ENERGY TRANSITION PARTNERSHIP

REPORT

Supply Chain Integration of Battery Value Chain for Energy Transition in Indonesia

2025 | Comprehensive report on the analysis of the supply chain of batteries

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"Supply Chain Integration of Battery Value Chain for Energy Transition in Indonesia" - Project

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About the Southeast Asian Energy Transition Partnership (ETP) and this project

The Southeast Asia Energy Transition Partnership (ETP) is a program of the United Nations Office for Project Services (UNOPS) and is a dynamic partnership of government and philanthropic partners, working to facilitate sustainable energy transition in Southeast Asia. ETP is strengthened by its knowledge of the region, unwavering commitment to inclusive growth and ability to mobilize support services that cater to unique project requirements.

ETP's teams synergize the strengths of the public and private sectors and implementing partners, with the project management expertise of UNOPS to coordinate technical and financial resources needed to make a difference.

Through the design and delivery of targeted technical assistance programs, aligned with ongoing initiatives in the region, ETP provides the expertise, coordination, dialogue and knowledge expansion needed to expedite energy transition.

ETP's work is structured around four strategic outcome (SO) areas:

(i) Policy Alignment with Climate Commitments,
(ii) De-risking Energy Efficiency and Renewable Energy Investments,
(iii) Extending Smart Grids, and
(iv) Expanding Knowledge and Awareness building.

Supply Chain Integration of Battery Value Chain for Energy Transition in Indonesia

The overall objective of the "Supply Chain Integration of Battery Value Chain for Energy Transition in Indonesia" project financed by ETP is to help Indonesia expedite its energy transition efforts by integrating the local supply chain for batteries with electric vehicles (EV), Solar Photovoltaic (PV) businesses, and other RE power plants through the development of a supply chain roadmap, policy development, and identification of investment opportunities, along with corresponding investment guidelines.

The methodology and approach provided by the implementing partners in the Inception Report will assist:

(i) To catalyse the development of a *sustainable battery supply chain*[1],
(ii) To develop an integrated electric vehicle (EV) supply chain and
(iii) To leverage the abundance of natural resources in the country, particularly nickel.

Developed through four workstreams this report from **Workstream A** targets the analysis of the battery supply chain's current state, identifying key data sources and conducting a deep-dive analysis to inform policymakers of gaps and potential areas for development.

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[1] *A **sustainable battery supply chain** integrates environmental, social-economic, and financial consider-ations throughout all stages, from production to end of life. It recognizes potential negative impacts and implements measures to mitigate them, ensuring gender equality, social inclusion, ethical prac-tices, community well-being, and environmental protection from raw material extraction to recycling.*

It examines various secondary battery technologies, their supply chains, focusing on lithium-ion batteries (including nickel and iron variants, as well as solid-state batteries), and sodium-ion batteries. The report's Chapter 1 presents the most relevant battery technologies, its compositions and end uses, followed by the by a comparison of such technologies and probable future trends. Chapter 2 details the battery supply chain including a deep dive into the battery materials, refining process, cathode active materials (CAM), anodes, cell manufacturing and end of life. Then, Chapter 3 develops an assessment of the resource availability and production capacity in Indonesia and the current challenges and opportunities in the country. Later, Chapter 4 presents an overview of the operating industries and organizations relevant to the Indonesia battery supply chain. A geopolitical analysis for critical minerals is developed in Chapter 5. Afterwards, Chapter 6 develops a high-level economic analysis of batteries and EV adoption in Indonesia. Finally, Chapter 7 provides opportunities and recommendations for Indonesia to develop the battery supply chain. The recommendations provided in this report are specific to this deliverable's scope.

The project will be composed of three additional reports that will complement this report. The following reports will include additional topics such as the environmental and social impact assessment and will present a more detailed analysis for certain topics covered in this report like the comprehensive roadmap and recommendations for future policies.

Contents

Acronyms

ADB	Asian Development Bank
AEML	*Asosiasi Ekosistem Mobilitas Listrik/*Electric Mobility Ecosystem Association
APNI	*Asosiasi Penambang Nikel Indonesia/*Indonesian Nickel Miners' Association
ASEAN	Association of Southeast Asian Nations
ATCS	Area Traffic Control System
BAPPENAS	Ministry of National Development Planning
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BRI	Belt Road Initiative
BRICS	Brazil, Russia, India, China, and South Africa (intergovernmental association)
BRIN	*Badan Riset dan Inovasi Nasional*/National Research and Innovation Agency
CMEA	Coordinating Ministry of Economic Affairs/*Kementerian Koordinator Bidang Perekonomian*
$CoSO_4$	Cobalt Sulphate
DRC	Democratic Republic of Congo
ERP	Electronic Road Pricing
EU	European Union
EV	Electric Vehicle
FTA	Free Trade Agreement
G20	Group of Twenty
Gaikindo	*Gabungan Industri Kendaraan Bermotor Indonesia/*Association of Indonesian Automotive Industries
GWh	Gigawatt Hours
HPAL	High Pressure Acid Leaching
IA-CEPA	Indonesia-Australia Comprehensive Economic Partnership Agreement
IBC	Indonesia Battery Cooperation
INA	Indonesia Investment Authority
IRENA	The International Renewable Energy Agency
IRMA	Initiative for Responsible Mining Assurance
IUP	*Izin Usaha Pertambangan*/Mining Business Permit

