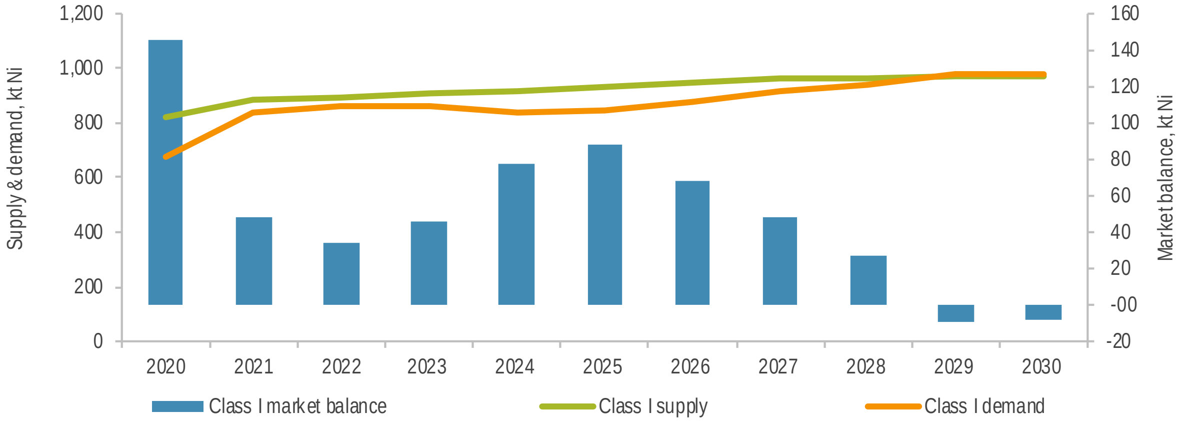
([4]) Cumulative investment requirement in a given year is defined as the variance between the previous years' total and the additional capacity of nickel units needing to be constructed in the current year

Roskill has assessed the cumulative investment requirement for additional units of new capacity in future years. This analysis, depicted in Figure 106 above, is underpinned by the total market balance and highlights the cumulative annual cost of new capacity needing to be brought online to re-balance the market. Under the base-case US$30,000/t Ni a total of €9.5Bn is estimated needing to be invested, which increases to over €34.8Bn by 2040. It is important to note that this analysis is predicated on the average capital intensity of all greenfields nickel projects globally determined by Roskill. As such, it does not indicate the cost of expanding capacity at existing operations (should there be economic scope to do so), which would inherently have a lower capital intensity than undeveloped assets. Regardless, before the end of the 2020's the nickel market is expected to require substantial investment flows to combat the forecast future deficits.

5.2.2 Class I

The outlook for the Class I nickel market balance is presented in Figure 107. It is derived by considering the difference between Class I supply and critical demand for Class I from dependent sectors, whilst also factoring in demand for nickel sulphate production from third-party processors of Class I metal.

Figure 107: Outlook for Class I market balance, 2020-2030 (kt Ni)



Source: Roskill, 2020.

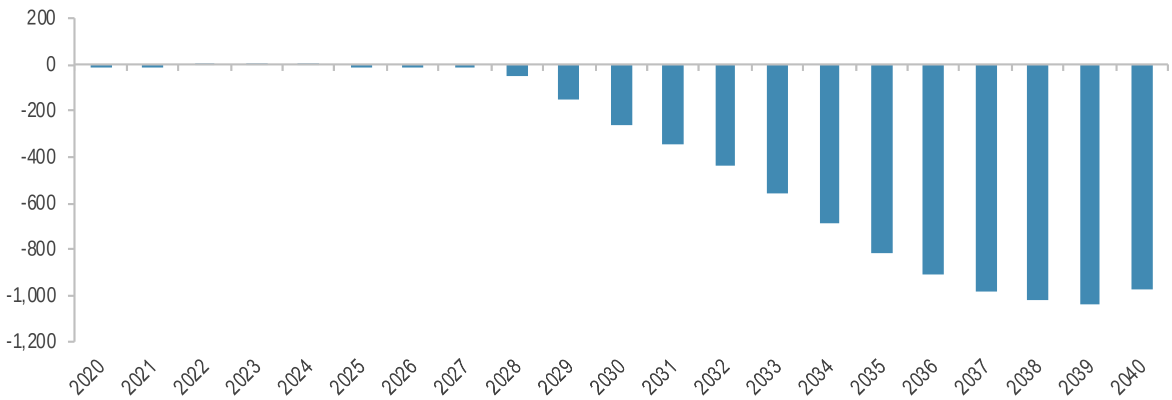
In 2020, COVID-19 has reduced demand for stainless steel, as well as for other first-use applications consuming Class I nickel. In addition to this, a small y-o-y decline in Class I production, is forecast to result in a surplus of 145kt Ni. We expect this surplus to reduce substantially in 2021 and 2022 as demand from all first-use consumers of Class I metal recovers. Between 2023 and 2025, amid rising demand for nickel sulphate, the stainless steel sector has the potential to increasingly substitute Class I (as discussed in Section 5.1.2). As a result, we forecast a growing Class I market surplus. We believe that the entirety of excess Class I metal substituted from the stainless steel sector will be consumed by third-party processors of nickel sulphate via metal conversion. By 2028, the surplus is forecast to decline once more as Class I supply growth slows and substitution by the stainless steel sector reaches a critical level as part of a base case 5% loading rate. By 2029, the Class I market is forecast to switch to a 9kt Ni deficit as supply starts to become outpaced by critical demand of Class I along with third-party metal converters of nickel sulphate.

The combination of a flat supply outlook alongside rising demand for Class I is likely to decrease quantities available for third-party processors of nickel sulphate. This is forecast to result in an overall decline of nickel sulphate produced via the Class I feedstock route during the 2030's (as shown in Figure 35). As a result, we forecast a consistently flat Class I market deficit of 8kt beyond 2030. This is predominantly due to demand from first-use sectors increasing and nickel sulphate production by third-party processors declining due to decreased availability. Such a deficit for Class I over the longer term could be interpreted as an incentive to invest in additional capacity. Where existing producers are considered most likely to do so given the lower overall capital intensity of expansion (i.e. Nornickel in Russia or BHP Nickel West in Australia). We are not aware of any greenfields nickel projects in the pipeline that intend to produce Class I metal and deems it unlikely for any to be announced in the short-term.

5.2.3 Nickel sulphate

We forecast a finely balanced nickel sulphate for the majority of the 2020's. Between 2020 to 2028, the market is expected to fluctuate between an approximate 15kt and 10kt deficit and surplus respectively. This is expected to take place until 2028 where supply is forecast to enter into a period of structural deficits for the remainder of the outlook period. This baseline scenario suggests that a large quantity new capacity would need to be commissioned, on schedule, prior to 2028 from both non-integrated integrated producers alike to keep the market adequately supplied. However, we deem it unlikely a high percentage of new supply would be realised owing to project risks, investment gaps and expected ramp up delays.

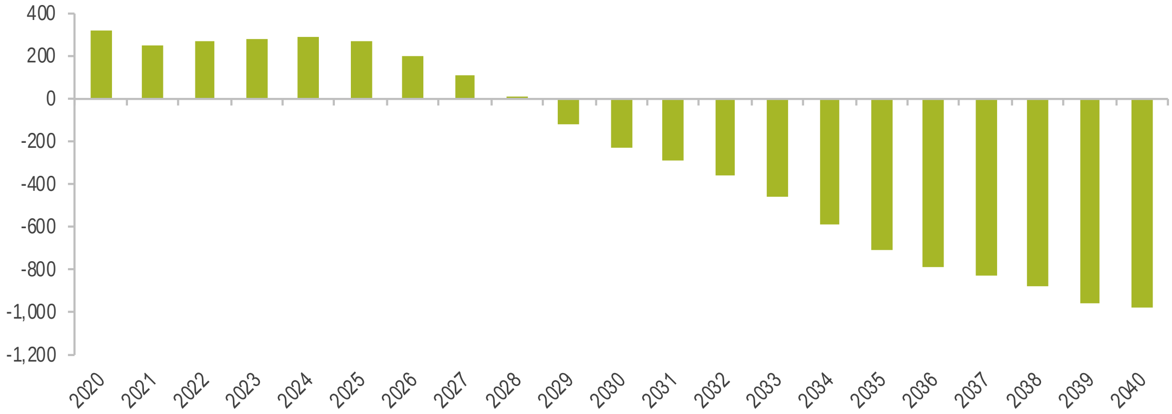
Figure 108: Outlook for nickel sulphate market balance (kt Ni)



Source: Roskill, 2020.

This finding is further evidenced by the limited upside in available feedstocks post 2028, as illustrated by Figure 109. The growing tightness in feedstock from 2027-2028, suggests new production will be required, mostly likely from fully integrated supply or new primary feedstock supply, both of which we believe need to be incentivised by a higher nickel price or nickel sulphate premium. Like that of the total nickel market, the mismatch between supply and demand in the latter half of the outlook period should be more so interpreted as '*additional investment requirements*' for both primary nickel sulphate capacity and recycling capacity.

Figure 109: Outlook for baseline nickel sulphate feedstock availability, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Under more pessimistic market conditions, which could result from the slower-than-expected uptake of electric vehicles, a reduction in battery sizes, or the faster introduction of new battery technologies that require less nickel, demand for nickel sulphate could be substantially lower. However, we believe such levels of consumption would still unlikely be completely met by expansions from existing operations reliant on primary sources.

Under more bullish market conditions, resulting from more rapid development of the market for electric vehicles, such high levels of consumption would be challenging for the industry to meet. Even if all projects currently announced were to achieve the full designed capacity, additional projects would still be required.

Primary feedstocks alone will be unlikely to meet such high demand levels, even assuming all projects announced so far were to fully ramp up. In that case, higher nickel prices and/or nickel sulphate premia may be required to (1) incentivise additions of new feedstock and nickel sulphate projects, (2) encourage more displacements of Class I nickel demand by the stainless steel industry, and (3) crucially, encourage more recycling from both battery and non-battery sectors.

6 EU27 refining and manufacturing capacities

Chapter Summary

Outlook for EU27 supply: Mined production of nickel ore from the EU27 in 2019 accounted for 2.1% of global mine supply. The only producing countries were Finland and Greece. Finland produced 39kt Ni-in-ore in 2019 with two companies, Terrafame and Boliden operating mines. Nickel mine supply in the EU27 is forecast to increase by 0.5%py, which will be solely driven by increased output from Terrafame in for its integrated nickel sulphate production.

Total intermediate production from EU27 countries is forecast to total 62kt Ni in 2020, which represents 5.7% of global intermediate supply. This is expected to rise by 2.2%py to 2030 and 1.1%py to 2040. Finland is responsible for the vast majority of intermediate nickel production in the EU27 (95% in 2020), which is forecast to remain the case over the outlook period. Nickel intermediate production in Finland comes from operations at Boliden in Harjavalta, Terrafame in Talvivaara, and to a much lesser extent, crude nickel sulphate from Mondo Minerals in Vuonos.

Primary refined nickel production (including Class I metal and primary nickel sulphate) in the EU27 totalled 71.8kt Ni in 2019. As with intermediate production, Finland makes up the bulk of refined nickel production from the EU27 bloc and is expected to account for 76% of refined output in 2020. Other refined nickel producing countries in the EU27 include France, Austria, Belgium and Germany. Roskill forecast 85% of EU27 refined nickel production is made up by Class I metal in 2020, with the remaining 15% primary nickel sulphate. By 2040, this share is expected to narrow to 54% for Class I metal and 44% primary nickel sulphate. This change is the result of Terrafame's nickel sulphate plant coming online in H1 2021 and ramping up to full capacity. Total Class I metal production from EU27 countries is estimated at 59kt Ni in 2020, which represents 7.2% of global Class I supply. This is expected to rise by 1.5%py to 2030 and 0.7%py to 2040.

