McKinsey&Company

The future of nickel: A class act

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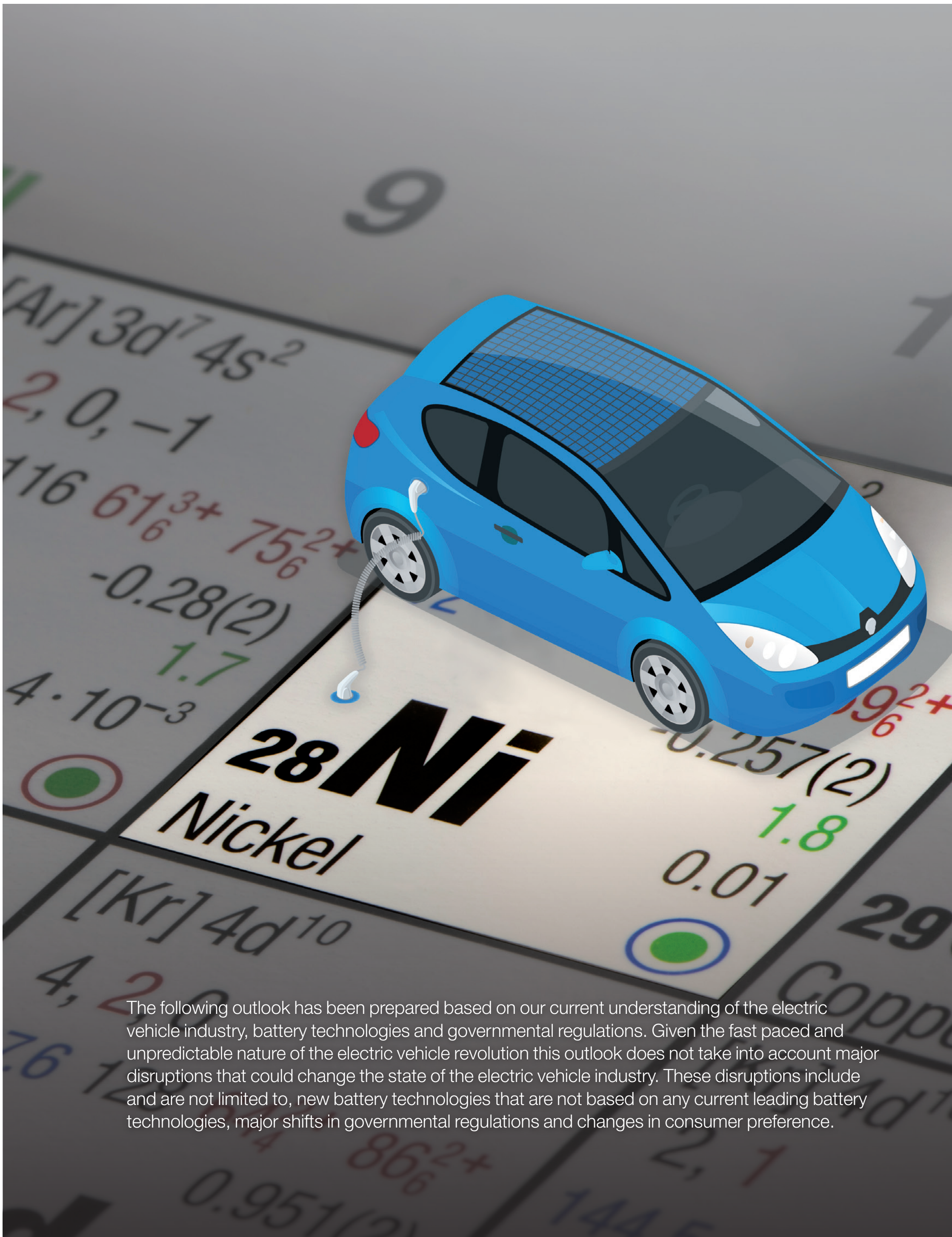

The following outlook has been prepared based on our current understanding of the electric vehicle industry, battery technologies and governmental regulations. Given the fast paced and unpredictable nature of the electric vehicle revolution this outlook does not take into account major disruptions that could change the state of the electric vehicle industry. These disruptions include and are not limited to, new battery technologies that are not based on any current leading battery technologies, major shifts in governmental regulations and changes in consumer preference.

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Executive summary

The global nickel market is entering a period of flux as two distinct commodity segments emerge: nickel used in the fast-growing rechargeable battery market – in particular for electric vehicles (EVs) – and nickel for the traditional stainless steel market, dominated by ferronickel and nickel pig iron (NPI). This shift presents a set of opportunities and threats that will require mining companies, battery manufacturers, and car OEMs to reevaluate their strategies.

The global nickel market has traditionally been driven by stainless steel production using both high-purity class 1 and lower-purity class 2 nickel products. Significant expansion of low-cost class 2 nickel capacity over the past decade – in particular NPI – has caused nickel prices to fall from the highs of USD 29,000 per metric ton in 2011 to an average of just above USD 10,000[1] per metric ton in 2017, resulting in the curtailment of higher-cost class 1 capacity. However, the growing adoption of EVs and the resulting demand for high-purity nickel is providing a much-needed reprieve for the industry as a shift towards nickel-rich battery chemistries accelerates.

