THE UK NICKEL SUPPLY CHAIN

Future supply and demand for electric vehicles

Produced in collaboration with:

SFA Oxford

UK Critical Minerals Intelligence Centre

This report does not constitute government policy.

Glossary

Term	Definition
BESS	Battery energy storage system
BEV	Battery electric vehicle
CAM	Cathode active material
ESG	Environmental, Social, Governance
ESS	Energy storage system
FCEV	Fuel-cell electric vehicle
GW	Gigawatt
GWh	Gigawatt hour
HPAL	High pressure acid leach
IMIP	Indonesia Morowali Industrial Park
IRR	Internal rate of return
IWIP	Indonesia Weda Bay Industrial Park
kt	Kilotonnes
ktpa	Kilotonnes per annum
LCO	Lithium cobalt oxide
LFP	Lithium-iron-phosphate
LiBs	Lithium-ion batteries

Term	Definition
MHP	Mixed hydroxide product
MSP	Mixed sulphide product
mt	Megatonne
MW	Megawatt
MWh	Megawatt hour
NCA	Nickel-cobalt-aluminium
$NiSO_4$	Nickel sulphate
NMC	Nickel-manganese-cobalt
NPI	Nickel pig iron
OEM	Original equipment manufacturer
pCAM	Precursor cathode active material
PGMs	Platinum-group metals
PHEV	Plug-in hybrid electric vehicle
TWh	Terrawatt hour

Note

Unless otherwise explicitly stated, all mass units in this report are given in terms of contained nickel units. This includes mine production data, production of nickel intermediates and nickel consumption by end-use. This is true for both charts and in the text.

Please note: Some tabulated data may not add up owing to rounding of individual numbers. © Published in April 2023 by SFA (Oxford) Ltd.

01.

DEVELOPING A NICKEL SULPHATE VALUE CHAIN IN THE UK

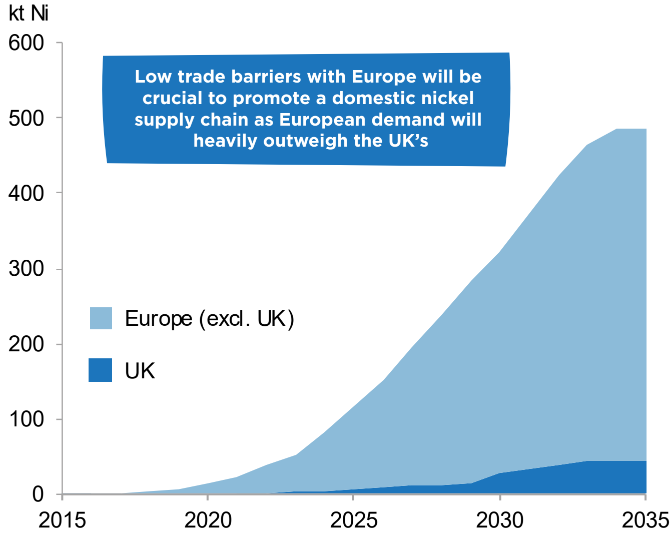
The UK must determine its motivation to build its nickel value chain

A strategy for the support and development of a battery-grade nickel supply chain in the UK needs to consider participation in wider battery supply chains, or at least those within Europe. While UK-only battery demand is expected to grow in the long term, European demand is expected to be realised much faster and at a greater scale. As such, a nickel supply chain in the UK is likely to make economic sense only if it is serving the European market in the short- to medium-term. Waiting to develop the supply chain until UK demand materialises is unlikely to be viable as the nature of supply chain localisation means that, once the EU nickel supply chain is established, UK industry will be unable to achieve the same economies of scale as within the EU for domestic supply security.

While the UK is lacking in primary nickel resources, there is a **high density of players in the country's battery recycling sector.** Supporting the development of these participators can help to ensure the UK is able to produce battery-grade nickel with a low carbon intensity – a product that is currently being valued over primary material (in terms of payabilities). As the UK is a leading nation in electric vehicle (EV) sales with a high stock of nickel-rich EV batteries, securing these batteries at end-of-life could provide the UK recycling sector with a healthy feedstock over the long term.

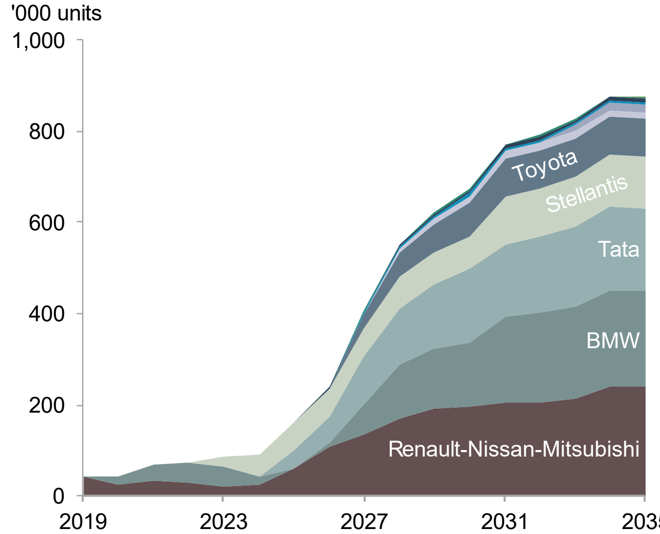
The automotive sector in the UK is increasingly moving over to battery electric vehicles (BEVs) to decarbonise fleets, specifically adopting high nickel-content battery technologies, namely nickel manganese cobalt oxide lithium-ion batteries (NMCs). Just five automotive OEMs are forecast to represent over 90% of BEV production in the UK by 2040, and the inferred demand for nickel. Retaining these OEMs will be crucial to the long-term nickel demand outlook in the UK.

Battery-grade nickel demand from BEVs



Source: SFA (Oxford). Note: 1kt Ni is equivalent to 22.3kt nickel sulphate crystals (NiSO4·6H2O).

UK BEV production forecast by sales group



Source: SFA (Oxford), S&P Global Mobility (Global Production based Powertrain Forecast, March 2023). Note: Includes all light-duty vehicles.

02.
HIGH-LEVEL CONSIDERATIONS FOR A UK NICKEL VALUE CHAIN

The assessments and recommendations presented in this report respond to the current state of battery materials markets, to the dynamics among industry players and to the functions of policy to optimise national and regional prospects of battery materials value chains. These reflect a need for strategic decision making, far-reaching policy interventions, partnerships for competitive positioning and enhancing the role of government.

Long-term strategic approaches to government fostered partnerships

The global transition towards sustainable and low-carbon economies is happening at an unprecedented pace, and **it is recommended that the UK defines its position in the market and the measures for its domestic supply security.** Nickel is a critical metal in lithium-ion batteries with longer ranges and will be increasingly needed to cover a relevant and growing share of batteries in EV markets. The demand for these batteries is rapidly increasing, and the UK can choose to develop a domestic supply chain to avoid disruptions and potentially expand its role as an export hub for the broader market.

The scale and complexity of the challenges facing the global nickel value chains require coordinated action with long-term thinking from industry, academia, and government. Policy interventions should address the entire value chain, from exploration and mining to refining and recycling. Developments in lithium-ion battery value chains take several years, often spanning decades. Policy interventions in the UK should acknowledge these dynamics and adjust their framing accordingly.

Collaboration is critical to building a competitive and sustainable battery-grade nickel supply chain in the UK. Partnerships among industry (including international participants), academia, and government can enable the sharing of knowledge, expertise and resources, and can foster innovation and commercialisation. Additionally, collaborations with international partners can facilitate access to global markets and enable the UK to remain competitive in a rapidly changing economic landscape. The lithium-ion battery industry has experienced two main business developments in the last five years: consolidation and integration. Industry players develop partnerships with other businesses in different segments of the value chain to consolidate their positioning in the market. At the same time, the integration of different segments of the value chain into a single operation has become the norm for lowering costs and price risks. These are factors that industry leaders have leveraged to reach their current position. Partnerships are therefore crucial and necessary in the planning of a nickel value chain in the UK.

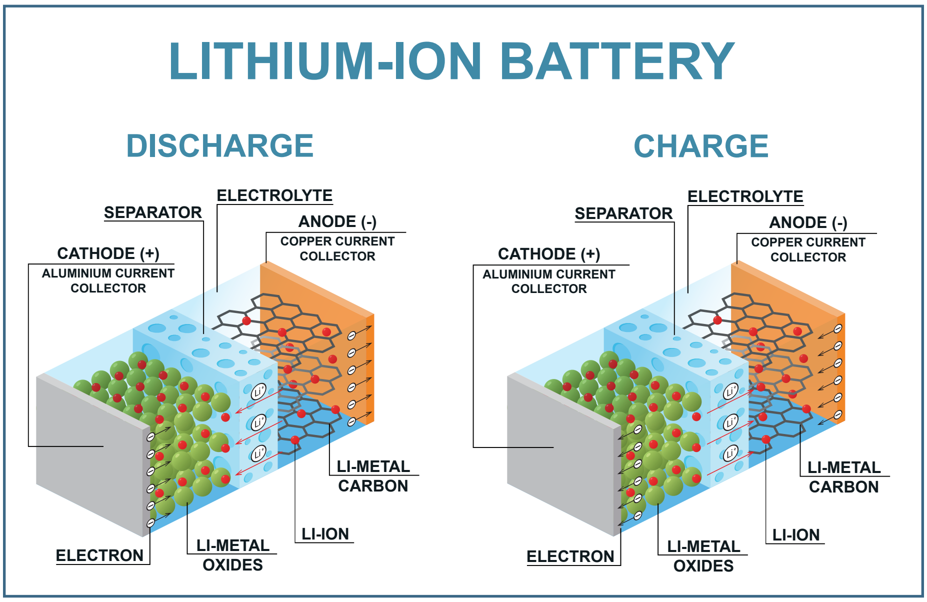
The role of the government in driving the transformation of the UK's nickel value chain is critical. Government policy, funding, and regulations can provide the necessary incentives, support and rulings to enable the development of a sustainable and globally competitive value chain. At the same time, regulations that are not aligned to industry timeframes and processes can block the development of the industry. The government can choose to take a leadership role in facilitating the establishment of partnerships, providing funding, and creating lean regulatory frameworks that support innovation, research, and development. It can also play a crucial role in promoting skills development and training to support a skilled and adaptable workforce that can meet the needs of a rapidly evolving industry. Lastly, the government can tailor a demand-development mechanism in the UK that attracts feedstocks.