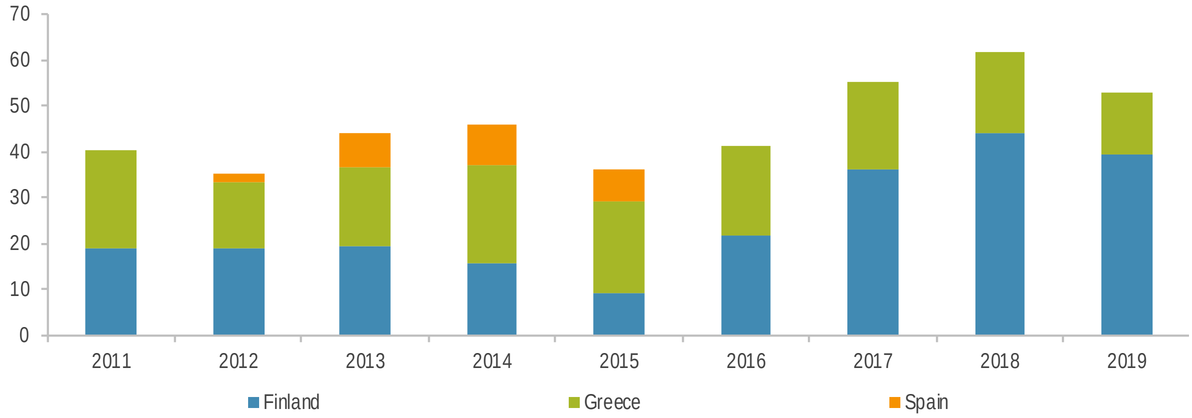
EU27 market balance: There are two distinct and independent market balances to consider within the EU27 bloc. The first is domestic supply against that of total demand from EV sales (end-use). On this front, we forecast a period of structural deficits post-2024 owing to limited scope for new primary supply being developed. This highlights the EU27's need for domestic investment in new nickel supply and/or the requirement for sourcing additional units from outside the EU27. Post-2030, however, rapid growth in EOL battery availability, and nickel units within such, could have a 'flattening effect' on the overall market balance deficit growth. Secondly, is domestic supply against that of physical demand from domestic precursor/cathode makers (first-use). We forecast domestic nickel production to adequately supply EU27 cathode makers until 2026. Post 2027, deficits could form when only considering primary refined supply. Such deficits could be mitigated if the EU27 utilises nickel available from EOL battery recycling, in turn generating a circular economy of nickel supply for EU27 cathode industry demand.

6.1 Mined ore

As in Section 3.2.1, mine supply includes ore used in Class II nickel production destined for consumption by the stainless steel industry. As evidenced in Figure 110, mine production from the EU27 nations, compared to global production, is very small and at present, only takes place in Finland and Greece. In 2019, the EU27 bloc accounted for 2.1% of global mine supply, which is forecast to decline to 1.6% by 2030 and again further to 1.5% in 2040.

Commercial nickel ore mining has historically taken place in Spain by Valoriza Mineria, which bought the mine from Lundin Mining's (now Sibanye Stillwater) when it took over Lundin's Spanish units Rio Narcea Recurson and Rio Narcea Nickel, in late 2016. The mine was closed in mid-2016 pending the receipt of an approval to proceed with underground production by the authorities, and also due to the sustained weak nickel price.

Figure 110: Mine production by EU27 country, 2011-2019 (kt Ni)

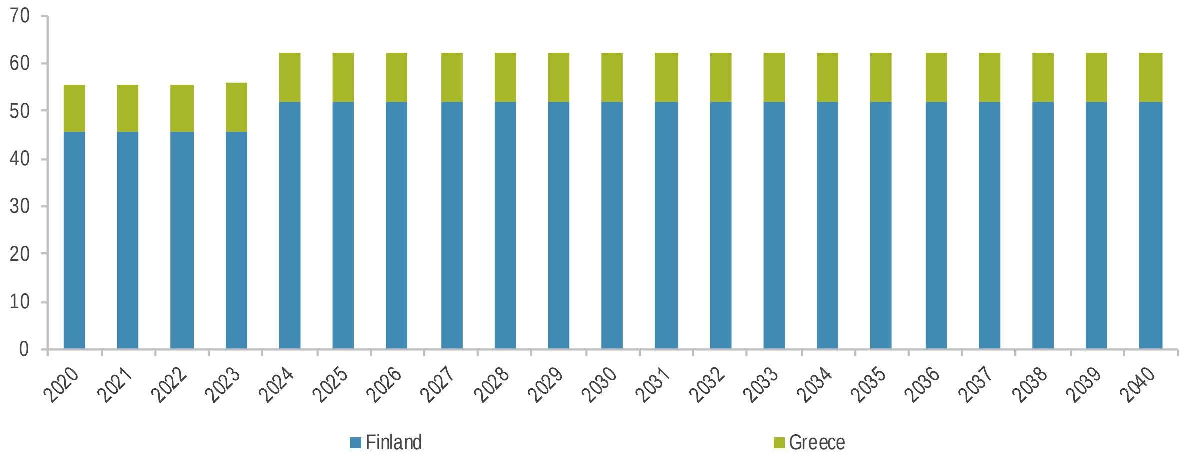


Source: Roskill, 2020.

In Finland, nickel is mined from sulphide ore deposits. Production is carried out by two companies, namely Terrafame, which took over Talvivaara in 2016, and by Boliden, which operates the Kevitsa and Kylylahti mines. Both companies process their mine production into intermediate products, which are then refined elsewhere. In 2019, the country's mine production was an estimated 40kt, down from 44kt in 2018. This decrease was the result of Boliden mining lower nickel grades and the company experiencing major planned maintenance at its smelters.

In Greece, mining of nickel laterite ore is estimated at around 14kt in 2019. Greece's General Mining and Metallurgical Company (LARCO) operates the mine and produces ferronickel. Output has declined since the company entered financial difficulty. LARCO is the only nickel producer in the country and most of its ferronickel output is exported to Spain, Italy and Belgium.

Figure 111: Outlook for expected mine supply by EU27 country, 2020-2040 (kt Ni)



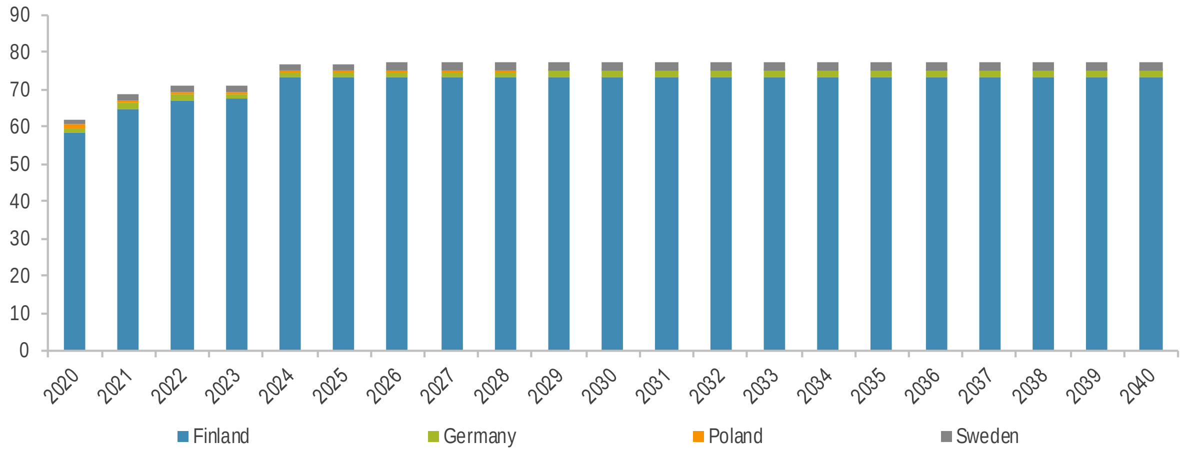
Source: Roskill, 2020.

Between 2020 and 2040, mine production from the EU27 is expected to rise by a modest 0.5%py. This will be solely driven by increased output from Terrafame in Finland for its integrated nickel sulphate production (discussed in Section 6.3). There are no projects within the EU27 bloc that are at an advanced exploration stage and providing an indication of new potential capacity in the medium or long-term future.

6.2 Intermediates

Total intermediate production from EU27 countries is forecast to total 62kt Ni in 2020, which represents 5.7% of global intermediate supply. This is expected to rise by 2.2%py to 2030 and 1.1%py to 2040. As is clear from, Finland is responsible for the vast majority of intermediate nickel production in the EU (95% in 2020), which is forecast to remain the case over the outlook period.

Figure 112: Intermediate production by EU27 country, 2020-2040 (kt Ni)



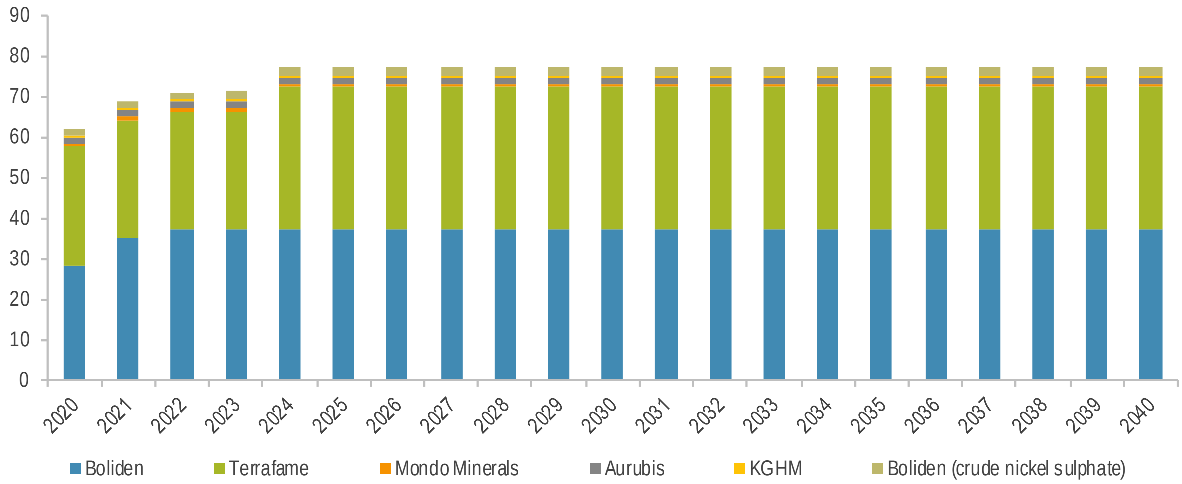
Source: Roskill, 2020.

Nickel intermediate production in Finland comes from operations at Boliden in Harjavalta, Terrafame in Talvivaara, and to a much lesser extent, crude nickel sulphate from Mondo Minerals in Vuonos.