Currently, class 1 nickel supply suitable for battery production represents approximately half of global supply of 2.1 million metric tons (Mt) – although only 350 metric kilotons (Kt) is available to be processed into powder and briquettes that could be used to produce nickel sulphate (in 2017 approximately 65 Kt to 75 Kt of nickel content will be used to make nickel sulphate). With annual EV production expected to reach 31 million vehicles by 2025, demand for high-purity class 1 nickel may increase significantly from 33 Kt in 2017 to 570 Kt in 2025. This comes on top of class 1 demand from traditional end-use segments i.e., plating, foundry and super-alloys. A shortfall in class 1 nickel production seems increasingly likely as current low nickel prices do not support class 1 nickel capacity expansions and alternative strategies e.g., shifting existing production from nickel cathode to nickel sulfate or refining nickel intermediates, seem unlikely to provide long term solutions. As a result, not only will nickel prices likely need to move towards incentive pricing but the future pricing mechanism is likely to reflect two distinct nickel products: class 1 and class 2.

How rapidly a potential shortfall in class 1 nickel supply emerges will depend on several factors, including the speed of EV adoption, the choice of battery technology, mining companies' willingness to restart class 1 production projects after a decade of low nickel prices, the potential for technology breakthroughs in cost-competitive refining of non-ferrous class 2 products and the potential for increased class 1 nickel recycling. Whatever scenarios emerge, value chain participants need to weigh the strategic moves to enable them to benefit from future nickel industry dynamics.

The following base case analysis is based on a set of assumptions regarding EV demand growth and battery chemistries. Although we believe these assumptions to have a high likelihood, how the industry actually evolves will be affected by government policies, battery technology innovations, and industry economics.

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1 Average from 1 January 2017 to 31 October 2017

Nickel: a market on the cusp of change

Historically, the global nickel industry has been driven by stainless steel production, which has represented approximately 80 percent of annual nickel demand. Stainless steel producers have traditionally used both high-purity class 1 products (defined as containing 99.8 percent nickel or above) in pure nickel metal form, and lower-purity class 2 products (containing less than 99.8 percent nickel) as nickel alloys and chemicals in various forms, such as nickel oxides and ferro-nickels. Over the past decade, class 2 nickel has greatly increased its share of the total supply – from 25 percent in 2009 to nearly 50 percent in 2016. The key driver has been increased demand from Chinese stainless steel producers seeking to reduce costs by using less expensive nickel units from NPI rather than traditional class 1 nickel. This has, in turn, led to a strong supply-side response, with Indonesia – and later the Philippines – dramatically expanding NPI production.

This shift to class 2 nickel has hurt mining companies producing the higher-purity class 1 nickel product as an increasing supply of lower-cost class 2 nickel caused nickel prices to plummet from approximately USD 29,000 per metric ton in 2011 to just above USD 10,000 in 2017. As a result, producers of class 1 nickel have been forced to close mines and defer capital expenditures.

However, the growing popularity of EVs represents a potential boon for struggling nickel producers. Nickel is used in a number of battery applications, primarily in the form of nickel sulfate. Of the 300 Kt to 350 Kt of nickel sulfate (65 Kt to 75 Kt nickel equivalent) produced in 2017, approximately half will be used for the production of EV batteries.

The EV industry is seeing rapid growth, with annual production projected to expand from a mere 3 million vehicles in 2017 to as many as 31 million by 2025. This bodes well for nickel demand – and in particular class 1 nickel – because only class 1, with its high purity and dissolvability, is suitable for battery manufacturing. As a result, the global nickel industry may enter a period of change driven by a shift in end-use demand and the emergence of two distinct markets: one focused on nickel used in rechargeable batteries, which is growing fast as the adoption of EVs accelerates; the other used in traditional stainless steel, dominated by ferronickel and NPI products.