The UK government should endeavour to clarify the UK's positioning with regards to 'Rules of Origin' (RoO) policies being implemented in major trading partners. Both the EU and the USA have recently announced policies aimed at incentivising the localisation of the battery supply chain. However, currently the UK is not counted as a free-trade nation for the purposes of the Inflation Reduction Act and its position for RoO compliance with the EU's Green Deal is at this point uncertain as well.

03.
GLOBAL NICKEL SULPHATE CONSUMPTION

Precursor cathode active materials for NMC drive nickel sulphate demand

Nickel sulphate consumption is primarily driven by EV markets where lithium-ion batteries (LiBs) are used. All LiBs utilise the flow of lithium ions to generate an electrical potential. However, a significant performance differential exists between LiBs that is dependent on the 'active materials' (chemistry) of the cell. 'Active materials' refers to the metals used on the two electrodes, along with the composition of the electrolyte. **For the purposes of nickel consumption, focus is on the cathode active material (positive electrode)**, as that is where nickel is required in select cathode chemistries. Since the introduction of the first commercial LiB (LCO cathode by Sony), numerous alternative cathodes have been commercialised but developments in anode chemistry have been limited.



Source: SFA (Oxford), image licensed from Sivvector through Adobe Stock.

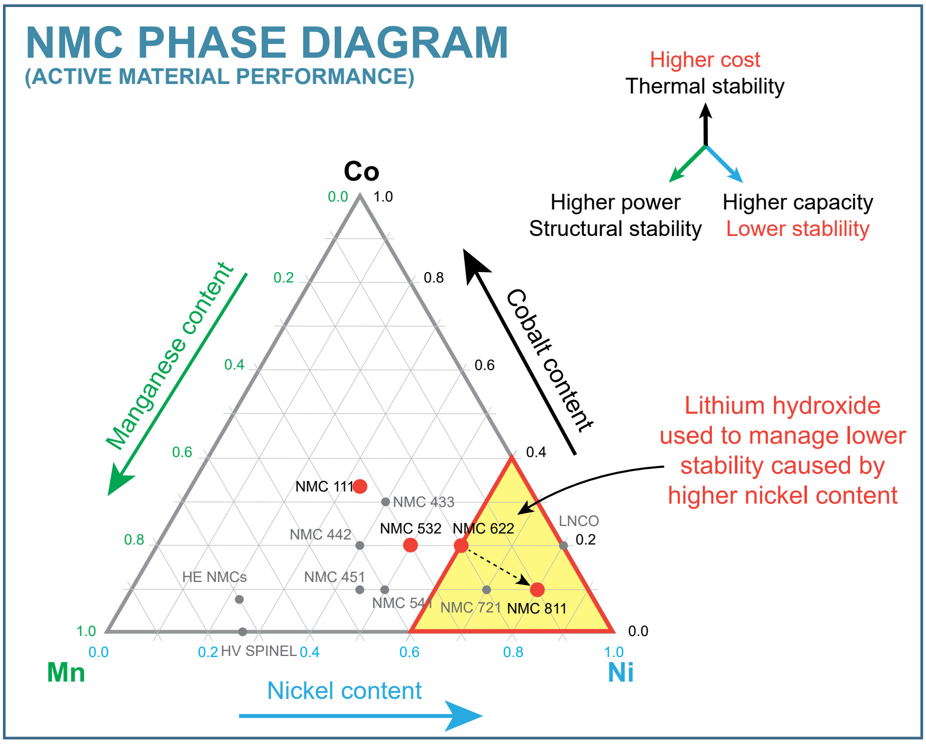
Automotive OEMs are under immense pressure to expand their electric fleets and meet increasingly stringent tailpipe emission standards or risk considerable fines. Furthermore, consumers are being incentivised to switch to EVs in most major markets as governments look to implement their climate change mitigation strategies. The nature of these incentives is both positive (subsidies and tax breaks for EVs) and negative (ultra-low emission zones, driving bans for combustion engine vehicles).

Today, the use of LiBs is standard practice, although the cell chemistry still varies amongst OEMs

Cathode chemistry	*Cathode composition*	*Select vehicles using cathode chemistry*
Lithium iron phosphate (LFP)	$LiFePO_4$	BYD Atto 3, Tesla Model 3 (MIC, SR only)
Lithium nickel cobalt aluminium oxide (NCA)	$LiNi_xCo_yAl_zO_2$*	Tesla Model 3 (LR, USW only)
Lithium nickel manganese cobalt oxide (NMC)	$LiNi_xMn_yCo_zO_2$*	Hyundai Ioniq 5, Volkswagen ID.3
Lithium cobalt oxide (LCO)	$LiCoO_2$	Tesla Roadster (2008)
Lithium manganese oxide (LMO)	$LiMn_2O_4$	Mitsubishi i-MiEV

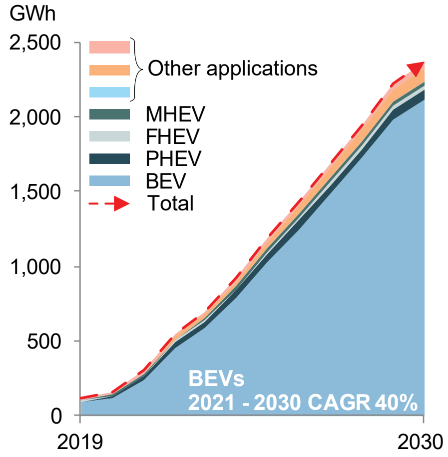
*Source: SFA (Oxford). Note: MIC = Made in China, SR = Standard range, LR = Long range*where x+y+z = 1*

There are different formulations for NMC and NCA cathodes, where the molar ratio of the metal oxides is varied which, in turn, has implications for cell performance. **As a general rule, nickel improves energy density, manganese improves cell power and cobalt improves battery life.** However, while LCO (100% cobalt) and LMO (100% manganese) are commercially proven, LNO (100% nickel) is inherently unstable and requires composite materials to be commercially viable. Nonetheless, **manufacturers are looking to increase nickel content** in order to improve battery capacity and, therefore, EV range.



Source: SFA (Oxford), adapted from BASF - Argonne National Labratory Collaboration on NCM Cathode Materials, slide 7.

Automotive battery demand



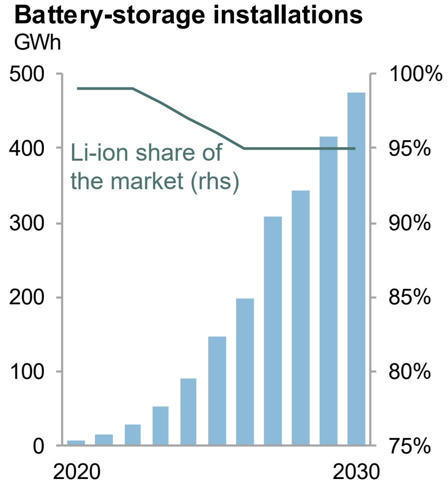
Source: SFA (Oxford)

Automotive battery demand is forecast to grow to 2,400 GWh by 2030 and 4,300 GWh by 2040, with BEVs capturing 90% of the market by 2040. Heavy-duty applications, including e-buses, are estimated to represent the next largest market segment (6%). Alternative electrified powertrains in the passenger car segment are expected to represent a nominal share of automotive LiB demand owing to a combination of lower production volumes and smaller battery packs. These powertrains also still have tailpipe emissions and so are expected to eventually be phased out under zero-emission policies.

Asia is the region with highest usage of primary nickel, accounting for 84.8% of global primary nickel demand. In Asia, China is the largest single consumer by far, accounting for 58.6% of global primary nickel usage, followed by Indonesia (12.7%), Japan (5.8%) and South Korea (3.1%). In North America, the US (4.1%) also represents a notable degree of primary nickel usage. In Europe, Germany (1.7%) and Italy (1.7%) lead primary nickel demand. As Western battery production and consumption catches up, there is an expectation that an international liquid spot market for nickel sulphate will emerge.