Boliden's Harjavalta smelter uses Outokumpu's flash smelting process to produce nickel matte. The smelter has a capacity of 50ktpy contained nickel and obtains concentrates from Boliden's two mines in Finland – Kevitsa and Kylylahti. As it produces more nickel matte than it mines domestically, Boliden also supplements its raw material requirements by purchasing substantial volumes of concentrate from third parties in Canada, South Africa, Norway and small quantities from Russia. In August 2020, it was announced that Boliden would increase its matte capacity at Harjavalta by investing €40M (US$47.2M). The investment is expected to be implemented in 2021 and feed capacity will increase from 310ktpy (gross) to 370ktpy (gross) raw material. It has not been revealed whether this capacity increase will be based on an expansion of Boliden's mines or whether it will boost nickel concentrate purchases from third parties. Roskill believes the latter to be more likely, and has thus factored no domestic mine supply increase into the mine supply forecast for EU27 in Section 6.1.

Terrafame is majority-owned by the Finnish state and started operations in August 2015, having acquired the assets of the defunct Talvivaara operation. The company owns the Sotkamo nickel deposit in Eastern Finland and uses bio-heap leach processing. At full capacity, the operation could produce 32ktpy of Ni-in mixed sulphide precipitate (MSP). The company has also committed €240M (US$271M) to building a nickel and cobalt sulphate plant at Sotkamo, making it the EU's first mine-integrated producer of nickel sulphate. Roskill expects operations to commence during H1 2021, with a capacity of 150ktpy nickel sulphate (equivalent to 32ktpy Ni).

Figure 113: EU27: Intermediate production by company, 2020-2040 (kt Ni)



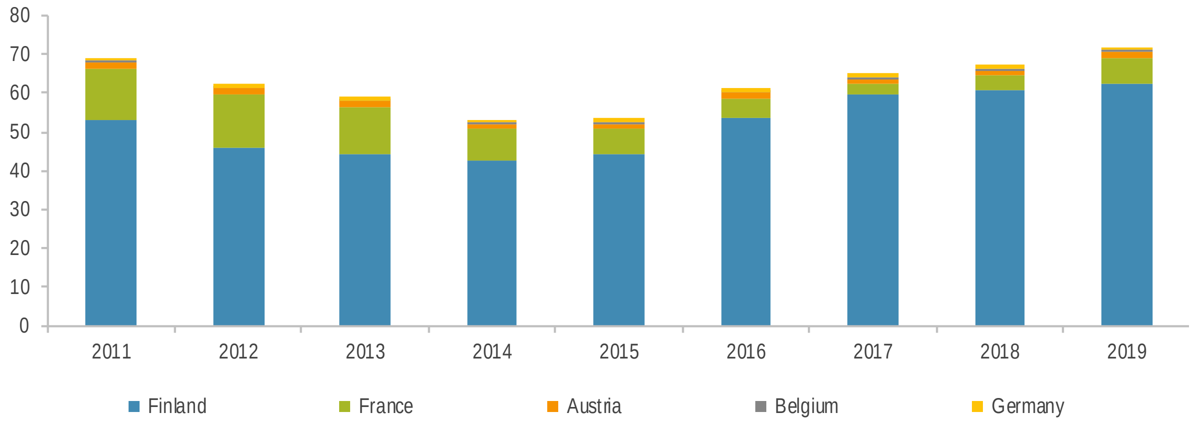
Source: Roskill, 2020.

Elsewhere in the EU27 bloc, intermediate production is purely in the form of crude nickel sulphate produced as a by-product from copper refining. This is suitable as feedstock for battery-grade nickel sulphate for use in cathode materials. In Sweden, a small amount of by-product crude nickel sulphate is produced by Boliden at its Rönnskär copper smelter. In Poland, KGHM Polska Miedź produces around 2.2ktpy from its copper refining operation near Lubin, where during the electrolytic refining stage, the nickel is crystallised into a crude nickel sulphate product. In Germany, some 1.6ktpy is produced by Aurubis. Most of this is sent to Umicore (Belgium), some to Finland, and the remainder to other EU countries, along with Brazil and Mexico, most likely processed at small-scale plants.

6.3 Refined

Primary refined nickel production (including Class I metal and primary nickel sulphate) in the EU27 totalled 71.8kt Ni in 2019, which was the highest output over the whole of the previous decade (Figure 114).

Figure 114: Refined nickel production by EU27 country[12], 2011-2019 (kt Ni)



Source: Roskill, 2020.

([1]) Inclusive of "primary" nickel sulphate from intermediate nickel feedstocks and does not include Class II ferronickel production from Greece

As with intermediate production, Finland makes up the bulk of refined nickel production from the EU27 bloc and is expected to account for 76% of refined output in 2020. Other refined nickel producing countries in the EU include France, Austria, Belgium and Germany.

There is a major refinery at Harjavalta, Finland, which is owned by Nornickel. Harjavalta has the capacity to produce 66ktpy Ni in the form of Class I metal and primary nickel sulphate. Both these products utilise imported matte feedstock produced at Nornickel's Kola MCC Monchegorsk operation in Russia, as well as small quantities from Boliden's Harjavalta smelter. In the past, Harjavalta has processed converter matte from BHP Billiton in Australia, but has not imported from this source since 2016. As a result, Nornickel has increased the share of Russian feed being refined at Harjavalta. In 2019, Nornickel Harjavalta produced an estimated 62.4kt Ni of nickel products.

From Q2 2017, the Monchegorsk refinery of Kola MCC started to gradually increase nickel feedstock supplies to Harjavalta, contributing to the gradual growth seen in the plant's sulphate output in recent years. Production in 2018 reportedly increased 22% over 2017, to 8.8kt Ni, and in 2019, output further increased to 9.4kt Ni, which can also be attributed to higher volumes of converter matte received from Boliden. As such, sulphate capacity at Harjavalta is likely to exceed 10ktpy Ni.

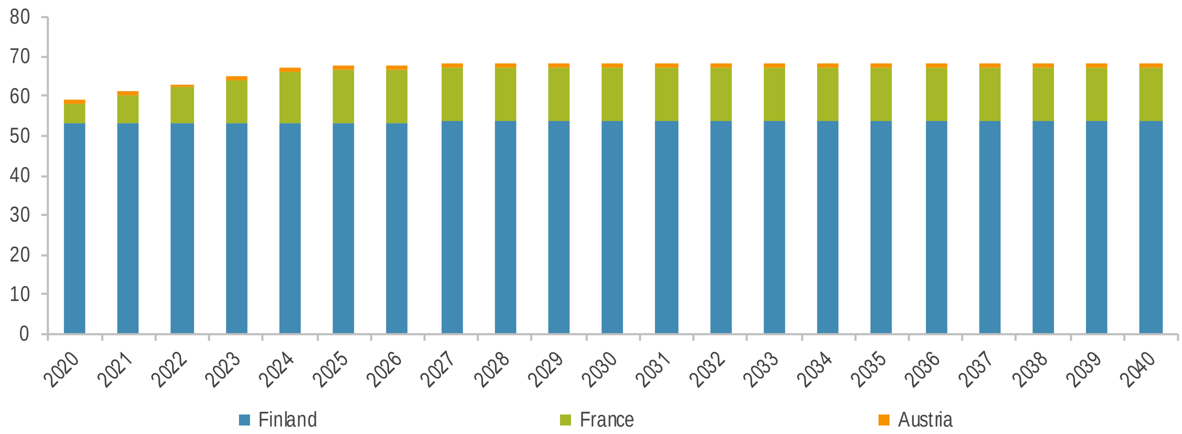
In a November 2017 presentation, Nornickel stated that its strategic view would be for Harjavalta to increase its supply to the battery sector up to 20kt Ni over the "mid-term", with longer-term expansion "in line with demand". In October 2018, Nornickel signed a long-term agreement to supply cobalt and nickel feedstock to BASF's new battery cathode precursor (PCAM) manufacturing plant with a planned start in 2022. In March 2020, BASF further announced that it will use recycled battery materials at its planned precursor plant through partnerships with battery recycling technology provider Fortum and Nornickel Harjavalta.

While some further expansion is possible based on recent partnerships and increased feedstock supply, as for Q1 2020, such plans have not yet been announced. Further, significant increases in production capacity for nickel sulphate by other producers might reduce the incentives for such. As potentially greater premiums could be achieved long-term in Nornickel's larger electrolytic nickel business. However, future production can potentially benefit from increased utilisation of secondary feedstocks alongside converting more metal to sulphate.

In France, Eramet produces electrolytic nickel cathode at its plant in Sandouville using imported nickel matte from Boliden in Finland. Previously, this matte came from its 56%-owned subsidiary SLN in New Caledonia, but that operation now exclusively produces ferronickel. The change in matte source, required a closure of the Sandouville plant in order to upgrade its production equipment, which led to a cut in its capacity from 16ktpy Ni to 13ktpy Ni. The refinery was re-opened in June 2017, with production in 2018 and 2019 estimated at 3.8kt and 6.9kt Ni, respectively. Some growth in cathode production is expected towards 2025, reaching 14ktpy Ni. This explains the rise in supply displayed in Figure 115.

In Austria, Treibacher Industrie operates a small refinery that produces around 1ktpy ni of refined nickel. Montanwerke Brixlegg also produced small volumes of nickel sulphate from its facility in Brixlegg.

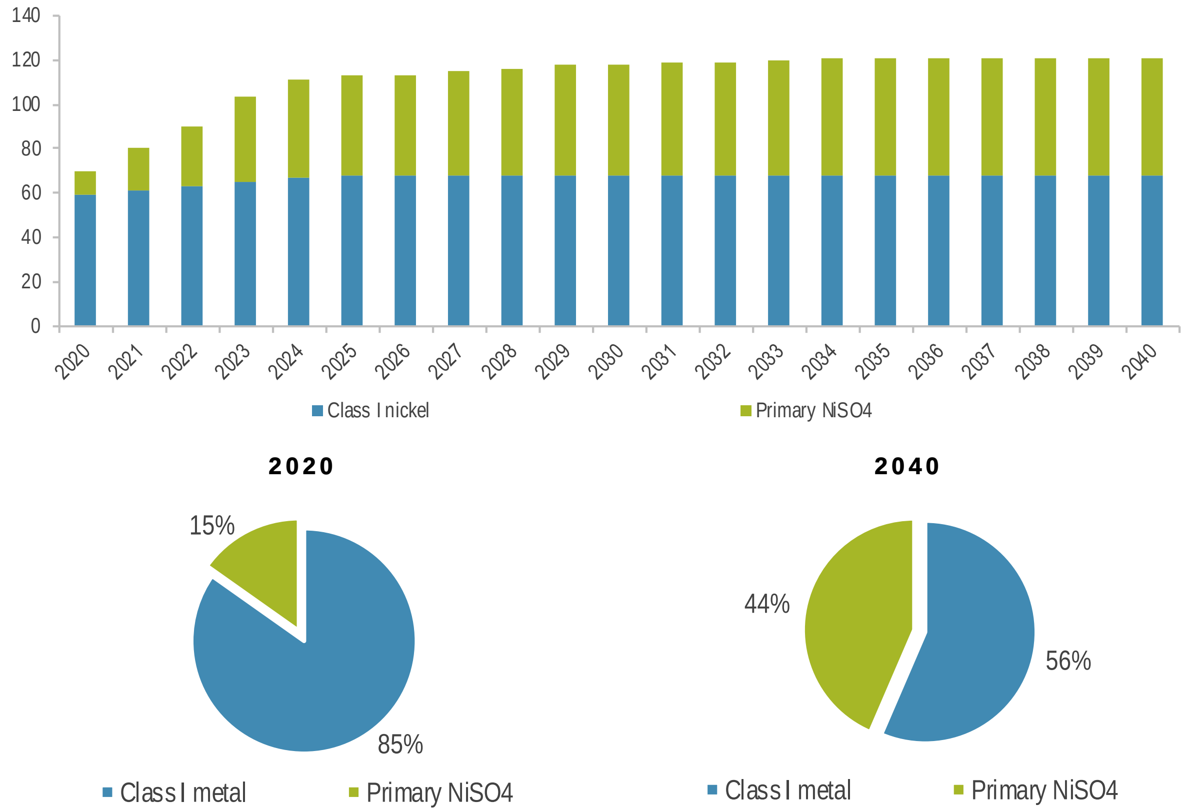
Figure 115: Outlook for Class I nickel production by EU27 country, 2020-2040 (kt Ni)



Source: Roskill, 2020.