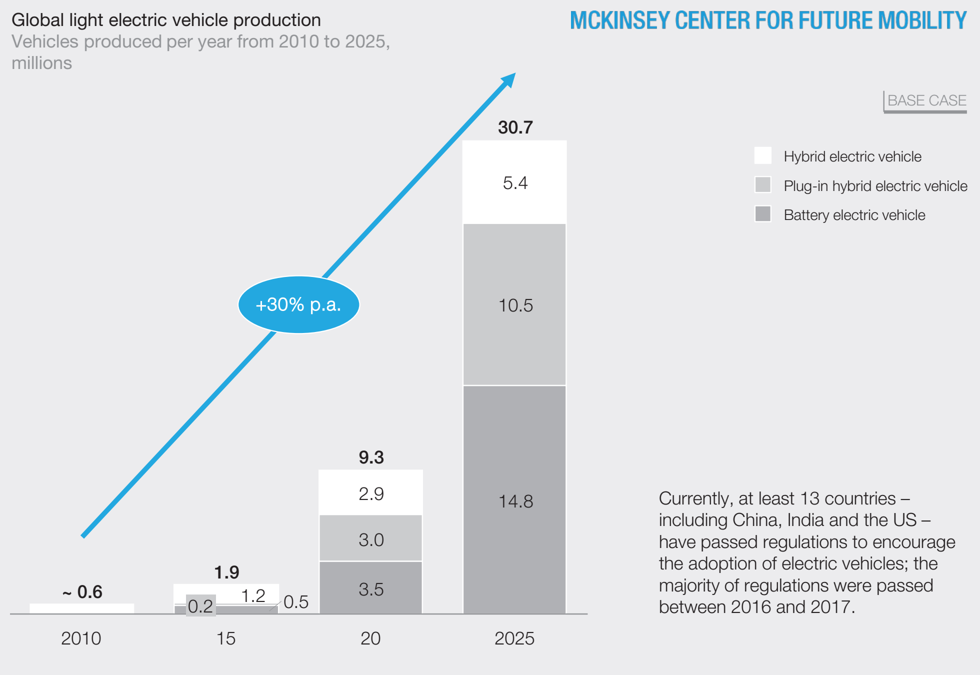
The EV revolution

The growth in EV production is being driven by forces similar to those that have propelled the rapid development of solar and wind power industries. Governments mandating a switch from conventional energy sources to renewables pushed companies to make significant investments in developing these technologies, resulting in their growing affordability. In time, these industries have managed to reduce their costs to below those of the traditional energy alternatives. Likewise, government policies are now fostering innovations in EV production that help lower costs. The introduction of emission limits, such as fleet emission limits, combined with penalties for not meeting these limits, helped to further focus the spend of OEMs on EVs. Additionally, EVs may gain an extra boost from the sheer number of countries looking to impose deadlines for the transition to EV over the next two decades – among them China, India, France, Germany, the UK, Norway, and the Netherlands.

The impact is already apparent. Global production of cars powered solely by batteries was less than 50,000 units in 2012; in 2017, it will reach almost 3 million. The base case of McKinsey's EV production model[2] projects that by 2030, nearly 40 percent of new cars sold in the US, EU, and China will be various forms of EVs, with battery-only electric cars representing almost one in five of all vehicles sold globally. Under our aggressive case for EV production, government regulations driving EV adoption, combined with technological advances, could lead EV distribution to reach 52 percent of all new vehicle sales in 2030.

Ultimately, the extent and speed of EV adoption will be driven by a combination of government regulations and targets, future battery costs (influenced by technology and

Exhibit 1: Growth in EVs from 2010 to 2025 split by hybrid and pure electric



SOURCE: McKinsey Center for Future Mobility

2 From McKinsey's Automotive Practice

manufacturing advances driving production efficiencies), the development of necessary charging and servicing infrastructure, the strategic positions adopted by leading automotive manufacturers, and consumer preferences.

Regulations. One of the lessons from recent government efforts to foster renewable energy production and usage is that mandatory changes, combined with incentives for switching to renewables, will create sufficient demand to drive scale efficiencies. These eventually deliver a cost advantage over traditional alternatives. A number of countries are now trying the same approach in the EV industry by eliminating cars with emissions, placing stricter emission restrictions on new models and subsidising the purchase of new EVs. For example, the Netherlands plans to phase out the sales of all new fossil-fuel cars by 2035. Already, EV owners are exempt from the typical registration fees and road taxes that drivers of traditional cars face in that country. In the UK, the “plug-in car grant” covers 35 percent of the cost of an EV up to GBP 4,500, and EVs are exempt from the annual circulation ownership tax. The US has introduced tax credits for the purchase of new EVs, ranging from USD 2,500 to USD 7,500 depending on the size of the vehicle and its battery capacity. China, meanwhile, has passed legislation aiming to put 5 million EVs on the road by 2020. The result of all these government moves is a race for the title of the first country to make EV technology the national standard.

Battery costs. One significant inhibitor of EV adoption has been the cost of batteries. That cost has begun to decrease dramatically in recent years. In 2010, the batteries used in EVs cost approximately USD 1,000 per kilowatt hour (kWh) for the weighted average battery pack; by 2016, this cost had dropped by 77 percent, to USD 227 per kWh. Today, some best-in-class batteries cost less than USD 150 per kWh. At USD 100 per kWh, we believe that batteries will reach the tipping point at which EVs will be cheaper than cars with internal combustion engines. Our base case projects the average cost of a lithium-ion pack to be USD 93 per kWh by 2030.

Several factors are behind this decrease in cost. The shift to large-scale, more efficient facilities (such as Tesla’s Gigafactory) have driven production efficiencies, reducing the average factory investments from USD 600 per kWh per annum only a few years ago to USD 200 per kWh per year for the most recent investments. Similarly, new battery design options are rapidly advancing companies’ abilities to optimize energy density, helping to increase the vehicle drive range and thereby reduce cost per kilometer traveled.

EV infrastructure. Currently, infrastructure for EVs significantly lags behind what is available for gasoline-powered cars. There are roughly 115,000 gas stations in the US, but only about 17,000 EV charging stations. Although electric cars can be charged at home stations, two of the main reasons deterring customers from buying EVs are worries about running out of power on the road and long charge times.