BEV projections have been raised significantly in the post-Covid era. The global market penetration of BEVs is now expected to reach 33% by 2030, requiring 2.4 TWh of battery capacity by the end of the decade. Market penetration is forecast to continue growing to 54% by 2040, requiring a further 1.9 TWh of battery capacity (for a total of 4.3 TWh). **China is estimated to represent 35% of total growth in BEV output** (+21 million units) through to 2040, although its total market share is likely to decrease with increasing output in other regions. Europe (+14 million units) and North America (+8 million) are predicted to represent 23% and 13% of growth, respectively.

Battery-storage installations



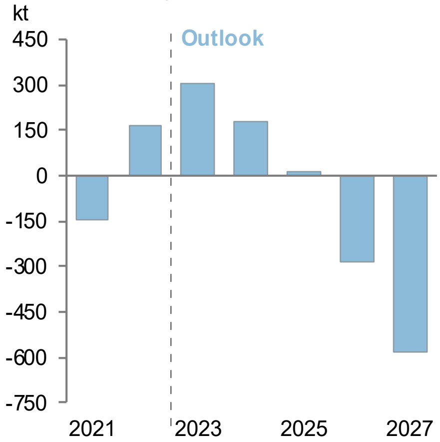
Source: SFA (Oxford).

Note: rhs refers to the right-hand side axis

Battery demand from battery energy storage systems (BESSs) is unlikely to generate significant nickel demand, despite the segment being forecast to generate strong demand pull globally and with lithium-ion batteries expected to capture over 90% of the market. This is because lithium-iron phosphate (LFP) batteries, containing no nickel, offer a lower-cost, longer-life solution. The typical drawback to LFP batteries, relative to their nickel-based counterparts, is lower energy density but this is not an issue in the ESS segment as energy storage applications are not space constrained, unlike in the EV segment. **Hence, global nickel consumption is set to increase in line with the EV sector.**

04.
NICKEL MARKET OUTLOOK

Nickel supply-demand balance



Source: SFA (Oxford)

Surplus set to increase in 2023, mainly in class-2 nickel

The nickel market is set to remain in surplus until 2026 on the back of a robust Indonesian supply response. In 2023, the refined nickel surplus is set to reach 301 kt.

Surpluses will mainly be in class 2 nickel. Upgrades to Indonesian NPI production are responsible for the majority of the change. Class 1 nickel supply is forecast to remain tight near-term, but the market should ease in 2023 and the NPI-to-matte conversion will help to alleviate any class 1 shortfall.

Battery demand growth is predicted to remain robust and other demand is expected to pick up after dipping this year owing to China's weak stainless steel demand.

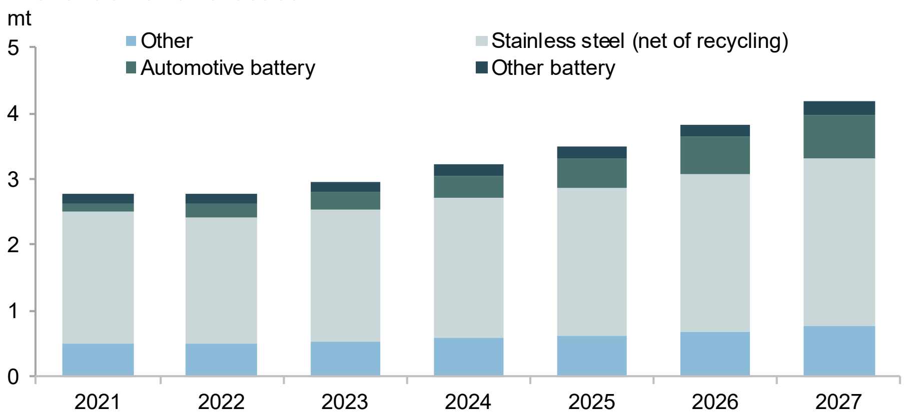
Demand to increase while LFP uptake poses a risk to the downside

Nickel demand will be driven strongly by usage in EV batteries, although the stainless steel market will remain the largest overall sector. Demand is projected to grow with a compound annual growth rate (CAGR) of 8.3% from 2022 to 2027 reaching over 4 mt.

Weakening Chinese stainless steel demand in Q4'22 and strong LFP uptake are posing risks to nickel demand growth, but this is being offset by higher EV numbers so the net impact is marginal.

Faster LFP uptake outside China presents a downside risk to nickel in the medium to long term but, currently, nickel-rich cathodes remain prevalent in Europe and North America.

Nickel demand forecast



Source: SFA (Oxford)

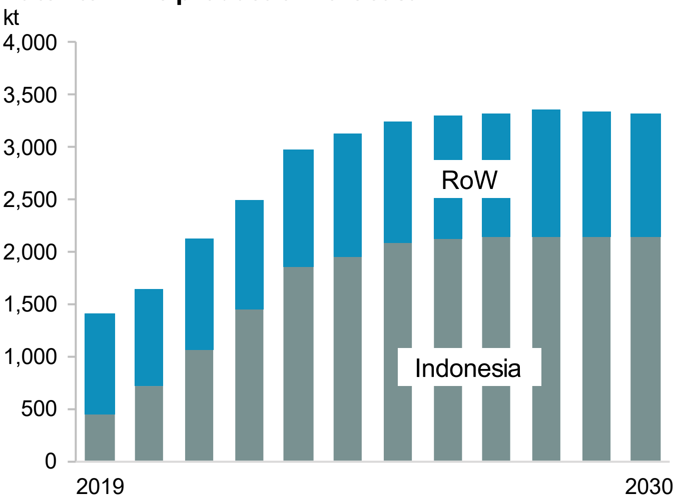
Primary supply

Global nickel resources are dominated by Indonesian laterite ore, which historically has been used for class 2 nickel compounds that are not suitable for battery technologies. The recent expansion in Indonesian laterite ore production and innovation in mid-stream processing have allowed laterite-derived compounds to be refined into class 1 nickel compounds and serve battery markets.

Nickel is also produced from nickel sulphide deposits and as a by-product of copper and platinum-group metals (PGM) refining.

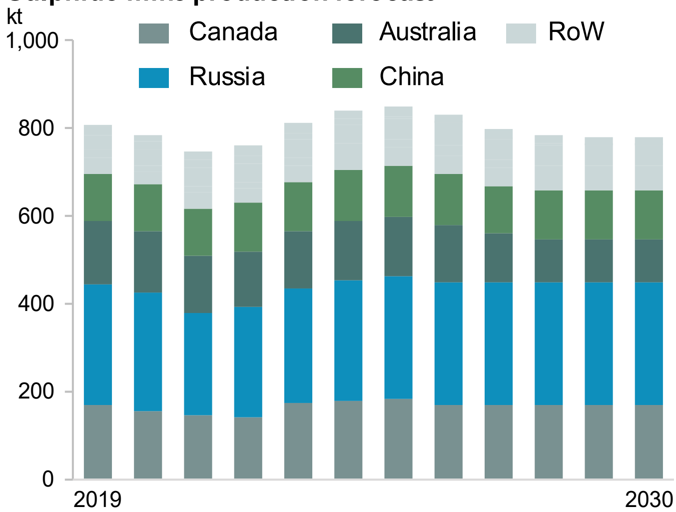
Russia holds the majority of nickel sulphide ore, followed by Canada as a resource base. Nickel sulphide ore has historically been refined to battery-grade class 1 nickel compounds.

Laterite mine production forecast

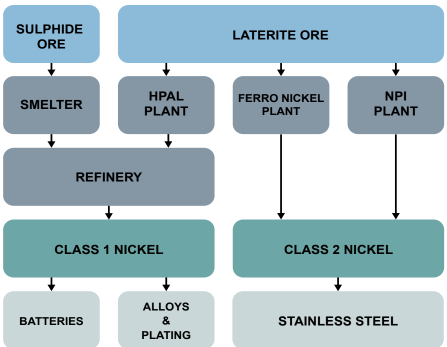


Source: SFA (Oxford). Note: Historical supply data is sourced from aggregating producer reports.

Sulphide mine production forecast



Source: SFA (Oxford). Note: Historical supply data is sourced from aggregating producer reports.

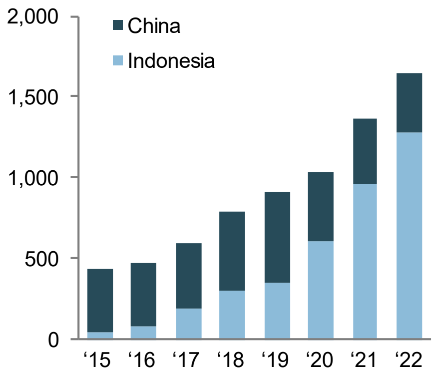


Source: SFA (Oxford)

Nickel processing pathways

Indonesia-based Tsingshan is the world's largest nickel producer, accounting for 21% of global nickel supply (650 kt), as of 2022. Chinese stainless steel manufacturer Jiangsu Delong (13% of global output) is now the second-largest supplier. Russian producer Norilsk Nickel is the third-largest, accounting for 7% of global production with the majority of its assets in Russia, unlike Glencore (4%), and Vale (6%) which have a diversified portfolio of global nickel assets.

Tsingshan's plan to provide the battery supply chain with nickel matte sourced from NPI is essentially allowing the conversion of class 2 nickel to class 1. This will require significant capital expenditure and the additional processing will add to the cost of production. The incremental cost to produce matte from NPI is estimated at around US$1,000 per tonne of nickel, while to convert the matte into nickel sulphate is estimated to require an additional US$2,000/t.