Roskill forecast 85% of EU refined nickel production is made up by Class I metal in 2020, with the remaining 15% primary nickel sulphate (Figure 116). By 2040, this share is expected to narrow to 54% for Class I metal and 44% primary nickel sulphate. This change is the result of Terrafame's nickel sulphate plant coming online in H1 2021 and ramping up to full capacity. Total Class I metal production from EU27 countries is estimated at 59kt Ni in 2020, which represents 7.2% of global Class I supply. This is expected to rise by 1.5%py to 2030 and 0.7%py to 2040.

Figure 116: EU27: Share of refined nickel production by type, 2020-2040 (kt Ni)



Source: Roskill, 2020.

6.4 EU27 market balance

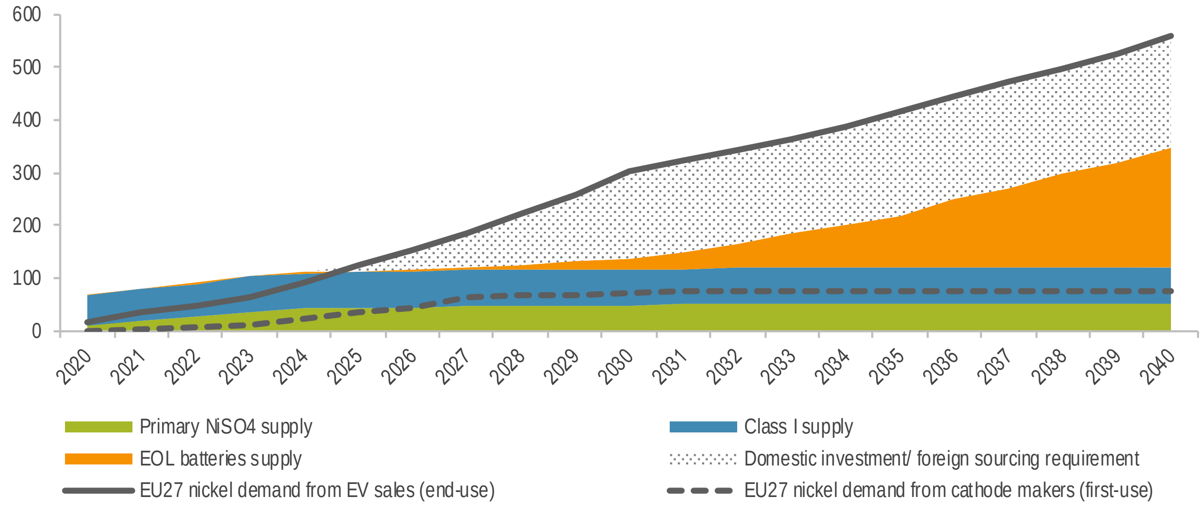
In previous chapters, Roskill has discussed detailed analysis of the EU27's demand (Section 4.3) and supply (Section 6) dynamics. The following discussion will place a specific focus on the market balance from the EU27's EV battery sector perspective. Within the narrative so far there are two clear developments expected to take place over the outlook period:

1. **Demand** – Based on OEM model announcements and forecast sales volumes, we consider it likely European EV's will focus mostly on high-nickel cathode chemistries. With the outcome being an exponential increase in demand of nickel in EV batteries. However, there is a significant mismatch and growing divergence between nickel demand segments. This being nickel demand from EV sales (end-use) versus the domestic cathode manufacturing industry (first-use).
2. **Supply –** Based on existing and expected future capacity, we forecast a significant increase in EU27 primary nickel supply (specifically nickel sulphate from intermediates) during the 2020's. This is considered likely to be complimented by an exponential growth in nickel available for recycling from EOL batteries, though critical mass volumes are not forecast to materialise until the late 2020's.

The importance of defining the variances in EU27 first-use and end-use demand profiles cannot be understated. We consider this crucial in the context of evaluating the EU27's physical industry nickel requirement in cathode manufacturing against that of the total regions supply/demand balance. Moreover, the events that are forecast to transpire at the first- and end-use levels could have their own respective bearings on policy formation and the EU27's approach to establishing nickel supply security.

The forecast for EU27's refined nickel market balance is depicted in Figure 117 below. The analysis takes into account the three-core nickel supply sources and plots them against first- and end-use demand from EV sales and cathode makers, respectively.

Figure 117: EU27 refined nickel supply and battery demand balances[1], 2020-2040 (kt Ni)



Source: Roskill, 2020.

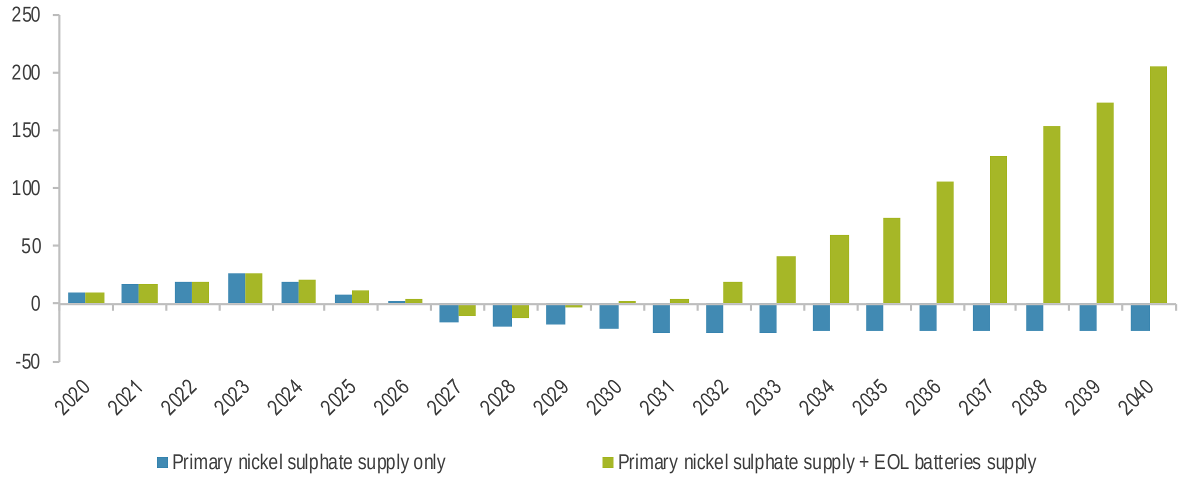
([1]) Figure displays total EU refined production. The volumes of Class I supply shown are not considered to be fully available for conversion to sulphate/directed toward the battery industry. Availability of such is dependent on EU 'critical demand' from other Class I consuming industries

When assessing the EU27's nickel market balance as a whole (solid black line), the graph above highlights a two-sided outcome. The first being an ability to sustain domestic refined nickel requirements until the mid-2020's, and the second being an inability of supply growth to keep pace with demand for the remainder of the forecast period. Roskill forecast EU27 nickel supply will enter a period of structural deficits owing to limited scope for new primary supply being developed after 2025. This is highlighted by the dotted segment between EOL battery supply and demand from EV sales. The dotted area, therefore, represents the EU27's need for domestic investment in new nickel supply and/or the requirement for sourcing additional units abroad. By 2030, this additional requirement could total 165kt Ni. Post-2030, however, rapid growth in EOL battery availability could have a 'flattening effect' on the overall market balance. Which further enforces the salience of recycling's role in future nickel supply security.

The forecast trend in the EU27's physical demand for nickel sulphate from cathode makers portrays a contrasting narrative to that of EV sales demand. Roskill considers this to reflect a 'two tiered' industry requirement for refined nickel within the EU27 for EV batteries. Owing to significant increases in primary nickel sulphate output in conjunction with an 'infant' cathode industry, domestic supply is forecast to have the ability to sustain first-use demand. Under the base-case scenario, this is considered likely to be the case until around 2026. However, this is predicated on the assumption that 100% of EU27 primary nickel sulphate supply is made available to local cathode makers first, prior to serving demand from abroad. Given that Roskill considers it likely the majority of EU27 Class I production will serve 'critical demand' from competing sectors first, it is prudent to consider primary nickel sulphate and EOL battery supply as the two key domestic cathode feedstock sources.

Where any additional Class I available for conversion decreases reliance on such. Figure 118 below shows the market balance when assessing just these two key feedstocks.

Figure 118: EU27 cathode maker nickel demand / primary nickel sulphate supply balance[1], 2020-2040 (kt Ni)

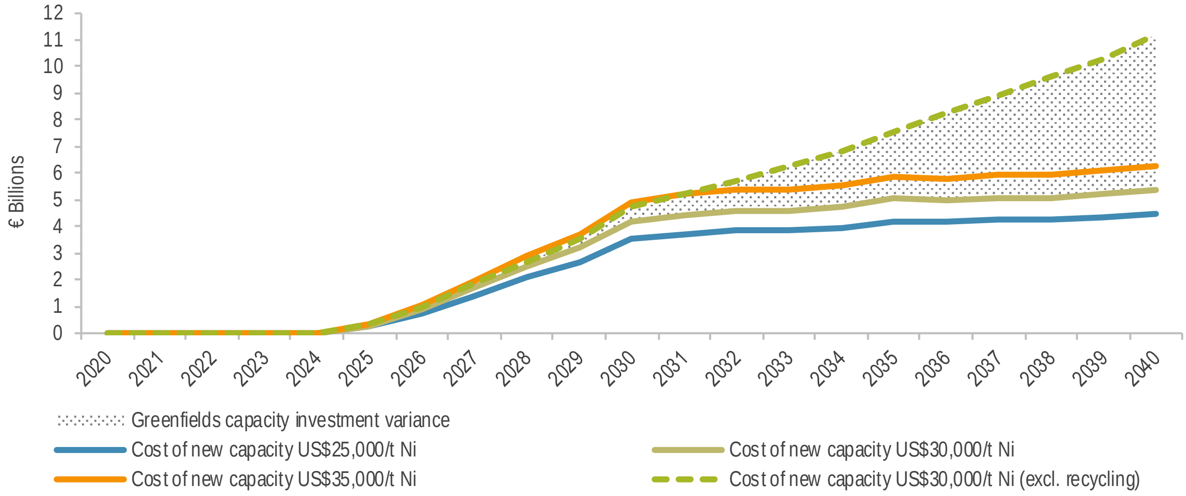


Source: Roskill, 2020.

Under the primary nickel sulphate supply only scenario, deficits in supply would emerge beyond 2026. Although, the depth of such deficits is capped at around 25kt Ni owing to the flatlining production of cathode makers. Leading up to the 2030's, we would consider it unsurprising if increases to EU27 cathode manufacturing capacity are announced, either via existing players or new market entrants. This would increase nickel sulphate demanded by industry and further deepen the size of the expected deficits. Should the EU27 not be able to develop additional primary nickel sulphate capacity by such time, recycling has the potential to provide ample additional quantities of nickel units for the cathode industry. This would remain the case even if EU27 cathode manufacturing output was to increase by 27% CAGR between 2030 to 2040, which is the growth rate of nickel availability from EOL batteries across this time period.