While some federal and municipal governments have pledged to build charging stations, much of the current infrastructure investment comes from car companies. For example, as part of its diesel emissions settlement, Volkswagen has committed to spending USD 800 million on EV infrastructure over the next decade. Tesla is also taking aggressive steps, with plans to build 7,200 rapid-charging stations round the world by the end of this year, while Porsche and Mercedes-Benz are collaborating to deploy ultra-fast 350kW EV charging stations.

OEM strategies. According to a study by McKinsey's Automotive Practice, 30 and 45 percent of vehicle buyers in the US and Germany, respectively, would consider an EV purchase today. This compares to almost none who were willing to do so ten years ago. Auto OEMs have responded to this rising interest by announcing plans for a combined 350 new EV models over the next several years. Volkswagen, for one, is aiming to leapfrog industry leader Tesla by 2025 by redirecting its efforts from diesel cars to EVs. The company is in the process of launching an EV series that it plans to sell around the world starting in 2020. BMW recently updated its EV plans with the addition of 12 all-electric cars, claiming that some will have a range of more than 400 miles. General Motors is also expanding its EV roster, with 20 new models under way in the next six years. The industry clearly believes that, with the help of government incentives, the market is ready to embrace EVs.

This demand has emerged in no small part thanks to Tesla making EVs stylish and sought-after: the company's cars are fast, sleek, and travel distances on single charges. But whether Tesla will be able to compete with the world's largest auto OEMs as they increasingly turn their attention to EVs remains unclear. Tesla's Model X small SUV has a base price of USD 91,500, and USD 136,200 fully loaded. Even factoring a US government subsidy in the form of a USD 7,500 tax credit, the vehicle is significantly pricier than a comparable luxury SUV, such as the Porsche Cayenne. While the operating cost of an EV can be substantially lower than that of a gasoline-powered car, and maintenance is far cheaper due to fewer moving parts, the cost differential is likely to remain a barrier for Tesla. Having said this Tesla, is currently exploring other areas of electrification that may prove to be profitable such as the Powerwall and the recently announced electrified semi-truck.

Consumer preferences. The vagaries of consumer preferences will also play an important role in the speed of EV adoption. Public acceptance of the new technology will be affected by everything from environmental concerns and car design to prices and the range of EV models and features available for those models. According to McKinsey's 2016 EV Consumer Survey, the top two reasons consumers cite for not buying an EV are high price and the driving range on a single charge. Increased battery densities have contributed to considerable progress on the latter point, with average drive range increasing from 200 km to as much as 400 km. For example, the previous generation of EVs, such as the original Nissan Leaf and Hyundai Ioniq, had battery energies in the range of 28 kWh to 30 kWh. This has increased in the latest generations, with the batteries in the new Nissan Leaf and the Tesla Model 3 storing energies in the range of 60 kWh to 75 kWh. If manufacturers can make similar strides in the cost of EV battery packs, the adoption of EVs should accelerate significantly.

Battery technology options

There are five lithium-ion battery technologies vying to be the main choice for automotive OEMs, each using a different blend of materials. Each type uses lithium as the charge carrier between the anode and the cathode, with the majority having graphitic anodes but different approaches to the cathode. These cathode chemistry archetypes are the basis for every producer's cathode "recipe."

Cobalt: supply continues to tighten

While the growing shift from the cobalt-rich NMC111 to the NMC811 cathode configuration is partly driven by the higher energy density of the 811, an even bigger factor is limited cobalt supply. According to the United States Geological Survey (USGS), approximately 123 Kt of cobalt was mined in 2016, and the organization projects insufficient supply to meet demand in 2017.

At present, approximately 30 percent of annual cobalt use is in a variety of chemical applications, including material used for EV batteries. This segment is expected to increase rapidly, with demand likely outstripping supply. The result has been a rapid price increase, from USD 20,000 per metric ton in January 2016 to over USD 60,000 per metric ton in September 2017.

Constraints in supply are likely to persist. Approximately 60 percent of cobalt production comes from the Democratic Republic of the Congo, which presents both operational and reputational risks for mining companies. Additionally, cobalt is rarely found in high concentrations and is mostly produced as a by-product of copper and nickel. Limited new investment in these two commodities has only increased the supply challenge for cobalt.

Consequently, cobalt supply constraints are likely to curb the growth of cobalt-rich battery technologies, including NCA and NCM. For now, manufacturers of these high-capacity batteries are trying to reduce the proportion of cobalt content by increasing the amount of nickel sulfate used. For example, the 622 battery (two parts cobalt per six parts nickel), used in a number of European EV battery applications, may be replaced soon by an 811 chemistry with only one part cobalt per eight parts nickel.

The five main technologies are:

1. **Lithium cobalt oxide (LCO).** Used extensively in the portable electronics industry, this chemistry has good performance and is relatively safe. However, due to its high cobalt usage, it is expensive and therefore not suitable for EV applications.

2. **Nickel manganese cobalt (NMC).** This chemistry takes three main forms: NMC111 (the simplest, based on an equal amount of the three elements' atoms), NMC622 (with a higher energy density and lower price than NMC111 due to a lower cobalt content), and the most recent and advanced, NMC811 (with the highest theoretical performance). NMC chemistries were mainly developed for the EV industry but, with their high performance and relatively low cost, they may well end up being used in other battery applications.