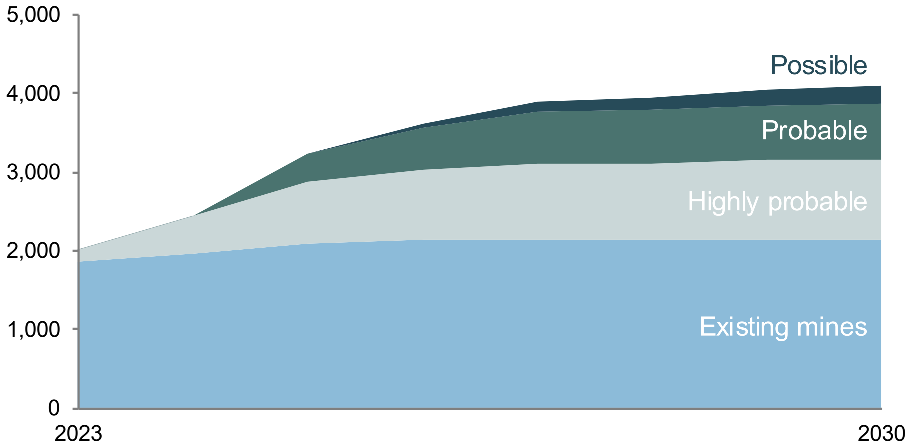
Source: SFA (Oxford)

Nickel pig iron production in Indonesia is set to rise with a CAGR of ~9% (including projects) between 2023 and 2030, reaching around 3 mt by 2030. Despite the positive outlook for the nickel industry in Indonesia, risks remain, especially in the form of ESG concerns as the country's nickel sector is particularly carbon-intensive and environmentally damaging.

The first ESG issue was the planned deep-sea tailings placement (DSTP) off the coast of Morowali, which has now been abandoned after being banned by the Indonesian government. Owing to the limited available suitable land for onshore tailings ponds, plus high rainfall and tectonic issues, dry tailings stacking is being implemented instead.

The second major issue has been land clearance and habitat loss resulting from mining activities, with high levels of resultant biodiversity loss in the Indonesian rainforests.

The third ESG issue is the **high energy consumption required for nickel smelting which is based on coal-powered stations in Indonesia.** The ramping-up of nickel production and new projects coming online will only exacerbate the already high carbon footprint. Some of the smelter operations are looking to resolve this in the longer term by replacing the coal-fired power plants with renewable energy sources. For example, Tsingshan intends to build a 2,000 MW clean energy base in Indonesia to support its IMIP and IWIP operations.



Source: SFA (Oxford)

Class 1 production by company, 2022

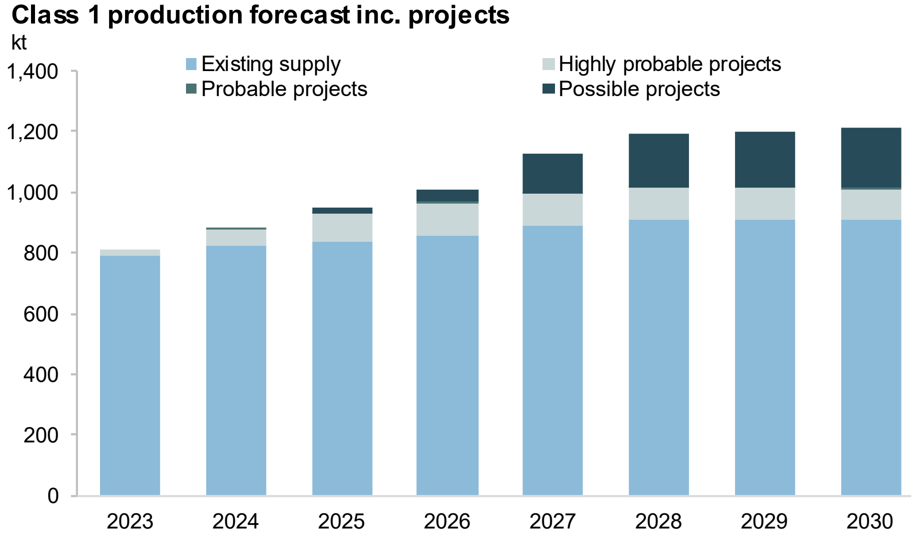
Source: SFA (Oxford), various company reports

The nickel market has been affected by various trade restrictions. **Indonesia's export ban on raw nickel ore has been a significant restriction in the market, causing tight supply and higher prices for nickel ore.** This export restriction has been in place since January 2020 and is expected to continue beyond 2024 when the current administration end its term. However, it has also led to the development of new nickel processing facilities as well as changes in the approach to low-carbon nickel compounds. **Western sanctions on Russia due to the war in Ukraine have also affected the nickel market**, disrupting the global supply chain and contributing to the uncertainty and volatility of nickel prices, especially for European end-users. **The impact of the sanctions on Russia has mainly been on class 1 nickel products derived from nickel sulphide ore.**

Class 1 nickel production has been marginally lower on a year-on-year basis as a number of major producers have reported some downturns in their annual output due to strikes, operational issues and rising costs resulting from the energy crisis caused by the Russian war on Ukraine. The current fundamental outlook for class 1 nickel points to a persistent and substantial shortfall in supply.

The **acute tightness in the class 1 nickel market is also at risk of worsening from the possible disruption of Russia's class 1 and intermediate supply.** The uncertainty around sanctions has made shipping commodities out of Russia difficult, whether due to reduced freight capacity or limitations on obtaining insurance.

Class 1 production forecast inc. projects

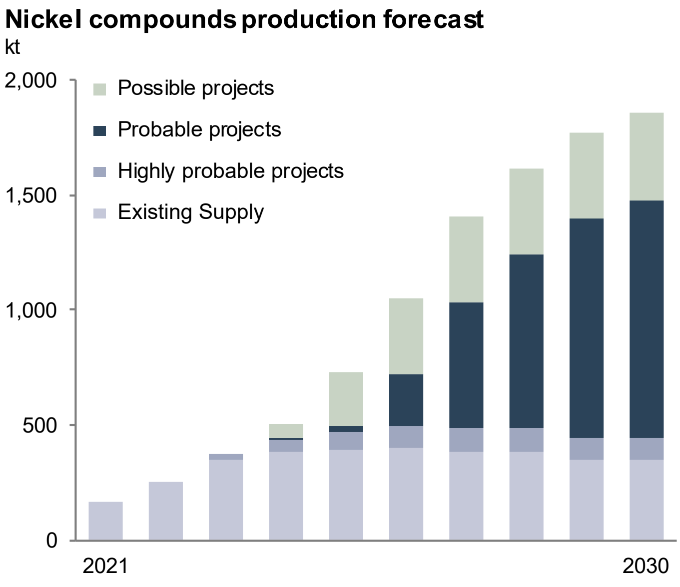


Source: SFA (Oxford)

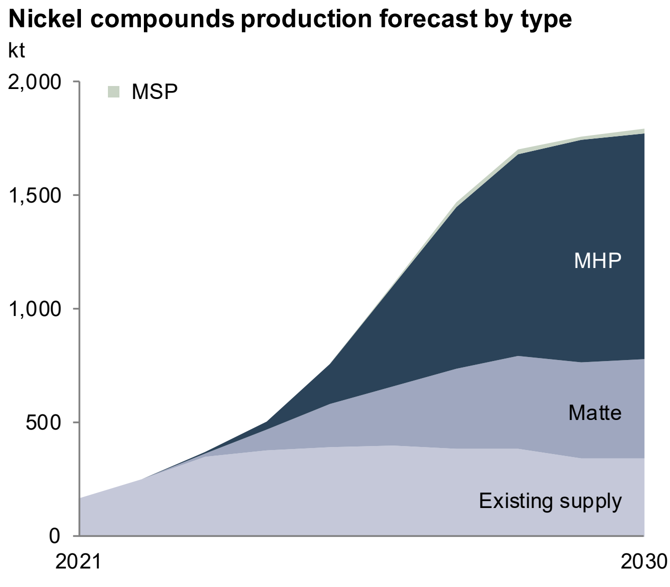
Nickel sulphate can be produced from various feed sources using different production routes, either directly from intermediates such as MHP, MSP, nickel matte, and crude nickel sulphate, by class 1 nickel dissolution, or by processing of the recycled materials (battery scrap). **In 2022, total nickel compounds production reached 250 kt and this is set to increase further to 348 kt in 2023.**

Mixed hydroxide precipitate (MHP) is emerging as the preferred intermediary product for nickel sulphate producers in China and beyond, as the HPAL process route begins to gain traction with its apparent low capital costs and faster ramp-up times compared to previous years. The production of and demand for nickel sulphate and other compounds are set to increase exponentially within the next few years.

Most of the nickel sulphate supply growth is attributed to new MHP-HPAL facilities being planned and commissioned at an accelerating rate in Indonesia. As the nickel market in its current form is not equipped to meet the rapid growth in EV battery-related demand, investment in HPAL and nickel sulphate facilities would help to cover any potential battery-grade class 1 shortfall.