We have assessed the investment value required by the EU27 to achieve complete supply security via greenfields projects by 2040. Based on the average capital intensity of greenfields nickel projects globally (as determined by Roskill at US$30,000/t Ni), a total of €4.2Bn could be required by 2030. Where most of the cumulative amount would be needing to take place in the 2020's, prior to reaching €5.4Bn by 2040. Should the development of EOL recycling capacity be lagging beyond 2030, the investment requirement for new primary supply exhibits an upward trajectory. In the complete absence of EOL recycling, the investment requirement is forecast total over €11Bn by 2040.

Figure 119: EU cumulative investment requirement for new nickel capacity[1234], 2020-2040 (€ Billions)



Source: Roskill, 2020.

(1) Analysis is based off the EU27 market balance under the EV sales demand scenario shown in Figure 117

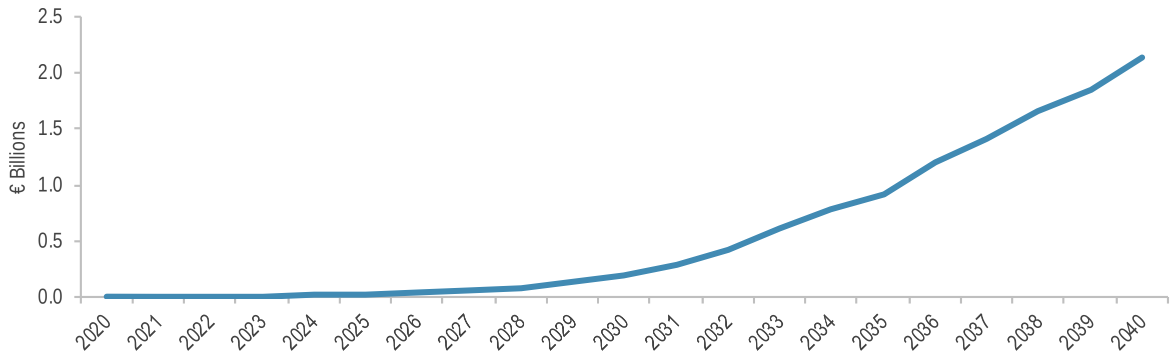
(2) Assumes USD:EUR of 0.85

(3) Cost of new capacity is also defined as the capital intensity of project development. The US$30,000/t Ni "base-case" represents the average requirement of existing global greenfields nickel projects, determined by Roskill's in-house analysis.

(4) Cumulative investment requirement in a given year is defined as the variance between the previous years' total and the additional capacity of nickel units needing to be constructed in the current year

It is important to highlight some caveats in the above analysis. Figure 119 shows the cost of constructing new nickel capacity from undeveloped assets. Hence, is not necessarily reflective to that required for existing mining and/or refining assets. As previously determined earlier in the chapter, the EU has limited scope for developing new greenfields projects and/or expanding existing mining capacity. This renders refineries as potentially the main supply segment available for investing in additional capacity. However, we have noted that several EU refineries are already undergoing expansion work which may stifle their ability to do so further in future (as a function of domestic feedstock availability). Should the EU consider a multi-faceted approach to sourcing nickel via a combined use of domestic and foreign assets, the above analysis would be reflective of the investment required abroad at the project development level.

Figure 120: EU27 cumulative investment requirement for EOL recycling capacity[1234], 2020-2040 (€ Billions)



Source: Roskill, 2020.

(1) Analysis is based off the EU27 nickel available from EOL batteries from EV applications forecast shown in Figure 100

(2) Assumes USD:EUR of 0.85

(3) Cost of new capacity is also defined as the capital intensity of project development. The US$11,000/t Ni represents the average capital intensity for a 10ktpy Ni plant capacity, determined by Roskill's in-house analysis. This is based on the current processing technology commercialised and in operation today. Various novel technologies are under development globally but remain at the R&D stage
(4) Cumulative investment requirement in a given year is defined as the variance between the previous years' total and the additional capacity of nickel units needing to be constructed in the current year

In addition to new primary nickel supply, we have assessed the investment required by the EU27 to establish a EOL recycling industry. The analysis represents the cumulative investment in capacity sufficient to recycle 100% of the forecast nickel from automotive EOL batteries (Figure 100). Based on a capital intensity for a 10ktpy Ni plant, (as determined by Roskill at US$11,000/t Ni), a total of €200M could be required by 2030, prior to reaching €2.1Bn in 2040. Should the development of EOL recycling capacity be lagging beyond 2030, the reliance on primary supply would increase and deficits would likely worsen.

When combining the EU27's investment requirement for both new primary nickel supply and EOL battery recycling capacity, it is clear a sizeable amount of capital needs to be deployed. Under the base case scenario, we estimate around €4.4Bn of investment is required by 2030. This is then forecast to increase to a total of €7.5Bn by 2040 in order to fulfil the EU27's nickel requirements from EV sales.

7 Conclusions and policy recommendations

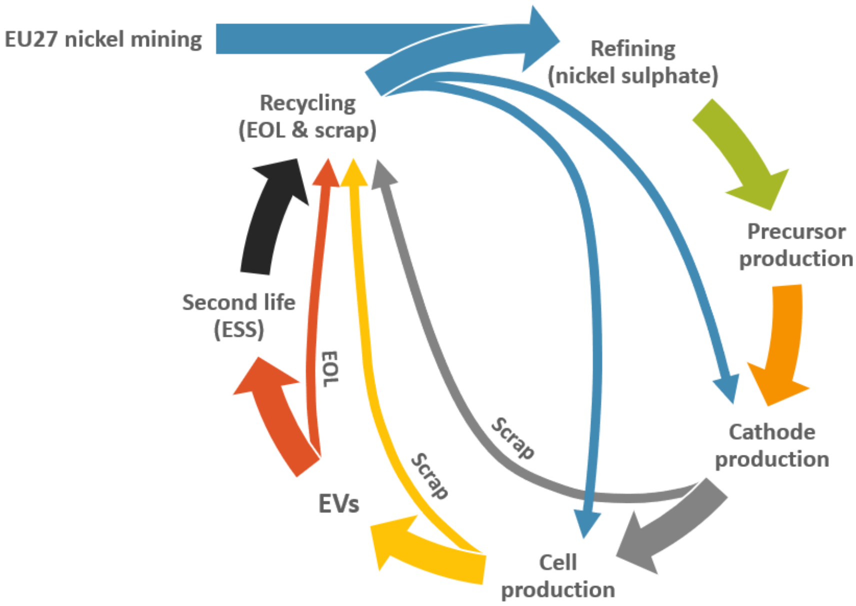
7.1 Concluding comments

This report analyses the supply and demand dynamics of the nickel market in the context of the automotive sector's transition towards electric mobility and development of a low carbon economy. Lithium-ion batteries are central to this future and nickel-rich cathodes provide the highest energy densities of the current commercialised cell variants. These being nickel-cobalt-manganese (NCM) and nickel-cobalt-aluminium (NCA) cathode types. The expected requirements for additional nickel are seismic for the market and there are multiple challenges to ensuring long-term supply security. This report provides a strategic review of the EU27's ability to source the quantities of nickel that it requires over the next twenty years in forms suitable for use in EV batteries. The conclusions from this form the basis of policy recommendations for the EU27 to enact to enable it to manage its future nickel needs.

We evaluated both global and EU27 specific supply and demand for nickel over a twenty-year forecast horizon, from 2020 to 2040. The intent of such was twofold:

1. Assess the EU27's ability to source and internally provide nickel units for use in its domestic EV battery supply chain; and
2. Identify strategic opportunities to establish a nickel circular economy to reduce or mitigate reliance on foreign nickel sources in the future.

Figure 121: Desired EU27 circular flow of nickel in the domestic battery supply chain



Source: Roskill, 2020.

The main outcomes and strategic conclusions are summarised below:

7.1.1 Demand

Automotive electrification is expected to represent the single-largest growth sector for nickel demand over the next twenty years. Within this sector alone, we forecast global demand to increase by 2.6Mt Ni to 2040, up from only 92kt Ni in 2020. Within the EU27, we forecast nickel demand from the automotive sector to increase by 543kt Ni, from 17kt Ni in 2020, under a base case scenario. Underpinning this growth is our expectation for EU27 OEMs to increasingly utilise high-nickel cathode chemistries from the mid-to-late 2020s and throughout the 2030s.

With respect to EV batteries, it is crucial to view the EU27's nickel demand through two lenses. The first is the total volumes of nickel contained in final consumer products (EV sales). The second is demand from first users (precursor/cathode manufacturing) representing physical industry demand prior to cell manufacturing. Given the possibility of trade in precursor and cathode materials, these totals do not necessarily move in step with each other. In the case of the EU27, we forecast that there will be a growing discrepancy between first-use and end-use nickel demand over the outlook period. This is due to the EU27's precursor and cathode industries still being in their infancy compared to Asia. As such, EU27 production from each of these industries is expected to lag the total requirements from cell manufacturing and EV sales for a number of years, at least. The EU27 will need to source the balance of its requirements from Asian based providers until the construction, commissioning, scaling up, and maturation of mid-down-stream battery industries takes place.

7.1.2 Supply

Demand for nickel from batteries requires a high-purity chemical product (nickel sulphate), which can only be produced from suitable feedstock forms (such as Class I nickel and intermediates). As a result, increasing demand from the battery sector presents the nickel market with both downstream refining and upstream feedstock challenges. Nickel supply has seen significant growth in recent years, but this has predominantly been in the form of Class II products not suitable for use in nickel sulphate production.

Supply of nickel products to the battery sector has attracted increased investor focus in recent years. Under the baseline scenario, we expect global nickel sulphate production to reach approximately 2,000kt Ni by 2040 growing at 13.5%py, from 159kt in 2020. Not all this production will be directed at batteries as demand growth from industrial end-use sectors (such as plating) also expected to grow to 2040. Between 2020-2030, it is expected supply growth will be driven by the use of intermediates, whilst output from Class I nickel as a proportion of feedstock use will remain relatively stable.

Class I metal production has limited upside moving forward. This is largely owing to a lack of investment in Class I-based refining capacity as well as no significant new sulphide resource discoveries in recent years. However, a greater proportion of the Class I production could be made available to nickel sulphate producers if stainless steel mills continue to reduce their required quantities. We consider the stainless sector to be the "swing player" in Class I availability moving forward. Conversely, intermediates present significant upside to supply growth in coming years as and if new projects are brought online in Indonesia. We forecast intermediate production to total 1.7Mt Ni by 2040 rising at an average of 2.2%py from 1.1Mt Ni in 2020.

Post-2030 there is limited visibility on new projects able to supply Class I and intermediate nickel products and stainless steel mills are likely to have reached their Class I reduction limits. Supply of both Class I metal and intermediates available to battery producers is, therefore, forecast to flatten. By this stage though nickel units available for recycling from

EOL batteries are likely to become a growing source of raw materials to produce nickel sulphate.

7.1.3 Market balance

At the global level, we forecast the overall nickel market returned to surplus (125kt Ni) in 2020 for the first time since 2015. This is largely owing to a decrease in nickel demand as a result of the ongoing COVID-19 pandemic. Given the planned additions to supply we expect this surplus to continue until supply begins to tighten and the market re-balances in 2024.