3. **Lithium nickel cobalt aluminum (NCA).** This chemistry was the first commercial attempt to substitute nickel for some of the expensive cobalt in the LCO cathode. It has a good energy density and an affordable price, making it ideal for EVs and portable electronics.

4. **Lithium iron phosphate (LFP).** Intrinsically safer than other chemistries, LFP is not protected by many intellectual property restrictions. Its high-power density makes it an ideal candidate for electric tools and e-buses and a good option for EVs.

5. **Lithium manganese oxide (LMO).** It was used in the first EVs, such as the Nissan Leaf, because of its high reliability and relatively low cost. LMO's downside is low cell durability compared to competing technologies.

Market dynamics of competing technologies

Except for LCO, all of the above battery types are used in the automotive industry today. Chinese battery producers such as BYD have historically preferred LFP due to government regulations on the types of batteries that could be produced, but the relaxation of these rules is leading manufacturers to start shifting to NMC. Tesla uses NCA for its Model S, but may deploy a high-performing NMC, such as 811, in the upcoming version (its Powerwall home battery will use NMC). Other OEMs' choices of cathode material vary by model, with a tendency towards NMC chemistries in recent years. The overall share[3] of each battery chemistry in the EV market will be influenced by its energy density and the availability and price of raw materials – particularly cobalt (see "Cobalt: supply continues to tighten"). Nickel-rich chemistries have an advantage over cobalt-based ones both in terms of superior energy density, lighter weight for any given battery size, higher vehicle range, and lower metal cost. The last is of significance given that in 2016, roughly 24 percent of a battery pack's costs came from the cathode[4].

The cobalt supply shortage is also benefitting nickel-rich chemistries. Should this shortage continue to grow, we expect EV battery producers to be hit harder than other cobalt users,

3 For all uses, including consumer electronics, EVs, e-bikes, and grid storage

4 This percentage will change based on the chemistry used and the cost of respective materials, as well as battery size (larger batteries may use more metal to better hold the charge)

such as manufacturers of super-alloys for aerospace and industrial cutting tools, due to higher amounts of cobalt needed for EV batteries. This shortage would likely move the market toward low-cobalt batteries. The high-performing, low-cobalt, high-nickel NMC811, and even the cobalt-free LMOs and LFPs that have fallen out of favor due to their relatively low performance, could see a resurgence. This shift is not certain as battery technologies continue to rapidly evolve, but it is clear the chemistries that emerge dominant will be heavily influenced by potential raw material constraints.

Exhibit 2: Battery technologies by chemistry

Key performance metrics of cathode chemistries
Cathode level metrics

Strong | Moderate | Weak

Material	Description	Safety	Cost USD/kWh	Energy density kWh/kg	Cycle life times	Ni content kg/kWh
LCO ($LiCoO_2$)	Mostly used in consumer electronics. Limited application for xEVs (e.g., Tesla)	Low	Low	0.58	1,500 - 2,000	0
NMC[1] ($LiNi_xCo_xMn_xO_2$)	Used mainly in consumer electronics but increasing use in xEVs	Mid	Mid	0.60	2,000 - 3,000	0.69 (51 wt[2]%)
LMO ($LiMn_2O_4$)	Relatively mature technology. Used in xEVs by Japanese OEMs (e.g., LEAF, iMiEV, Volt)	High	High	0.41	1,500 - 3,000	0
LFP ($LiFePO_4$)	Relatively new technology used in xEVs and ESS. Driven by A123 and Chinese manufacturers (e.g., BYD, STL)	Very high	High	0.53	5,000 - 10,000	0
NCA ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$)	Used mostly in consumer electronics (often blended with other chemistries) and e-vehicles (e.g., Tesla)	Mid	Mid	0.72	n/a	0.68 (49 wt[2]%)

1 For 811 configuration
2 By weight
SOURCE: Yoshio, M. et.al. 2009. Lithium-Ion Batteries: Science and Technologies. New York: Springer; McKinsey BMI battery materials demand model

Role of class 1 nickel in battery production. The process of making cathode materials starts with metal salts (generally sulfates), which are mixed and oxidized. Like most electrochemical devices, batteries require very pure raw materials. EV battery cathodes that contain nickel rely on nickel sulfate in the chemical composition $NiSO_4 \cdot 6H_2O$. By weight, nickel sulfate comprises approximately 22 percent nickel, and is produced when nickel is dissolved in sulfuric acid in the presence of oxygen.

Theoretically, all class 1 nickel can be used to produce nickel sulfate, but the nickel used is typically in the form of powder or briquettes to optimize the reaction time between the nickel and the sulfuric acid. We estimate that today, approximately 350 Kt of nickel powder and pellets is available for the manufacture of the 300 Kt to 350 Kt of nickel sulfate that is required across all uses (or 65 Kt to 75 Kt nickel equivalent). Class 2 nickel could also be used to make nickel sulfate, but the cost to purify and dissolve it is prohibitively high. Although nonferrous class 2 nickel is a potential contender in the future, nickel sulfate production for now depends on class 1 nickel.