Source: SFA (Oxford)



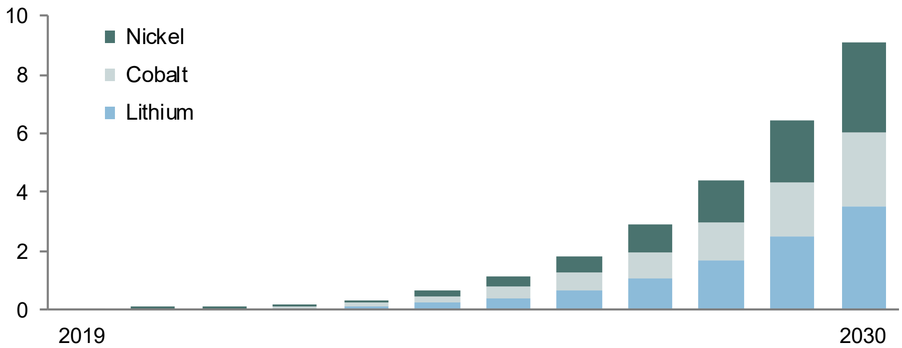
Source: SFA (Oxford)

Secondary Supply

Nickel compounds are also produced through secondary production routes that involve battery recycling. Europe, the UK and North America have seen considerable investments in battery recycling projects, with Europe currently leading the expected capacity developments. Battery recycling uses pyrometallurgical (pyro), hydrometallurgical (hydromet), hybrid (hydromet+pyro) or direct recycling processes. In European battery recycling operations, hydromet processes are favoured for new projects over pyro processes. Hydromet enables the recovery of more metals, but capacity additions to legacy pyrometallurgical plants make pyro the process with higher expected capacities in the region.

Legislation in Europe will dictate a minimum recovery of lithium (70% by 2030) from end-of-life batteries which is likely to favour the cheaper operating and capital costs of a hydromet process. Direct recycling offers the possibility to produce full CAM rather than just recovering individual metals, but the technology is still in its early commercialisation stage. The economics of battery recycling show that **most revenue is derived from recovering cobalt, nickel and lithium.** Prospects for battery-grade nickel value chains favour hydromet processing where refined product outputs are higher and closer to battery cell manufacturing requirements.

Contained metals value in scrapped BEVs
US$bn, 2021 avg. prices



Source: SFA (Oxford), Bloomberg for metal prices

In Europe, Germany has the highest number of black mass producers, with existing capacity of 36 ktpa of LiBs distributed between 12 companies. Germany's planned gigafactories are an important driver for investments in recycling in the country, owing to the proximity to manufacturing scrap. German gigafactories are projected to account for more than a third of Europe's total LiB manufacturing scrap by 2030, with >18 GWh from scrap that is potentially available for LiB recyclers.

Poland is an emerging frontier in LiB recycling capacity. Players in Poland have so far focused on producing black mass for export to processing facilities mainly outside Europe. Other companies in Poland are integrating processing capacity from purchased black mass and battery rejects. This diversification of plants, along with the country's proximity to German gigafactories, could give Poland an edge over Germany for LiB recycling in the region.

05.
UK NICKEL TREATMENT CAPACITIES AND TRADE FLOWS

The UK receives class 2 nickel products from primary nickel sources

The UK currently plays a marginal role in global nickel production (1%) and consumption (0.5%) and any change in this is considered unlikely at this time, based on recently announced plans by relevant industrial players.

Given its lack of pCAM manufacturing capacity, the **UK's nickel trade is at present focused on nickel compounds used for stainless steel production.**

The main nickel product imported into the UK is nickel oxide sinter, mainly provided by Japan (77.4%), Indonesia (11.1%) and Canada (5.4%). Ferronickel imports in the UK currently represent 18.6% of total imported nickel products. The main ferronickel supplier is Brazil (50%), followed by Germany (14.5%) and Greece (12.1%). Unwrought nickel is another key product imported into the UK, accounting for 14.2% of total nickel imports in 2022. Norway supplies 30.5% of the UK's unwrought nickel imports, followed by the Netherlands (23.4%), Finland (17.2%), Australia (9.1%) and Taiwan (8.4%). Nickel powder and flakes is not representative of UK usage, due to its unsuitability for stainless steel.

Nickel matte is an interesting import sector to examine: In 2022, UK imports were significantly low for nickel matte, but historical data shows consistent supply from Canada above 2 kt from 2018 to 2021. This halt in Canadian nickel matte supply, which is produced from nickel sulphide ore as in Russia, could be related to a complication at the supplying company or perhaps to a premium paid by another non-UK buyer in light of sanctions imposed on Russia.

UK nickel product exports in 2022 were primarily unwrought nickel. In 2022, 25.2% of UK exported unwrought nickel was supplied to Belgium. China represented another major export destination with 20.4% of UK unwrought nickel supplied in 2022. **Nickel powder and flakes represents under a third of UK nickel exports but it accounts for the largest distribution of recipient countries**, spanning 49 different destinations in 2022. The US receives the highest current share of UK nickel powder and flakes exports, accounting for 22.1%.

The London Metal Exchange (LME) and its nickel contracts ensure nickel trade in the UK. However, in 2022, the exchange experienced an unusual event and temporarily halted nickel trade from 8 to 16 March 2022. The LME received serious criticism for this and, in January 2023, **the exchange announced it will reform its nickel contracts at the end of the first quarter of 2023.** Players in the nickel industry had pressed for this due to the contract market being disconnected from the physical market. The relevance of the LME as a price benchmark for Class 1 nickel is something policymakers should endeavour to maintain.

UK TRADE FLOWS

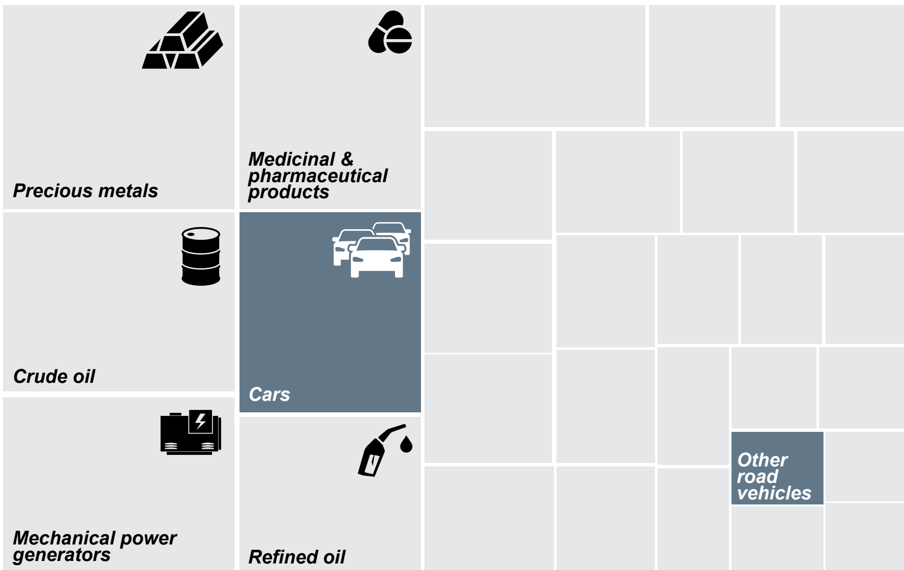
Source: SFA (Oxford), International Nickel Study Group

UK Automotive trade

The automotive sector is crucial to the health of the UK economy. As per official trade statistics, cars were the UK's fifth highest value export in 2022 (5.9% by value). Expanding this to include all road vehicles, such as commercial and heavy-duty vehicles, moves the sector to overall second place (7%) – behind only precious metals. According to the Society of Motor Manufacturers and Traders, 80% of cars manufactured in the UK are exported and the largest trade partners are Europe, the US and China – all three of these are markets with the fastest rates of powertrain electrification.

To enable a sustainable battery industry in the UK, **it is essential to retain the existing passenger car manufacturing footprint and facilitate its transition to electric powertrains.** As previously highlighted, light-duty vehicles, and in particular passenger cars, will be the largest battery demand segment from the automotive sector owing to their larger production volumes and higher battery pack sizes, relative to the heavy-duty and other electrified powertrains respectively. A crucial component of the economics will be access to nickel, in the form of nickel sulphate, which is required for the cathode of high energy density lithium-ion batteries.