For the Class I part of the nickel market we also expect a supply surplus this year, of approximately 145kt Ni. Based on current production plans, demand trends and forecasts of recycled material availability we would expect this part of the market to remain in surplus until 2028. This though is predominantly a function of the stainless steel sector progressively reducing its Class I feedstock requirements from over 10% of its nickel units to 5% under our base case scenario. Should the sector's use of Class I feedstock remain higher than 5% by the end of the 2020s, a decrease in the Class I market surplus and tightness in supply is likely to occur earlier.

With regards to the nickel sulphate market segment, global supply capacity is not expected to tighten until the 2027/28 period. Beyond then supply deficits are also likely to emerge and potentially reach 977kt Ni in 2040. It is important to note, however, that (as with Class I nickel production) we view the total long-term nickel feedstock availability deficit of equal importance to that of nickel sulphate. This is due to the former being conducive to the outcome of the latter as some consumers and producers will switch between the consumption and production of nickel in its different forms to balance different segments of the market, regardless of whether nickel sulphate production capacity is made available or not.

Given the focus on "battery-grade" nickel within this study, analysis of the EU27 market balance has been based on the demand and supply of Class I nickel metal, intermediates and the recycling of EOL batteries. There are two tiers of this market balance that need to be considered. On an end-use basis, where demand is based on contained nickel in EV sales in the EU27, we forecast the EU27 has the ability to meet our forecast internal demand until 2024/25. Beyond this point, we expect supply will fall into a sizeable and increasing deficit, reaching 165kt Ni by 2030. Owing to flat supply of new nickel units during the 2030s, recycling of EOL batteries will be crucial in limiting this growth in the EU27's market deficit. Under our base case, supply from EOL recycling could total 228kt Ni by 2040, from 21kt Ni in 2030. A market deficit of 165kt Ni and 206kt Ni is forecast in 2030 and 2040, respectfully.

At the industry level (precursor/cathode maker first-use), forecast quantities of nickel demanded by the EU27 are multitudes lower than that contained in the EU27's EV sales. This is a function of a relatively small "mid-stream" industry in the EU27 compared to that of Asia. Regardless, supply security of nickel is still a concern. Should a sizeable EOL recycling industry not be established by the late-2020s, we expect a EU27 first-use supply deficit to form in 2027 and then remain over the rest of the outlook period. If recycling is included, the EU27 would have ample ability to sustain its domestic precursor/cathode industry with domestic supply throughout the 2030s. This does assume, however, EU27 first-use industry does not grow in scale beyond that of the base case forecast. This though assumes the EU27 will continue to be a significant importer or precursor and cathode materials, which may not be possible if the global market is in deficit.

7.1.4 Strategic conclusions and apparent risks

The availability of suitable feedstock rather than processing capacity is the biggest "bottleneck" in the nickel sulphate supply chain and is the cause of the market going into a structural deficit post-2027 (Figure 109). Threats that may exacerbate this risk, and also diminish the EU27's access to nickel sulphate production that is available to the market, include - but are not limited to - the following:

- Primary mine supply: few existing operation expansions and/or new projects
- Stainless steel sector: refusal or inability to reduce use of Class I nickel metal
- Integration of Indonesian intermediates: removing volumes available to the open market
- EOL recycling: i) lacklustre cell recovery rates, and/or ii) insufficient establishment of industry recycling capacity
- Battery second life uses: re-use of automotive batteries in other end-use sectors such as ESS would reduce quantities of nickel available for recycling
- Access to capital markets: insufficient investment funds would delay potential new capacity (both primary and recycling) being brought online
- Investment timing: long development, construction and ramp up periods are likely, investments in projects are therefore required ahead of future supply tightness
- Resource nationalism: nickel producing nations preferences for "value-added" products could increase, specifically in Indonesia, potentially forcing integration to nickel sulphate production

We do not, however, view our forecast nickel sulphate supply and feedstock availability deficits as definitive or inevitable. Beyond 2030, supply/demand dynamics are increasingly uncertain and medium-long-term projections of a deficit should be more accurately interpreted as the "investment requirement" for additional new supply, or alternatively the amount by which demand would need to be reduced. Assuming EU27 demand is not reduced then to meet the requirements of end-users in the region we estimate cumulative investment in additional new primary supply capacity would total €4.2Bn and €5.4Bn by 2030 and 2040, respectively. However, the EU27 may not even be able to deploy such capital owing to a lack of development ready nickel deposits domestically. This increases the need for instead directing investment focus towards a domestic battery recycling industry to fill the gap where new supply of feedstock for producing nickel sulphate is not able to be developed internally or sourced externally. We estimate the cumulative investment requirement in capacity to cover 100% of available nickel from automotive EOL batteries to total €200M and €2.1Bn by 2030 and 2040 respectively. In reality, investment in both new primary supply and recycling is required to de-risk future supply security within the EU27.

There are three main procurement models the EU27 could adopt to increase supply:

1. Solely domestic
2. Solely foreign
3. Combination of domestic and foreign sourcing

It is unlikely that the EU27 could solely meet its supply needs domestically (1) and sole foreign dependence (2) creates security of supply issues. Thus, we believe the lowest risk approach would be (3) a combination of domestic and foreign sourcing. This could be structured under a “procure and own” approach. The former pertaining to primary nickel supply (mining and refining), and the latter underpinned by EOL recycling in a circular economy.

7.2 Implications for policy

In the context of the EU27 establishing future nickel supply security, well directed policy will play a crucial role alongside the organic responsiveness of the free market. When determining suitable policy, the two-tiered structure of EU27 nickel demand (end-use vs first-use) requires consideration. The timing of implementation is also important and may determine the effectiveness of policy outcomes. Challenges to achieving supply security are multi-faceted, and so no single policy is likely to generate the outcome of future nickel availability alone. Our recommendations for potential policy direction and options should, therefore, not be taken independently, but rather collectively where the benefits from each can be compounded together. Policy is rarely costless and can have direct fiscal costs and indirect costs on producers and consumers. Imposing regulations or taxation can also lower the long run productive capacity of an economy. Such trade-offs need to be taken into account when designing policy. To maximise effectiveness of policy adoption and implementation establishing consistency across EU27 member states would generate clarity for industry to act upon.

Nickel is not classified as a critical material in the EC, however various facets of the critical materials debate are relevant to this study on nickel. Future security of supply for this economically important metal is of paramount importance to the EU27. The European Commission (EC) intends that its critical materials studies should help to strengthen the competitiveness of European industry in line with the renewed industrial strategy for Europe; stimulate the production of critical raw materials by enhancing new mining and recycling activities in the EU27; foster efficient use and recycling of critical raw materials; increase awareness of potential raw material supply risks and related opportunities among EU27 countries; negotiate trade agreements, challenge trade distortion measures; develop research and innovation actions and implement sustainable development goals. To what extent has this been the case?

While raw material supply risks have certainly been promoted, other aims of the EC’s critical materials agenda, such as strengthening European industrial policy, stimulating the production of raw materials in Europe, fostering more recycling of critical materials, and improving sustainable development, have not yet been met. Thus far, European policymakers have not much advanced the important critical materials agenda past the definitional phase. It is important to advance the debate on critical materials beyond classification and definition so that strategies can be formulated and applied and so that the EU27 can work towards its aim to cut greenhouse gas emissions by 50-55% by 2030, and achieve climate neutrality by 2050.

To its credit, the EC seems to now be taking steps towards this. It has launched a new industry alliance aimed at building a complete EU27 supply chain for raw materials vital to renewable energy, electric vehicles, and the circular economy. The new policies are connected to the European Green Deal (its plan to make its economy sustainable) and the

Just Transition Fund (a fund aimed at supporting EU27 regions most affected by the transition to a low carbon economy). There will be an industry-driven process led by EIT RawMaterials (funded by the European Institute of Innovation and Technology), whose task will be to identify opportunities and barriers and to create relevant investment cases with stakeholders and industry partners. The EC has also pledged to strengthen its work with Strategic Foresight Networks to develop robust evidence and scenario planning on raw materials supply, demand and use for strategic sectors. The criticality assessment methodology may be reviewed for the next list (2023) to integrate the latest knowledge.

In *Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability*, the EC asserts that the EU27 should act urgently to ensure a secure, sustainable supply of raw materials, pooling the efforts of companies, sub-national and national authorities as well as the EU27 institutions. It notes that the EU27 action plan for critical raw materials should:

1. **Develop resilient value chains for EU industrial ecosystems** – through new industrial alliances, including a dedicated industrial alliance on raw materials. In a first phase, the European Raw Materials Alliance (to be launched Q3 2020) will focus on the most pressing needs, seen as increasing EU27 resilience in the rare earths and magnets value chain, before exploring other areas. Another key action is the development of sustainable financing criteria in the mining, extractive and processing sector. Notably, the European Investment Bank has recently adopted its new energy lending policy, in which it states that the bank will support projects relating to the supply of critical raw materials needed for low-carbon technologies in the EU27. This is important to help de-risk projects and attract private investment in the EU27 and in those resource-rich third countries within its operating mandate.

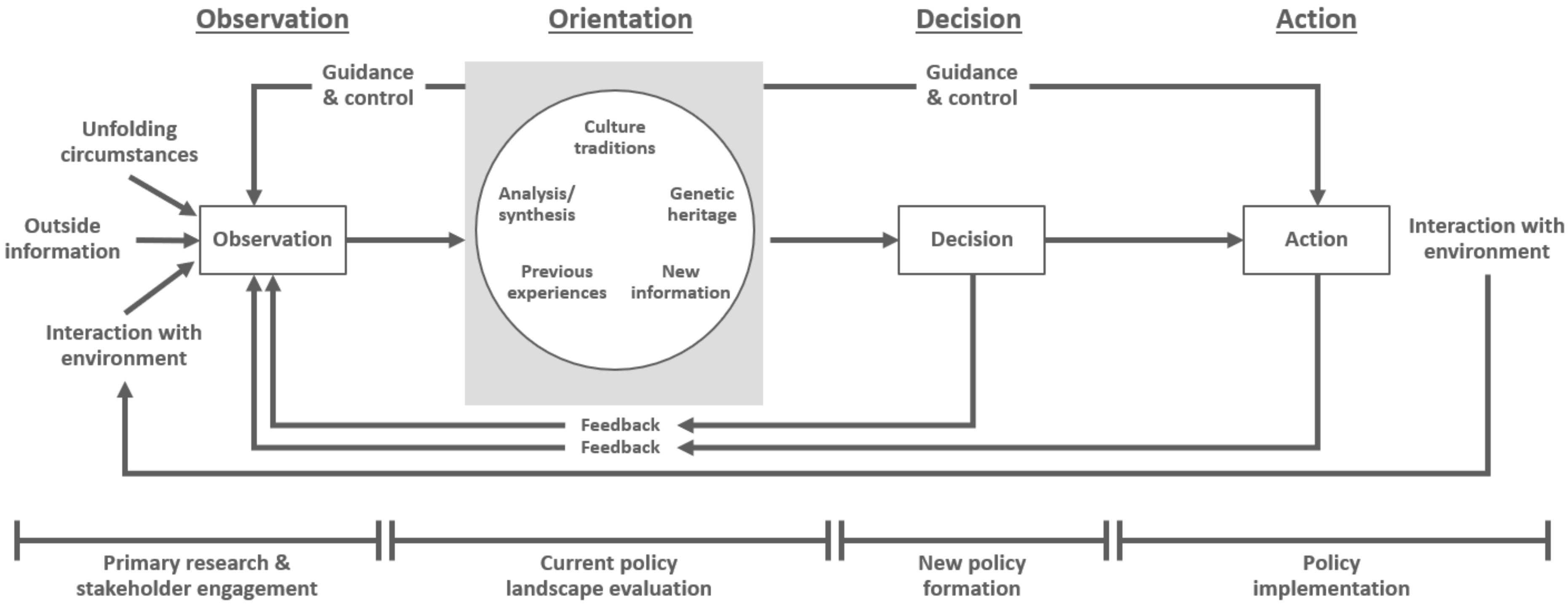
2. **Reduce dependency on primary critical raw materials through circular use of resources, sustainable products, and innovation** – in line with the European Green Deal's Circular Economy Action plan, which aims to decouple growth from resource use through sustainable product design and mobilising the potential of secondary raw materials. As a first step, the intention is to launch critical raw materials research and innovation in 2021 on waste processing, advanced materials, and substitution, using Horizon Europe, the European Regional Development Fund, and national R&I programmes. EC documents argue that a better understanding of secondary materials is needed, thus a key action is the mapping of potential supply of secondary critical raw materials from EU27 stocks and wastes and identify viable recovery projects by 2022.