Stainless steel: ongoing shift away from nickel-bearing grades

In our base case, we see global stainless steel production increasing from 47 Mt to 54 Mt between 2017 and 2025. The resulting growth in primary nickel demand will be partially offset by a continuing shift away from 300 series stainless steel towards the non-nickel-bearing 400 series. Meanwhile, the 200 series stainless steel market share has doubled due to high nickel prices limiting the growth of the 300 series, from about 10 percent in 2006 to roughly 20 percent in 2017 . We expect this pace of growth in the 200 series to remain constant through to 2025. The remainder of the primary nickel demand will be offset by an increased recycling of scrap, growing from 0.9 Mt in 2017 to 1.2 Mt by 2025

Over the same period, we estimate demand for nickel from electroplating, super-alloys and other products outside stainless steel to show a modest decline, from 520 Kt in 2017 to 510 Kt in 2025 (an implied -0.3 percent CAGR). However, the biggest change will come from the soaring demand for nickel in batteries, which will grow from about 33 Kt in 2017 to over 570 Kt by 2025.

Battery nickel demand. We expect battery production to grow from the current 120 gigawatt hours (GWh) per annum to 1580 GWh per annum by 2025. The major driver of this growth will be the increasing production of EV (growing up to 30 percent per year between 2017 and 2025), but other sectors, such grid storage and e-bikes, will also see between 5 and 15 percent CAGR over this period.

For nickel-containing lithium-ion batteries, nickel content ranges between 0.3 and 0.7 g/Wh, which translates into 15 kg to 30 kg of pure nickel for a medium-size, fully electric car depending on the chemistry used (NMC111, NMC622, NMC811, or NCA). As a result of likely cobalt supply shortages, we expect a shift toward the nickel-rich chemistries of NMC (811 in particular) and NCA. Production of these chemistries is currently at 48 GWh per year, and we expect it to grow to 990 GWh per year by 2025 – representing an increase in market share from 40 percent in 2017 to 63 percent by 2025.

In this scenario, demand for nickel from the battery industry alone would reach 570 Kt by 2025 – more than 10 times the current demand[5] – and be exclusively focused on class 1 nickel. However, the availability of cobalt could significantly affect this estimate. If the cobalt supply remains severely constrained, nickel demand would fall to 250 Kt per year as manufacturers would be forced to switch to cobalt-free batteries such as the LFP, which does not contain any nickel. Without any cobalt constraints, demand for class 1 nickel could exceed 800 Kt per year as manufacturers focus on high-performing, nickel-rich chemistries while abandoning the lower-performing LFPs and LMOs. This scenario does not account for potential changes in the recycling and secondary uses of batteries which may also provide an additional source for class 1 nickel units. Currently, the industry is focusing on recycling looking to extract the valuble battery raw materials at a low cost while complying with the high regulatory standards for recycling. Secondary usage while a promising technical solution is being hampered by the high initial cost of the batteries.

Implications for the nickel market

In 2016, global nickel primary demand was estimated at two million metric tons (Mt). That demand is expected to increase to 2.5 Mt by 2025. Although stainless steel production is likely to remain the largest end use for nickel, its share will decrease from 70 to 60 percent as the EV revolution accelerates nickel demand for batteries.

Between 2016 and 2025, we expect the respective segment demand for nickel to evolve as follows: stainless steel demand for primary nickel will fall from 1.5 Mt to 1.4 Mt, non-stainless steel demand will fall slightly from 520 Kt to 510 Kt ; and EV battery demand will grow from 33 Kt to 570 Kt. As noted above, only class 1 nickel is suitable for battery production; thus, growth in overall nickel demand will be accompanied by a shift in the product class share: between 2016 and 2025 class 1 will increase from 0.9 Mt to 1.5 Mt, and class 2 will remain flat at 1.1 Mt.

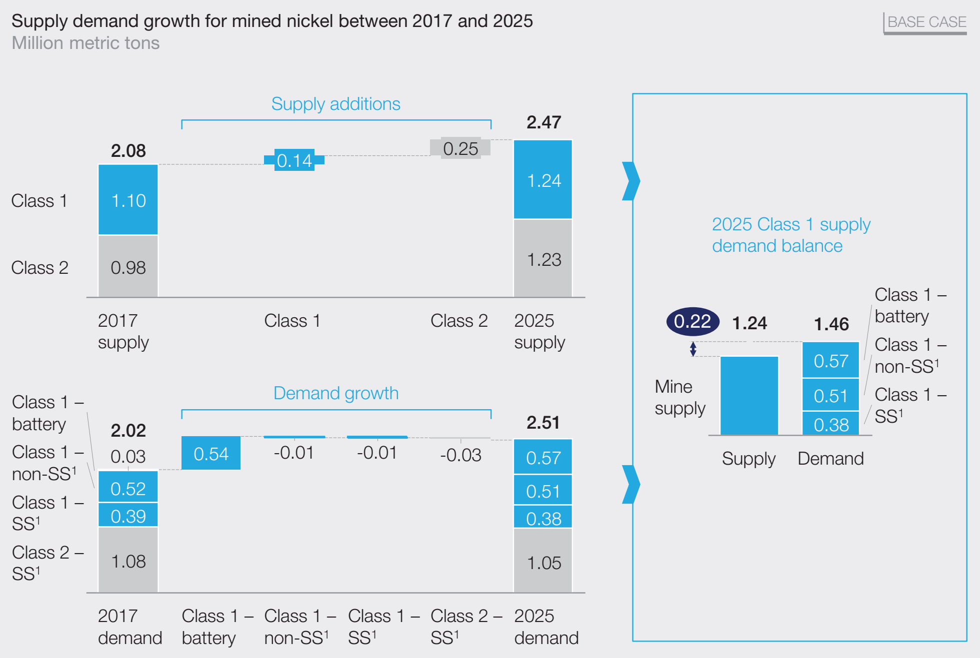
However, the nickel industry faces a major challenge in the lack of an easy and suistainable way to increase the supply of class 1 material suitable for battery applications. Under