UK's top 30 commodity exports, 2022

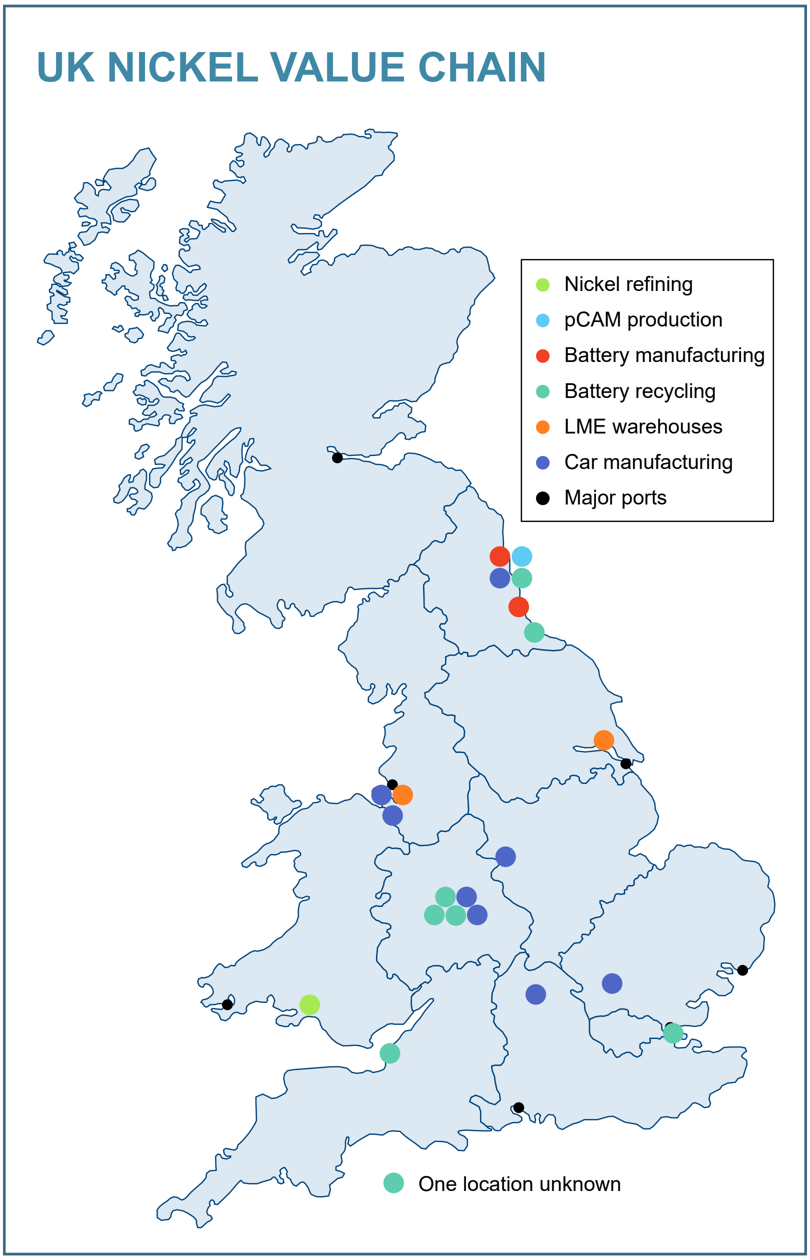


Source: SFA (Oxford), UK Office for National Statistics (accessed online February 2023)

06.
UK NICKEL SULPHATE PLAYERS MAPPED

Most growth seen in battery recycling

In terms of the required facilities for a nickel sulphate value chain, UK capacity is currently limited to one nickel refinery (Vale), one planned pCAM plant (Altilium Metals) and seven planned battery recycling plants. As the point of demand for nickel sulphate is at pCAM manufacturing, battery manufacturing facilities will not directly support a domestic battery-grade nickel supply chain given their lack of influence on direct metal consumption. Explicitly, building gigafactories will not necessarily directly support a domestic nickel value chain given that CAM /cells can be sourced from overseas. The point of interest to create nickel compound demand, and thereby a reason to develop a nickel value chain, would be to implement pCAM manufacturing, or facilitate trade with pCAM manufacturing regions, where high-quality nickel compounds are used.



Source: SFA (Oxford)

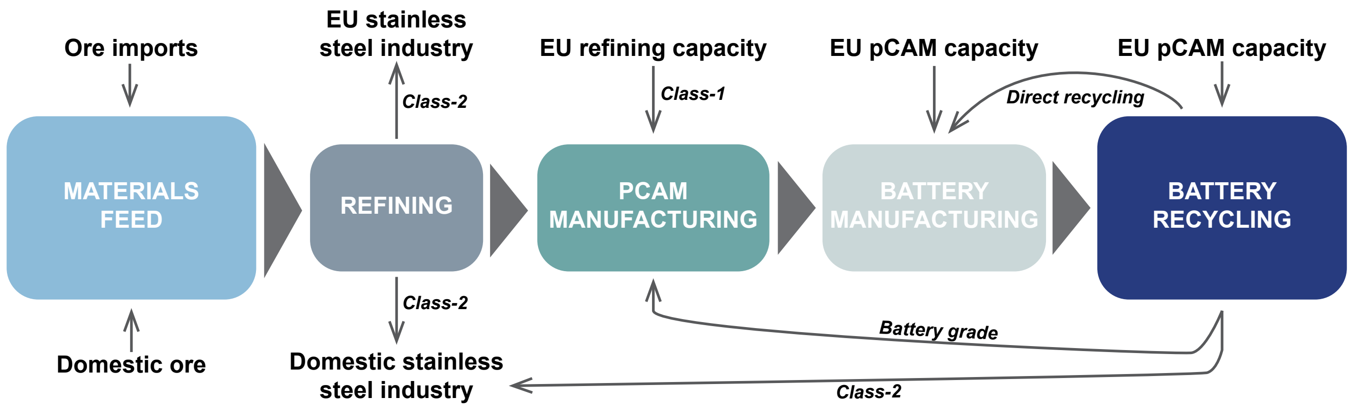
07.
POTENTIAL NICKEL SULPHATE VALUE CHAIN IN THE UK

Strong collaboration needed with partner countries

The UK is well positioned to participate in the nickel value chain for electric vehicles by leveraging capacities in the UK and Europe, and with strategic trade partners in North America and Asia. The London Metal Exchange (LME) provides a global benchmark for nickel pricing and its warehouses position the UK as a centre for nickel trade. The country has also supported relevant policies for decarbonising major production regions and it has taken an active role in promoting the critical mineral resource development with allied nations.

A nickel value chain in the UK will play out in close collaboration with the EU and raw material sourcing partners. Domestic industry will require partnerships to ensure resilience in operations. By incorporating the possibility of relying on some capacity from European facilities to balance outputs at different stages of a domestic value chain with the expected market demand for battery-grade nickel sulphate, pCAMs and LiBs, the UK can create a more flexible and adaptable nickel value chain. This will help to ensure that the country can meet the demands of the lithium-ion battery market while also maintaining the resilience and stability of its domestic nickel supply chain. Additionally, by leveraging the existing mining, refining, stainless steel production, pCAM production, battery manufacturing, and recycling industries in the UK and Europe, a robust nickel value chain can be created.

UK NICKEL MATERIAL FLOWS



Source: SFA (Oxford)

Trade will play an important role in the UK nickel value chain. The country can leverage its position regarding international alliances for critical minerals and strengthen ties with partner countries that provide primary nickel supply. **The ability to secure feeds will in part depend on the role that the UK government takes to assess and support cooperation between UK firms and sourcing locations.** Instruments such as the UK's Critical Minerals Strategy, and financing therein, will play heavily in the UK's sourcing ability. These measures, along with domestic infrastructures designed to ease international trade and domestic business, can increase the UK's attractiveness as a nickel processing hub, in response to other localisation incentive initiatives such as the US Inflation Reduction Act and the EU Critical Raw Materials Act.

Leveraging **low-carbon nickel can place the UK in a top-tier position** in nickel and pCAM markets. The majority of global nickel smelting occurs in areas heavily reliant on fossil fuels. For instance, Indonesia, the world's largest nickel ore exporter, generated 83% of its power in 2020 from coal, gas, and oil, and the two main nickel industrial parks in Indonesia are off-grid so rely heavily on captive power generators, the majority of which are supercritical coal-fired power plants. Hence, the UK's ability to provide secondary sources of nickel with lower-carbon intensities should not be disregarded. This will become particularly important when the EU sustainable battery regulations, set to take effect from 2024, will require batteries sold in the EU to be accompanied by a carbon footprint declaration. These EU regulations will become more stringent in 2026 and 2027 and **companies that fail to meet the EU's sustainability requirements may face carbon border taxes, further increasing the cost of nickel products and setting barriers to trade.**

With regard to meeting low-carbon standards and premiums, the UK is a member of the US-convened Minerals Security Partnership (MSP), which supports ESG-based knowledge transfer and investments on critical mineral value chains, and is a supporter of the Just Energy Transition Plan (JETP) for Indonesia, which mobilises capital for decarbonising the Indonesian energy grid. Both of these initiatives are highly relevant for collaborating in the international trade of battery metals and materials and ensuring low-carbon feeds and premiums.

The growth of battery recycling in the UK and EU offers avenues for secondary nickel supply, but primary supply will continue to play a leading role even when planned secondary supply is fully operational. Hence, the country would benefit from robust trade networks for primary sources and processed materials such as nickel compounds and black mass. The focus should be on **ports and transportation infrastructure, nickel refining and pCAM production facilities and battery recycling facilities.** These facilities will need to be strategically located to ensure easy access to feedstock and transportation infrastructure. By working with local governments and industry partners, the UK can identify suitable sites for new facilities and account for volatilities in electricity prices and labour forces.

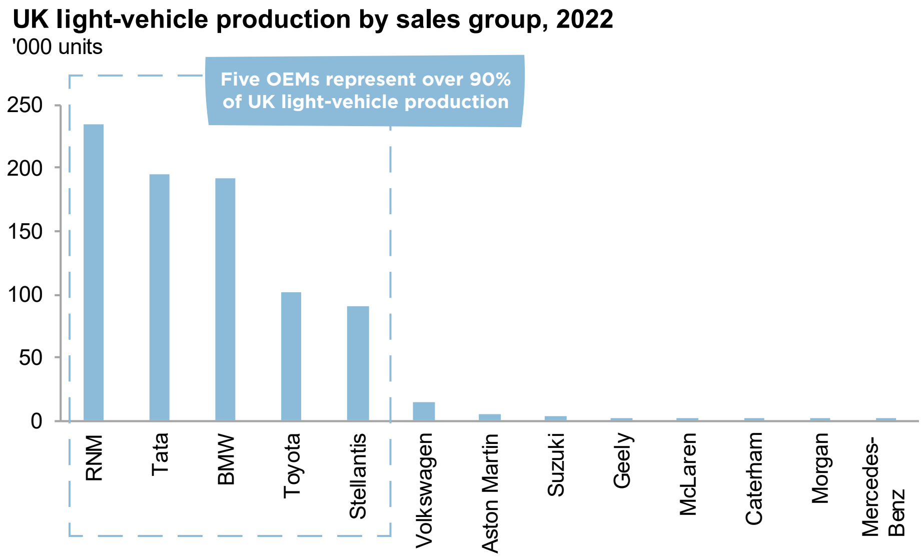
The UK currently does not have the capacity or the infrastructure to establish a domestic nickel value chain. The elements required to develop a domestic value chain and to lure investment, feedstock and technologies to the UK are complex and require long-term planning and engagement from both government and industry.