3. **Strengthen the sustainable and responsible domestic sourcing and processing of raw materials in the European Union** – mobilising Europe's domestic potential better. Key actions are identifying mining and processing projects and investment needs and related financing opportunities for critical raw materials in the EU27 that can be operational by 2025, with priority for coal-mining regions; developing expertise and skills in mining, extraction and processing technologies, as part of a balanced transition strategy in regions in transition from 2022 onwards; deploying earth-observation programmes and remote sensing for resource exploration, operations and post-closure environmental management; and Develop Horizon Europe R&I projects on processes for exploitation and processing of critical raw materials to reduce environmental impacts starting in 2021.

4. Diversify supply with sustainable and responsible sourcing from third countries, strengthening rules-based open trade in raw materials and removing distortions to international trade – principally by reinforcing use of EU trade policy tools.

These represent positive action plans from the EC, but much work is still to be done if the critical materials agenda is to gather some momentum. In a developing industry such as the battery value chain, policy should also not be viewed as stagnant. Industry progression and needs are extremely fluid as various stages of the battery supply chain may not develop concurrently and technological factors and market conditions are likely to change over time. Ongoing assessments and reviews of policy suitability and their impact are therefore required. The need for promoting future nickel supply security, whether to support the needs of end-use or first-use sectors, is likely to evolve over time. We recommend that any policy enacted should be periodically reviewed against the goals it set forth to achieve and its effectiveness in doing so. The Observation, Orient, Decide Act (OODA) decision framework highlights the need for constant review in the decision-making process.

Figure 122: Boyd's OODA decision loop



Source: Roskill, 2020; Boyd, 2017.

That all said, given the findings of this report then in order for the EU27 to be able to meet the objective of establishing a nickel circular economy and reducing or mitigating its reliance on foreign nickel sources in the future it is recommended to put policies in place that address the following three headline areas:

1. Demand deflation
2. Supply strategy
3. Research and development

Table 11: Policy recommendation summary[1]

Focus area	Policy ref.	Policy target	Implementation time horizon
Demand deflation	**A**		
	A1	Infrastructure	Medium, long term
	A2	Nickel battery alternatives	Short, medium, long term
	A3	Automakers	Short term
	A4	Pooled mobility	Medium, long term
Supply strategy	**B**		
	B1	Mine/refined supply	Short, medium, long term
	B2	Finance	Short, medium, long term
	B3	Precursor/cathode makers	Short, medium term
	B4	EOL recycling	Medium term
Research & development	**C**		
	C1	Cell technology	Short, medium, long term
	C2	Intellectual Property	Short, medium, long term
	C3	Labour market	Short term
	C4	Sustainability	Short, Medium term

Source: Roskill, 2020.
([1]) Short term = 0-3 years; medium term = 3-6 years; long term = 6+ years

7.2.1 Demand deflation (A)

In order to promote a reduction in reliance on nickel for e-mobility, we believe the EU27 should place a focus on policy that addresses the following:

1. Investment in public infrastructure
2. Where end-use segments allow, encourage use of alternatives to nickel-based batteries
3. Establish clear guidance for industry to act upon emissions policy
4. Regulation, where necessary

- **A1: Investment in e-mobility infrastructure** – Transportation to substitute car demand would decrease nickel requirements from the automotive sector. Built up cities and urban areas are likely to have the greatest impact on such. Train, tram, e-buses, e-taxis and e-bikes are potential avenues for consideration. E-mobility of these kinds can utilise non-nickel-based batteries (such as LFP) as distance in built up areas is less of a concern. Policy could help guide investment in transportation networks of this kind as part of a medium-long term strategy to reduce reliance on nickel. This may be accompanied by regulation or taxation to discourage private vehicle ownership.

A2: Utilise nickel alternative cells where best suited - LFP batteries could be used by carmakers to manage the procurement risks of nickel and cobalt. An increase in LFP use in Europe, particularly in urban vehicles, could reduce nickel requirements by 5-15% (28-84kt Ni) on a cumulative basis between by 2040. Non-nickel battery types are best suited specific end-use segments in built up areas (e.g. small car, buses, taxis etc.), where performance and range are less of a concern. Policy could help stimulate the adoption of such but should only target e-mobility segments where nickel-based cells are not considered a necessity. Additionally, hybrid vehicles would decrease nickel demand. However, policy could be used to enforce control systems that such vehicles are driven on electric mode to the full extent they can. This would also minimise CO_2 offsets from the over-use of the ICE powertrain. Policy of this kind would most likely be effective in urban/built up areas, where adequate charging infrastructure is also installed.

- **A3: Industry responsive emissions policy** – So far fleet average emissions targets impact on e-mobility adoption is unclear. This could be due to OEMs being able to prioritise the use of hybrid powertrains to achieve their respective emissions targets. While OEMs will eventually need to produce zero emissions vehicles (BEV, FCEV), ambiguous routes to achieve emissions targets could lead to underinvestment in the automotive industry. This is occurring in the areas of dedicated EV platform design and cost-efficient production. More stringent policy measures could force OEMs delaying mass EV adoption to fast-track investment. Crucially, a balance needs to be achieved between phasing out fleet average emissions completely and the industry's expected timeline to profitability on EV models OEMs. For example, if OEMs are forced to produce zero emissions vehicles too soon their profitability will be impacted owing to EV manufacturing not yet reaching cost parity with ICE equivalent models.

- **A4: Boost uptake of pooled mobility** – Ride sharing services could play a role in reducing overall demand for and use of cars on the road. Promoting shared e-mobility services are likely to be most effective in city/urban areas. Development of such networks would reduce the total demand for nickel in two ways. The first being the requirement for utilising non-nickel-based batteries, and the second being a decrease in the total number of cars potentially sold. Regulation or taxation may also assist this development.

7.2.2 Supply strategy (B)

We believe the EU27 should place a focus on policy that addresses the following:

1. Facilitate the use of domestic supply in local industry
2. Provide access to sustainable international resources and supply-chains
3. Prioritise "closing the loop" as part of long-term recycling industry development

- **B1: Mine and refine more nickel** – Domestic and international sourcing is necessary to fulfil the forecast EU27 nickel requirements:

- Domestic: The EU27 currently only has two mining assets in operation producing suitable nickel for use in EV batteries. Both are expanding production in coming years but their ability to expand more in future may be limited. For development projects policy should seek to streamline any governmental application processes (such as permitting, drilling, construction etc.). Should any further nickel sulphate refineries be developed, governments could provide packages of strategic land, zoned for chemical manufacturing and/or in proximity to precursor/cathode makers.
- International: Shortages in supply of battery-grade nickel is a global issue and not unique to one region. The EU27 should therefore not seek to separate itself from the international nickel market as it will be needed fill the balance left by domestic supply. Policy could be directed at:
  - Forming alliances with suitable countries and mining projects that produce Class I or intermediate nickel products in a sustainable manner.
  - Providing incentives for EU27 buyers to source from approved operations such as the removal of any import duties, quotas and VAT applicable. Free Trade Agreements pertaining to nickel are considered beneficial.
  - Enacting measures that help deploy investment in foreign assets. Investments could take place via direct ownership, equity stake, long-term offtake or joint venture agreements. Investments required in new primary nickel supply to fulfil EU27 demand could total €4.2Bn and €5.4Bn by 2030 and 2040, respectively (assuming EOL recycling scenario).
  - Provide technical assistance to counties with the potential to supply nickel raw materials. This includes improving their geological knowledge and mining codes, developing skills, establishing effective fiscal regimes and improving legal and other property rights.

- **B2: Funding platforms** – Existing organisations such as EIT RawMaterials, European Investment Bank and the European Battery Alliance should continue to play a part:
  - Early stage: Provision of funds for developers of upstream supply. Where early stage nickel sources are identified within the EU27, funding platforms for exploration and resource delineation could establish strategic resources bases for the longer term.
  - Development stage: Projects at the Scoping Study, PFS or DFS stages could be provided funds for the provision of technical related works (e.g. engineering or processing).
  - Construction stage: In conjunction with private sector funds and offtake partners, finance vehicles for project development could provide access to low cost capital and de-risk deployment of investment funds from the private sector.

- **B3: Ensure local industry supply –** Precursor/cathode manufacturers could be comfortably supplied by local primary nickel sulphate production to 2025. Post-2025, primary supply from the EU27 alone is expected to be insufficient. Redirecting EU27 Class I nickel away from 'critical demand' sectors will have its limits. Primary nickel sulphate and EOL recycling supply should therefore be the focus, with any Class I nickel available for conversion to sulphate an added plus.

- Under our base case forecast: A policy framework could be developed to incentivise the engagement of local buyers and sellers. This could include the removal of any VAT, duties etc. and provide EU27 industry with a 'first right of refusal' for quantities of product. Only enforcing this once the associated buyer (precursor/cathode maker) has reached consistent commercial production should be taken into consideration. This would not place an unnecessary risk on nickel producers by stifling their ability to trade outside the EU27. Encouraging industry to buy local supply first is also the first step in establishing a nickel circular economy.
- Industry growth expectations: As the EU27 battery supply chain matures, it is considered likely first-use industry will grow in scale to reduce the reliance on Asian made precursor/cathode materials. This will in turn increase local industry demand for nickel sulphate where volumes may exceed EU27 supply. Policy should then be directed at facilitating and streamlining access to sustainable foreign producers of nickel sulphate to ensure adequate feedstock supply.

- **B4: Establish a circular economy** – Fostering a scalable EU27 EOL recycling industry is considered a key part of a longer-term approach to supply security. However, this is unlikely to be economically viable as a standalone business, unless subsidised, until large volumes of EOL batteries are consistently available for collection. We forecast this point to be between 2027-2029. In order to guarantee nickel in batteries remains in the EU27 supply loop, the EU27 could adopt a *sold in the EU27, stays in the EU27* policy. This would be applied to EVs sold domestically and could be implemented via tracking mechanisms (such as pack ID codes). Such policy would provide a "continental ownership" for such batteries without stifling OEM freedoms for international trade (sales overseas). A total of €200M could be required in investments in recycling plant capacity by 2030, potentially reaching €2.1Bn in 2040.

7.2.3 Research and development (C)

We believe the EU27 should place a focus on policy that aims to achieve the following:

1. Explores alternatives to reducing the sector's dependency on nickel in the future
2. Generates international comparative advantages in technology and sustainability
3. Drives active citizen participation in industry

- **C1: Reduce dependency on nickel-use –** Although nickel provides the highest energy density for current lithium-ion technologies, high-nickel cathodes are not required in all e-mobility applications. LFP is one alternative to such, however continuous investment in developing technologies, inclusive of non-lithium-ion batteries, should take place. Battery technologies using high-energy density anodes like silicon or lithium metal could progressively reduce nickel requirements in batteries by up to 30% by 2040. However, such technology transitions are expected to be slow and incremental versus fast and disruptive. This should therefore form part of a long-term strategy to reduce the battery industries reliance on nickel. Where end-use applications do not require nickel-based batteries incentives could be provided to promote their use.