5 Based on the 15 kg to 30 kg of nickel needed to produce an NCA or NMC cathode for a compact hatchback battery EV (BEV)

current market assumptions, the majority of nickel supply growth will come from class 2 sources (in particular NPI) increasing from 1 Mt to 1.2 Mt between 2016 and 2025. At the same time, based on the current project pipeline class 1 mine capacity is expected to grow only slightly, from 1.1 Mt to 1.2 Mt, as historically low nickel prices have led to mine closures and the deferral of over 250 Kt of class 1 capacity. Nickel scrap recycling for stainless steel production will also increase from 0.9 Mt to 1.2 Mt by 2025 (this material is not suitable for batteries).

As a result, based on the current project pipeline, we project that class 1 supply will lag demand by 2025, with only 1.2 Mt of supply available to meet 1.5 Mt of demand[6]. We also believe there will be limited potential to increase class 1 supply for batteries by switching nickel cathode refining to nickel sulfate refining, due to cannibalization of existing cathode demand. This is despite the fact that some producers are expanding capacity for nickel sulfate production. For example, BHP Billiton at Nickel West has approved a nickel sulfate plant that will produce 100 Kt a year. While refining nickel intermediates may be possible, it remains more costly than dissolving class 1 metal powders and briquettes.

Exhibit 3: Class 1 mined nickel supply demand balance



1 Stainless steel
SOURCE: McKinsey

On the assumption that nickel batteries will become the prevalent technology, the industry will be presented with several options to meet the increased demand for class 1 nickel units,

6 Supply demand balance is based on the current market outlook and project announcements. It does not account for any projects that could be incentivized by high prices in the future or demand shifts to lower content nickel products

either to further substitute remaining class 1 nickel demand (380 Kt in 2025) away from stainless steel production – although there is a technical limit as high grade 300 series stainlesss steels requires class 1 nickel ; to see a continued shift away from nickel bearing stainless steels or a reduction in austenitic ratios by increased 200 series usage; or to bring new class 1 supply projects into production. Given the expected ongoing growth in the EV market and hence growing demand for class 1 nickel the third option represents the most sustainable long term solution.

Again, the industry will be presented with two options for expanding capacity, both with potential drawbacks. The first is to use lower-quality laterite ores which have a relatively low nickel content and a wide range of metal contaminants that will create complexity and an increased cost in beneficiation to a class 1 product. For example, an African nickel project is producing class 1 material from a complex laterite ore, albeit at a significant capital cost of USD 90,000 per metric ton, in contrast to NPI expansions that are in the USD 20,000 per metric ton range. The second option is to bring on sulphide ores which also represent a significant cost investment (a recent project in the United States and in Finland both had a capital cost of between USD 30,000 and 40,000 per metric ton[7]) and are relatively rare. The USGS reports that only 40% of currently available reserves are in sulfide deposits and in addtion to that most of the sulfide deposits in well established mining regions have been depleted necessitating additional exploration in new regions.

The need for additional class 1 capacity driven by EV battery demand will influence both future nickel prices and the pricing mechanism. Currently, nickel is priced in relation to the London Metal Exchange (LME) reference grade (98.8 percent or higher), to which a premium or a discount is applied. For example, ferronickel not refined to an LME grade is priced at a discount to LME. Class 1 nickel powder used to manufacture nickel sulfate, on the other hand, has traded at a premium of up to 35 percent over the LME reference price, driven by a combination of the additional processing cost and the demand for the higher-grade product.

A shortage of class 1 nickel will likely see pricing revert to incentive pricing levels required for the introduction of new capacity or the reopening of mothballed capacity. These incentive pricing levels will need to be above current nickel prices and could increase significantly if the supply-side response is slow. At the same time we expect to see two distinct nickel price mechanisms emerge reflecting two distinct commodities: class 2 nickel, primarily for use in stainless steel production, trading at a lower price that reflects its abundant supply; and class 1 nickel trading at LME prices – or above for high-end nickel powders and pellets used to make nickel sulfates – reflecting required incentive prices. Such a development would be a boon for class 1 suppliers, who require the higher prices to finance new investments, and for stainless steel manufacturers purchasing class 2 nickel but less advantageous to class 2 producers whose material will be priced in a market likely oversupplied by 2025.