The UK needs to invest in facilities, infrastructure, and technology leaders at each step of the value chain. However, investing in facilities alone will not ensure success. For instance, retaining EV manufacturing and usage is critical for ensuring that inferred nickel demand develops in the UK and that spent EV batteries continue to be processed in recycling facilities.

This means lowering cost of ownership for EVs by improving energy and charging settings, and working with automakers to support and retain their operations in the UK.

While there are currently 13 OEM groups manufacturing light-duty vehicles in the UK, including some under multiple brands, just five represented over 95% of total production in 2022: Renault-Nissan-Mitsubishi (28%), Tata (23%), BMW (23%), Toyota (12%) and Stellantis (11%). This trend is expected to continue, with these five OEMs representing the bulk of UK light-duty vehicle production, including EVs, through to at least 2035, based on currently known production plans. As such, **the retention of these high-volume producers and their plans to transition to EV production in the future, will be crucial to nickel sulphate demand from the UK's automotive sector.**

Strategic planning based on global-reaching business models will also be needed. For instance, the ability to receive cargoes of black mass would be required as several recyclers operate under 'spoke-hub' business models where black mass is produced in spoke facilities and is then transported to hubs where it is processed to produce battery-grade metals, pCAMs or CAMs. Thus recycling facilities can provide a source of recycled nickel, reducing the reliance on imported feedstock, but they will not optimally support the UK in a global context if government interventions for market development do not align with the global market and its operations. In addition, co-location for integrating players can boost the economies of planed facilities. For instance, any development of battery manufacturing facilities needs to consider the likely locations of pCAM plants in order to streamline component transportation and reduce costs, favouring the establishment of pCAM facilities in the UK.



Source: SFA (Oxford), S&P Global Mobility (Global Production Based Powertrain Forecast, March 2023). Note: Tata produces under the Jaguar Land Rover brand, BMW produces under the Mini brand, Stellantis produces under the Vauxhall brand. RNM refers to Renault-Nissan-Mitsubishi

08.
CHALLENGES FOR THE UK

Addressing these challenges could benefit from clear objectives that align with broader government policy directions. For instance, actions such as levelling the playing field in nickel supply and demand concentrations, managing investor expectations, streamlining permitting and material qualification periods, developing new energy infrastructure or fostering innovation and skills development, and community-industry partnerships can ensure a longer-lasting impact if undertaken in parallel with existing frameworks that bolster the role and position of the UK in global battery supply chains.

Scale of project timelines

Challenge 1: Concentrated feedstock supply and access. The nickel market anticipates a consistent concentration of supply as Indonesian HPAL and NPI production ramps up, causing tightness in the market and fiercer competition for securing nickel feeds and products. Government intervention from UK and EU authorities is necessary to level the playing field in nickel supply and demand concentrations.

Challenge 2: Limited short-term return on investment. Battery materials and manufacturing industries tend to have unattractive investment conditions due longer payback periods and uncertain scaling up. Longer-term periods for IRR calculations are needed to prioritise battery-sector investments over other less capital-intensive industries. Investor expectations need to be managed appropriately to ensure capital is available.

Challenge 3: Long permitting and project approval timelines. The UK and EU have displayed difficulties in streamlining permitting and material qualification periods for battery industries. This leads project developers to look for other jurisdictions where timelines are faster and more predictable. Importantly, delays significantly reduce the value of projects.

Challenge 4: Lack of domestic manufacturing equipment and logistics. A lack of domestic supply of specialised processing equipment can limit the competitiveness of nickel refineries, pCAM facilities, and LiB recycling sites in the UK owing to reliance on foreign manufacturers who may be incentivised to prioritise their own domestic requirements. Co-locating machine manufacturers with plants improves resilience and attractiveness to situate in the UK.

Responsible sourcing and ESG

Challenge 5: Missing renewable energy deployment in key areas in the UK. New facilities required for a nickel value chain in the UK need access to clean, competitively priced, and reliable energy. The UK's current electricity grid limits the availability of areas suitable for plants with high electricity loads. Businesses are looking for cheaper electricity in other regions due to the impact of electricity costs resulting from the war in Ukraine. This is driving business away from the UK. Any attempt to reduce energy costs should be associated with renewable energy capacities to prevent damage to ESG profiles that results in higher costs due to stringent emissions requirements in the EU.

Challenge 6: Misalignment between UK and EU on nickel carbon content and responsible sourcing. The EU is implementing carbon content rules for imports and is moving ahead with emissions intensity scrutiny of battery materials and components. The UK needs to coordinate with the EU to ensure alignment in its supply chain carbon regulations. Failure to do so will mean that the UK will experience increased trade costs and administrative burdens.

Domestic production practices

Challenge 7: Lack of clarity on benefits of localising and increasing expenditures on UK intermediary products. The UK struggles to compete with landed costs of importing battery components from Asia, leading to many battery manufacturing sites not developing domestic value chains. Incentives to foster industry are critical in encouraging advanced industry entrants to prioritise domestic sourcing.

Challenge 8: Limited support for UK R&D and pilot-scale projects. The lack of pre-seed funding and pre-commercial-scale costs limit entrepreneurship in battery and critical materials spaces. The UK Battery Industrialisation Centre (UKBIC) R&D programmes can be used as a blueprint to develop and support new institutes and target a wider audience. However, failure to swiftly progress from R&D to commercial scale could also put intellectual property at risk.

Challenge 9: Lack of mid-stream technical expertise. The UK's lack of mid-stream know-how hampers the development of industry for processing nickel feeds and manufacturing pCAMs, despite the potential for a domestic nickel value chain. Technical training and high-volume production are needed to establish the UK's mid-stream facilities and refine pCAM production processes, which would allow battery manufacturers to use domestic feed for producing battery cells.

Access to materials, investment returns, innovation and mid-stream know-how

Four objectives are outlined for addressing the high-level challenges the UK faces to establish a successful domestic nickel value chain. A set of recommendations are outlined to meet these objectives and are aimed at supporting the growth and development of the nickel industry in the UK. They cover a range of areas, including international partnerships, domestic exploration, infrastructure investment, different forms of incentives, R&D funding, and skills development. The recommendations are intended to support the growth and competitiveness of the UK nickel industry, promoting sustainability and reducing carbon emissions.

Objective 1: Enhance access to feedstocks and refined materials

The UK can improve its resilience with regard to nickel supply concentrations and disruptions by diversifying and solidifying its feedstock sources and establishing responsible material sourcing. This can be achieved by identifying potential domestic sources of raw materials, investing in R&D to enable the utilisation of alternative feedstocks, and incentivising the recycling of end-of-life batteries and battery manufacturing scrap. The development of **partnerships with key global nickel producers and consumers** could help achieve this objective, which would benefit from close attention and action on permitting and qualifications for nickel products, and upgrades in ports and transport infrastructure. **Aligning standards with trade partners** could also support access to feeds. For example, harmonising UK emissions standards for battery materials with EU counterparts, specifically addressing the EU Critical Minerals Act and the EU Battery Passport, to support trade across regions. Likewise, incorporating renewable energy for facilities in the UK nickel value chain can help align their carbon footprint with tightening emissions standards across the world, reducing costs for trade with key regional partners, and improving ESG performance for UK players.

Recommendations:

1.1 Investing in raw material supplying countries: Increase the UK government's stake in the Just Energy Transition Plan (JETP) led by the US, Indonesia, and Japan. Leverage increased UK participation in JEPT to secure feeds of low-carbon nickel products at a discount.

1.2 Strengthening international partnerships: Leverage the membership of the UK in international cooperation partnerships on battery metals and critical minerals, such as the Minerals Security Partnership (MSP), to increase access to information and technologies for battery recycling, and financing for nickel supply chains. Form new agreements with strategic partner countries and regions for nickel trade, such as Canada, the US, Japan and Europe, to coordinate standards, reduce trade barriers across borders, and transfer knowledge and technology for nickel industries.

1.3 Securing feeds for the UK via traders: Partner with physical nickel trading firms to finance feedstock supply for the UK from locations implementing responsible sourcing measures.

1.4 Identifying domestic resources for exploration: Create and disseminate a database of historical records of nickel resources in the UK for exploration and development purposes.

1.5 Developing knowledge in alternative production directions for nickel sulphate: Finance research and early-stage commercial development grants for processing and refining methods for producing battery-grade nickel sulphate from alternative nickel ores and compounds, for example the production of nickel matte from nickel pig iron.