- **C2: Build technological advantages** – Currently, Asian-based cell manufacturers have the technological advantage in battery cell design and manufacturing. In order for the EU27 to build a home-grown industry, technological advancements and IP ownership should be a priority. Policy could guide the creation of EU27 battery "think tanks", where grants and industry partnerships drive lab, pilot and commercial scale research and development. Incentives for major industry players, such as OEMs and cell makers, could be provided in the form of tax offsets, where the tax offset would be equal to the total annual investment. The goal of this type of policy would be to decrease the EU27's technological dependence on foreign nations with which it competes with. Patent registrations could be a key indicator of success in this area.

- **C3**: **Establish skilled labour** – In 2017, the European Battery Alliance announced the target of capturing €250Bn of value annually from its battery industry (from 2025). In order to maximise this value capture, EU27 production must be contributed to by local labour. The requirement for highly skilled labour is only going to increase. Policy could guide the promotion educational programs, upskilling and apprenticeships in industry. Foreign companies could be required to train and employ a minimum percentage of its required workforce from local areas. The outcome of such policy should be aligned to enabling citizens to participate in the value capture. With respects to nickel labour skills could be directed at the following:
    - <u>Exploration and mining:</u> Geologists, mine engineering, metallurgy, environmental remediation etc.
    - <u>Processing and refining:</u> Primarily directed at nickel sulphate production from various feedstock types (chemists, metallurgists, plant operators etc.)
    - <u>Supply procurement:</u> Commercial procurement active in sourcing supply of nickel units both domestically and internationally

- **C4: Nickel extraction and refining** – Policy could promote investment in improving existing process technologies as well as investigating the commercialisation potential of novel ones. The main goal of such would be to i) improve overall efficiencies in nickel processing (e.g. higher recovery rates, waste reduction etc.) and ii) improve the sustainability of the nickel industry (e.g. energy intensiveness, waste disposal treatment etc.). Such work could be undertaken in partnership with local participants (mining, refining and chemical companies) and other countries where the EU27 also sources nickel from.

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List of abbreviations and definitions

Metrics and terms of measurement

M	Million
Bn	Billion
t	Tonne
kt	Thousand tonnes
Mt	Million tonnes
tpd	Metric tonne per day
tpm	Metric tonne per month
tpy	Metric tonne per year
py	Per Year
CAGR	Compound Annual Growth Rate
g	Gramme
kg	Kilogramme
mg	Milligramme
lb	Pound
km	Kilometre
km^2	Square kilometre
wt %	Weight percent
ppm	Parts per million
V	Volt
Ah	Ampere-hour
kWh	KiloWatt hour
Wh/kg	Watt hours/kg
^oC	Degrees Celsius
Pa	Pascal
dwt	Deadweight tonnage

Project status

PEA	Preliminary Economic Assessment
PFS	Preliminary Feasibility Study
DFS	Definitive Feasibility Study
BFS	Bankable Feasibility Study

Battery types

LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
LMO	Lithium Magnesium Oxide

LTO	Lithium Titanate Oxide
NCA	Nickel Cobalt Aluminium
NMC	Nickel Manganese Cobalt (also NCM)
NCMA	Nickel Cobalt Manganese Aluminium
eLNO	Lithium Nickel Oxide

<u>Battery Market and Terms</u>

BEV	Full Electric Vehicle
BMS	Battery Management System
ESS	Energy Storage System
EV	Electric Vehicle
ICE	Internal Combustion Engine
HEV	Hybrid Electric Vehicle
PHEV	Plug in Hybrid Electric Vehicle
SEI	Solid Electrolyte Interface
SOC	State of Charge
xEV	Any Electric Vehicle Type

<u>Alternative Battery Types</u>

Li-S	Lithium Sulphur
LMP	Lithium Metal Polymer
Na-ion	Sodium Ion
Na-O	Sodium Oxygen
Na-S	Sodium sulphur
NiCd	Nickel Cadmium
NiMH	Nickel Metal Hydride
VRB	Vanadium Redox Battery

<u>Nickel product and market terms</u>

Ni	Nickel
NPI	Nickel pig iron
FeNi	Ferronickel
MSP	Mixed sulphide precipitate
MHP	Mixed hydroxide product
RKEF	Rotary Kiln-Electric Furnace

Material elements

Al	Aluminium
C	Carbon
Co	Cobalt
Cu	Copper
EC	Ethylene Carbonate
FEC	Fluoroethylene Carbonate
Fe	Iron
Li	Lithium
LCE	Lithium Carbonate Equivalent
Mn	Manganese
Ni	Nickel
NMP	N Methyl 2-Pyrolidone
PA	Nylon
PE	Polyethylene
PCM	Phase Change Materials
PP	Polypropylene
PVDF	Polyvinylidene Fluoride
SBR	Styrene Butadiene Rubber
Si	Silicon
Si/C	Silicon Composite

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Annex 1. Indonesian intermediate HPAL plants in construction/planned

- Vale already produces intermediate products in Indonesia (in the form of nickel matte) in Sorowako, but other plants producing intermediate products are likely to be built in the country. Vale is investigating the possibility of just such an option. At Pomalaa, the company is undertaking a joint venture with SMM to look into the possibility of building an HPAL plant that would process limonite ores into 40ktpy nickel-in-MHP, which would then be further processed into battery-grade material for the electric vehicle market. An investment decision was due to be made by Q2 2020, but was delayed, and is now expected in H2 2020.

- The first concrete announcement of Chinese investment in Indonesian battery-grade intermediate projects, was made in September 2018. A joint-venture comprising Tsingshan, GEM Co, Brunp (a subsidiary of CATL), Japan's Hanwa and Indonesia's IMIP unveiled a US$1.0Bn investment in an HPAL plant that will produce nickel and cobalt intermediates. The plant is being built in Morowali and is expected to produce around 50ktpy of nickel-in-MHP, of which 30ktpy is to be processed onsite to nickel sulphate. The operating company is PT QMB New Energy Materials. Construction of the greenfield battery material project commenced in January 2019.

- A second nickel HPAL plant is planned for Morowali (a JV between Tsingshan, Huayou and China Molybdenum). This plant would have a capacity of 60ktpy nickel-in-MHP and be operated by PT Huayue Nickel Cobalt (HYNC). The project obtained the approval from the National Development and Reform Commission (NDRC) to commence construction, which began in March 2020. In November 2019, China Molybdenum, through its financial arm W-Source, acquired 100% of one of the project's shareholders. After the acquisition, China Molybdenum will increase investment capital by a maximum of US$69.1M, which effectively gives them a 30% stake in PT Huayue Nickel Cobalt, with Huayou holding 57%, Tsingshan holding 10% and the remaining 3% being held by Hualong and Long Sincere. As agreed by project shareholders, Tsingshan (via Qingchuang International and associated entities) will ensure laterite ore supply for Huayue over the 10 years following commissioning, and for the final output, Huayou (via Huaqing) will take 59% of nickel and cobalt products with China Molybdenum (via Woyuan) taking 31% and Tsingshan (via Qingchuang) receiving the remainder). The JV is targeting first production in late 2021.

- Another Chinese investment project using HPAL processing, is Indonesia's Harita Group and Chinese Ningbo Lygend's plant in Obi Island. With trial production targeted for Q4 2020, Roskill considers this to be the most advanced of the battery-grade intermediate projects in the country. The JV operating subsidiary, PT Halmahera Persada Lygend, plans to produce 37ktpy nickel-in-MHP, which will be processed to nickel sulphate in Indonesia. The HPAL plant will benefit from locally sourced laterite ore, with Ningbo Lygend owning a stake in nearby nickel mining operations. The total CAPEX is estimated at around US$1.5Bn.

- Jinchuan WP is conducting a feasibility study on the construction of an HPAL plant next to its NPI facility on Obi Island. JNMC WP would be able to hydrometallurgically process the limonite ore left behind after saprolite mining used in NPI production, targeting an initial capacity of 20ktpy Ni-in-MHP. All MHP output would be used to produce nickel sulphate either in Indonesia or China.

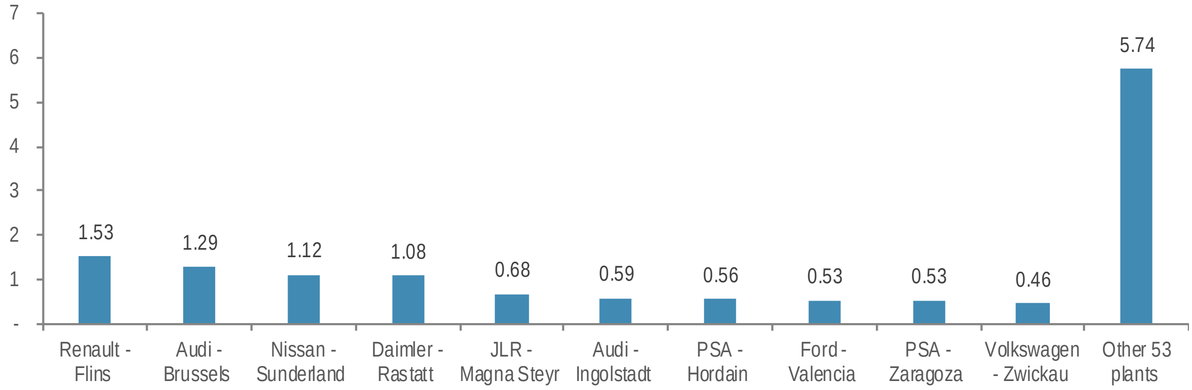
- Chengtun Mining has announced that its subsidiary Hongsheng International will invest US$145M to construct a nickel smelter in North Maluku. Total investment in the project is expected to be US$407, which lies within the Weda Bay Industrial Park in Halmahera province of the Island. The JV subsidiary PT Youshan Nickel Indonesia is a joint venture between Tsingshan (35%). Chengtun Mining (35.8%) and Huayou Cobalt (29.3%). The project is targeting capacity of 34ktpy nickel-in-matte. It is unclear whether the nickel matte would be processed domestically or exported elsewhere within Asia.

Annex 2. European battery capacity by Tier and company (GWh)

Tier	2020	2030	2040
Tier 1			
CATL	5	59	97
LG Chem	15	107	166
Samsung SDI	5	19	29
SK Innovation	8	21	31
Tesla	-	46	76
Sub-total	33	252	400
Tier 2			
AESC	4	12	19
Farasis	-	14	21
Northvolt	8	88	140
SVOLT	-	31	50
Sub-total	12	144	230
Tier 3			
Akasol	1	2	2
BMZ	-	10	16
Bollore	1	1	2
Britishvolt & AMTE Power	-	44	75
FREYR	-	47	83
GS Yuasa	0	0	0
Inobat	-	18	29
Leclanche	1	3	4
Liacon GmbH	0	2	2
Morrow Batteries	-	40	68
NEVS	-	25	43
PSA-SAFT Consortium	-	83	150
Sub-total	3	274	475
Total all tiers	47	670	1,104

Source: Roskill, 2020.

Annex 3. Nickel demand by EV production plant in Europe, 2020 (Kt Ni metal)



Source: Roskill, 2020.

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