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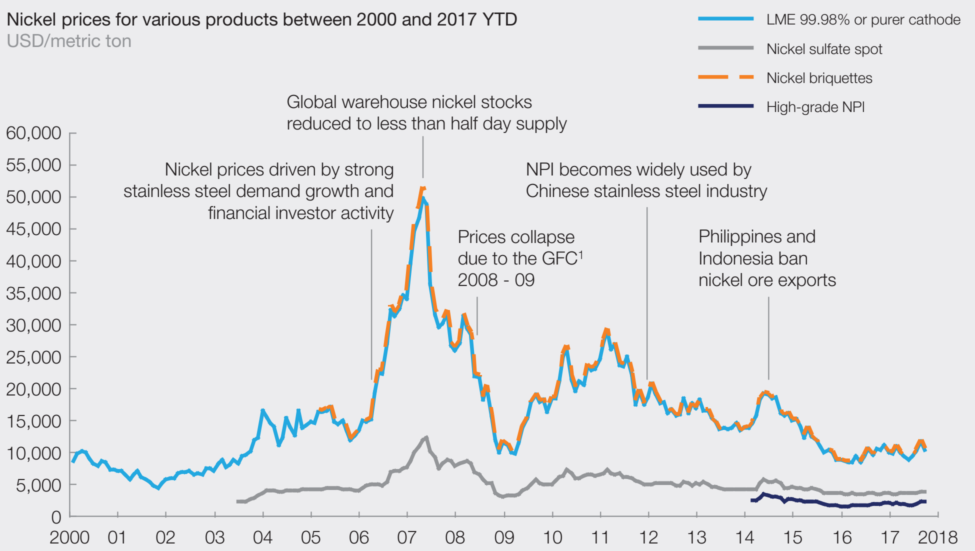
7 Total capital cost divided by nickel capacity and does not include capacity of other metal production

Exhibit 4: Evolution of nickel prices by product



- Pure nickel is traded on the LME with premiums/penalties for different nickel products
- Briquettes traded at premium vs NPI traded at a penalty to reflect its lower quality
- Nickel sulfate is based on the LME price adjusted for nickel content in the salt

1 Great Financial Crisis

SOURCE: Bloomberg Finance L.P.

Implications for industry players

The key determinants of the nickel industry's future will be the extent and speed of EV adoption, the battery technology that becomes the industry preference (NMC, NCA, or a yet-to-be-invented solid-state battery using nickel as a material), and the supply-side response to the changing demand picture. Additionally, these factors will evolve driven by politcal consensus, implementation speed and infastructure requirements, requiring players throughout the value chain to consider what strategic moves to take in light of future industry dynamics.

Nickel miners are facing an important choice. Should they invest in a market that offers future potential, but may not make them a profit at today's prices? Or would they be better off waiting for the EV sector to mature before investing in supplying its needs? Miners that follow the first path face significant capital outlays. The cost of upgrading refining and processing facilities to handle battery-ready class 1 soluble material can run into hundreds of millions of dollars. The USD 43.2 million investment BHP's Nickel West made to enable its Western Australia facility to convert class 1 soluble nickel into nickel sulfate is an indicator of how much capital the industry will need to allocate if it seriously pursues the EV battery opportunity. One way to create a financial incentive for investing in new supplies of class 1 nickel-bearing material would be for miners to create a separate class 1 pricing structure. By differentiating their pricing structure from the general class 2 and stainless steel scrap nickel prices, class 1 producers would gain a price reflective of their own supply and demand dynamics. This would encourage new supply to be brought onto the market if needed, as class 1 prices would be independent of the downward pull of the low-priced and oversupplied class 2 market.

Battery manufacturers and automotive OEMs will need to develop sourcing strategies to secure sufficient supplies of class 1 nickel to insulate themselves from the risk of shortages and potential price spikes. Indeed lower price volatility, more predictable pricing and less speculation in nickel by financial investors may make nickel more viable as a key raw material for EV batteries. Partnerships between miners and battery manufactures are one possible solution. BASF and Nornickel, for example, are already working together, with Nornickel agreeing to supply the nickel needs of BASF's future cathode-manufacturing facilities. Volkswagen, meanwhile, has struck a long-term cobalt supply deal with Glencore to ensure the supply of the other critical battery material. By devising creative, long-term contracts that provide incentives for and share the cost of upgrading the material, both sides may stand to benefit.

At the same time, miners, battery manufacturers, and auto OEMs will need to weigh up the considerable risks of investing heavily in the class 1 soluble market for nickel-rich batteries. While the energy density in nickel-rich chemistries certainly makes for a strong choice for use in battery storage, other materials could come along to dislodge it from the battery-making process. Battery technologies such as solid state batteries are seeing massive interest from manufacturers and could completely change the outlook for nickel demand if they become the dominant technology. It is unlikely that these technologies will mature before 2030 however, they should still be tracked closely in case of any breakthrough. The decision is a difficult one, with many interrelated factors and contingencies. But the high stakes make it essential for industry players to weigh their options carefully before crafting future strategies.

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