1.6 Investing in key transport and trade infrastructure: Mobilise financing for the port, road and rail building and refurbishing needed to connect the various parts of a domestic nickel value chain.

1.7 Increasing the integration of renewable energy in areas relevant for nickel facilities: Invest in grid expansion and coordinate between government, renewable energy developers, landowners, electricity suppliers and grid operators to develop new renewable energy infrastructure for dispatching electricity to facilities involved in nickel industries, including direct use in facilities, domestic equipment manufacturers and transport, in order to reduce costs and 1, 2 and 3 scope emissions.

1.8 Reforming permitting for nickel compounds: Implement changes to permitting processes to ease the administrative load, accelerate and clarify decision times and stages, and render processes that are transparent and can be monitored.

Objective 2: Support investment performance in the UK nickel value chain

Attracting investment in a UK nickel value chain can be supported by improving the perception and actual performance of expected returns. Incentives specific to the industry can be provided to support investment performances. These could include a mix of **tax and capital incentives, demand incentives, and the development of R&D grant programmes** for commercialisation. For example, tax credits and capital allowances could be offered for the construction of new nickel refineries and related infrastructure, while demand incentives could be provided through government procurement policies.

Additionally, the UK can support operational certainty by securing domestic manufacturing and a logistics infrastructure for the nickel industry and arranging preferential ordering with key manufacturing equipment providers overseas. This could mean developing partnerships with equipment manufacturers, promoting the establishment of new domestic manufacturing facilities, and obtaining price benefits for UK facilities.

Gaining the support and acceptance of local communities can also help in meeting this objective. Engaging with local communities and ensuring they understand the potential benefits and impacts of the UK nickel value chain can help to address concerns about environmental issues and community impacts. This could include developing community benefit agreements, conducting community consultations, and establishing local hiring policies.

Recommendations

2.1 Defining and implementing tax and capex incentives: Develop tax and capital expenditure (capex) incentives tailored to the nickel industry, such as targeted investment allowances, reduced corporate tax rates, and accelerated depreciation schedules. Provide loans with minimum or zero interest rates to reduce or eliminate the cost of debt for participants in the nickel industry.

2.2 Defining and implementing R&D and demand incentives: Establish grant programmes for R&D that are specifically targeted at improving the commercialisation of nickel refining and pCAM manufacturing technologies in the UK. Set up demand incentives, such as long-term contracts or government procurement schemes, to provide a secure market for nickel products in the UK, especially for the automotive and energy storage sectors.

2.3 Expanding equipment and logistical capacities: Form strategic partnerships with equipment manufacturers, promoting the establishment of new manufacturing facilities in the UK, and leveraging the scale of the UK market to obtain price benefits for these facilities. Expand incentives to address the production costs of manufacturing equipment. Provide loans to leading manufacturing equipment companies to prioritise orders from UK nickel refining, pCAM facilities and battery recyclers.

2.4 Supporting community acceptance: Establish frameworks for community benefit agreements that ensure local communities receive benefits such as jobs, training, and funding for community projects. Conduct community consultations to understand local concerns and develop strategies to address them. Establish local hiring policies that prioritise the hiring of local workers to increase the benefits to the local community. Evaluate community shareholding schemes.

Objective 3: Accelerate innovation and commercialisation capabilities

Fostering innovations in the nickel value chain can improve the position of the UK with its trade partners, making it an attractive place in which to build facilities to manufacture nickel materials and battery components and to trade final products and feedstock. To meet the objective of improving conditions in the UK for innovation in the nickel sector, the government could **increase funding for R&D and pilot-scale projects.** This would support the manufacture of next-generation nickel-containing components for lithium-ion batteries, refining processes for different nickel ores, and technologies to process black mass from spent batteries. Establishing research and development centres, providing grants and subsidies for pilot-scale projects, and promoting collaboration between academia and industry would also help **streamline paths to the validation, scaling, and commercialisation of ventures.**

Recommendations

3.1 Investing in R&D facilities: Establish new research and development centres in the UK that focus on the development of next-generation nickel-containing components for lithium-ion batteries, refining processes of different nickel ores, and technologies to process black mass from spent batteries. Provide world-class facilities for researchers and developers, as well as access to funding, expertise, and networks.

3.2 Supporting demonstration and pilot-scale factories for nickel refining, pCAM testing and manufacturing, and lithium-ion battery recycling: Provide grants and subsidies to support the development of demonstration and pilot-scale factories for nickel refining, pCAM testing and manufacturing, and lithium-ion battery recycling. Implement sharing schemes to reduce costs at demonstration and pilot scales.

3.3 Developing paths to commercialisation: Establish programmes that offer guidance and expertise in commercialisation, as well as providing access to funding and resources to support the scaling-up of ventures.

3.4 Fostering basic research in next generation lithium-ion batteries and pCAMs: Encourage and fund the R&D of materials, processes, and technologies associated with nickel refining and pCAM manufacturing and recycling. Make competitive offers to national and international student bases.

3.5 Implementing grant programmes for R&D aimed at joining industry needs with academia: Encourage partnerships between industry and academia through grants. Provide funding and support to accelerate the development and commercialisation of new technologies and processes associated with nickel industries in the UK. Enable the participation of key partner regions, such as the EU, to accelerate innovation development.

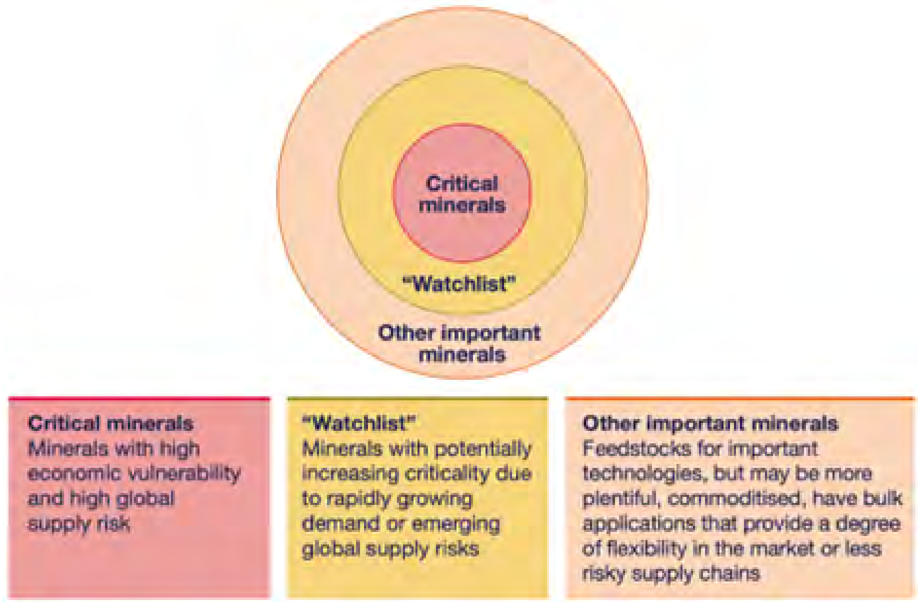
10.
POLICY DIRECTION TO SUPPORT COURSE OF ACTION

Supply chain management and R&D should be priority considerations

In the last year, the UK has moved forward with strategies to decisively engage in battery materials markets. Mainly led by the Critical Minerals Strategy, the UK government has identified risks and prepared action plans to secure competitiveness and comparative advantages in the global trend to electrify energy grids and transport fleets. **The most notable progress is in an outward-looking policy direction.** This is in response to the government's acknowledgement that the UK's competitive position in critical minerals value chains is an international issue.

To date, announcements of progress made specifically in nickel compounds and pCAM manufacturing involve funding from the Automotive Transformation Fund (ATF), the Faraday Institute and the Critical Minerals Intelligence Centre (CMIC). For example, the ATF has supported funding for the demonstration stage of Altilium's battery recycling and pCAM manufacturing plant in Teesside, the Faraday Institute holds the Faraday Battery Challenge in conjunction with the UK Battery Industrialisation Centre (UKBIC) to boost early stage R&D in battery innovation, and the CMIC has begun researching, compiling and publishing studies and data on sector material requirements.

Schematic of critical minerals, as a subset of all important minerals



Source: UK Department for Business, Energy & Industrial Strategy

Expected groundwork for the Critical Minerals Strategy can serve to prioritise actions identified in this report for supporting a nickel value chain in the UK in a way that it is aligned with current government goals. The UK is in a good position to prioritise and select a sub-set from these recommended actions following the framework established by its Critical Minerals Strategy. **Specifically, next steps could focus on supply chain management and R&D** in the short-term in order to integrate specific recommendations for a UK nickel value chain into the milestones of the Critical Minerals Strategy.

The impact of the Critical Minerals Strategy can be augmented by implementing the recommendations set out in this report. The UK Critical Minerals Strategy is a pragmatic approach to the country's national involvement in battery supply chains, but it needs to intensify its ambition for specific niches, such as nickel, where action is possible and can better position the UK in terms of battery electrification.

Establishing a UK nickel value chain needs as much input as that needed for UK leadership in battery industries. Following the recommendations in this report in line with the UK Critical Minerals Strategy can accelerate the delivery of some of the milestones in the Critical Minerals Strategy and augment their impact and value contributions. The UK's pragmatism in its approach to involvement in battery materials markets enables it to build from its leading position in trade and finance. However, the UK also needs to engage with new markets and sectors in order to fully accomplish its environmental and economic goals.

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