IUPK	*Izin Usaha Pertambangan Khusus*/Special Mining Business Permit
KBLBB	*Kendaraan Bermotor Listrik Berbasis Baterai /* Battery – based Electric Motor Vehicles
MT-LCE	Metric Tons of Lithium Carbonate Equivalent
LFP	Lithium Iron Phosphate
LIB	Lithium-ion Batteries
LME	London Metal Exchange
MDB	Multilateral Development Bank
MEMR	Ministry of Energy and Mineral Resources/*Kementerian Energi dan Sumber Daya Mineral*
MHP	Mixed Hydroxide Precipitate
MIND ID	Mining Industry Indonesia
MoF	Ministry of Finance/*Kementerian Keuangan*
MoI	Ministry of Industry/*Kementerian Perindustrian*
MoInv	Ministry of Investment/*Kementerian Investasi (BKPM)*
MoM	Ministry of Manpower/*Kementerian Ketenagakerjaan*
MoSOE	Ministry of State-owned Enterprises/*Kementerian Badan Usaha Milik Negara*
MoT	Ministry of Transportation/*Kementerian Transportasi*
MPIA	Multi-Party Interim Appeal Arbitration Arrangement
MPMSM	Medium-Purity Manganese Sulfate Monohydrate
NCA	Nickel Cobalt Aluminium Oxide
NMC	Nickel Manganese Cobalt
NMT	Non-Motorized Transport
NTT	Nusa Tenggara Timur
NZE	Net Zero Emission
PLN	*Perusahaan Listrik Negara* (State-owned Electricity Company)
REC	Renewable Energy Certificate
RoW	Rest of the World
Sakemas	*Survei Angkatan Kerja Nasional/*National Labor Force Survey
SIBs	Sodium Iron Batteries
SOE	State-owned Enterprise
SPKLU	*Stasiun Pengisian Kendaraan Listrik Umum*/Public EV Recharging Station
SSLBs	Solid-State Lithium Batteries
TOD	Transit Oriented Development

TRL	Technical Readiness Level
UN	United Nations
UNCLOS	The United Nations Convention on Law of the Sea
UPS	Uninterruptible Power Supplies
US	United States
WBES	World Bank Enterprise Survey
WTO	World Trade Organisation

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Executive summary

Battery technologies

Due to their technological readiness level and end-use applications Lithium-ion and Sodium-ion batteries are the most common type of secondary batteries on the market. However, each of these offer distinct characteristics and advantages based on their chemistries and therefore, the raw materials they use. Lithium-ion batteries dominate the global market, being the preferred choice for electric vehicles (EVs) due to their high energy density and efficiency. However, the search for next generation battery chemistries has driven companies to explore alternatives such as lithium-metal batteries and sodium ion batteries (SIBs).

Sodium-ion batteries (SIBs) are more cost-effective, less prone to thermal runaway, and have a lower environmental impact when compared to lithium-ion batteries (LIBs), yet, SIBs industry lacks scale and maturity relative to LIBs. In 2022, the LIB market was valued at USD $70 billion and it is projected to exceed USD $387 billion by 2032. While SIB market was valued at USD $0.86 billion in 2022 and it is expected to reach around USD $4.8 billion by 2032, showing that the LIBs will continue to dominate the battery market during the next decade. These are encouraging projections for Indonesia since the country has large resources and reserves of critical mineral used in LIBs, especially nickel.

Most commercial LIBs use graphite for the anode and lithium salt for the electrolyte but the cathode's chemistries composition, which is also the most intensive part of the battery, varies across different sub-chemistries. Lithium Nickel Manganese Cobalt Oxide (NMC) and Nickel Cobalt Aluminium Oxide (NCA) are currently the most material-intensive batteries, relying on scarce and expensive elements such as nickel and cobalt. So, the use of these materials contribute to higher production costs and potential supply chain risks as the anode accounts for 10-15% of the total battery costs, while the cathode makes up for 50% or more. Lithium Iron Phosphate cells (LFP) provide a more sustainable and cost-effective alternative, particularly in markets that prioritize affordability and safety. LFPs have significantly lower costs than NMCs and NCAs due to the abundance and low costs of iron. Unlike these three previous technologies, Solid-state Lithium-ion Batteries (SSLBs) employ solid electrolytes. Although, SSLBs offer higher energy density and enhanced safety, they still depend on the same key minerals as conventional lithium-ion batteries, meaning they face similar supply chain constraints. While NMCs, NCAs and LFPs are fully mature and have widespread commercial use, having a technological readiness level (TRL) 9, SSLBs are still in the development phase with a TRL 5. Ongoing advancements in battery technologies aim to strike a balance between performance, cost, and environmental impact.

Over 50% of the global raw material processing for key battery minerals and around 75% of the battery cell production capacity is currently in China. Around 25% of the global EV production capacity is in Europe, with the share likely to increase due to the adoption of recent legislative instruments calling for increased domestic production. The US currently holds a 10% share of the global EV production, and 7% of battery production capacity. Like the EU, the US has also adopted a legislative framework supporting 'domestication' of the industry, which might lead to increased production in the future. While Indonesia's current battery production volumes are not globally significant, the country has implemented measures to change this. In 2020, Indonesia implemented a nickel export ban to add value to their minerals to expand its participation in the battery supply chain beyond extraction. The country has the target to produce 600,000 EV units by 2030, which would require 37,600 tons of Nickel assuming all EVs use Lithium Nickel Manganese Cobalt Oxide (NMC811) batteries. According to the Ministry of Energy and Mineral Resources the country has 184,606,736 thousand tons of metal nickel, including estimates, indications and measured resources, which means they have enough nickel resources to cover their national production target and still have a large amount of resources to produce EVs for the international market. However, other Asian countries are in the running too. Both Korea and Japan hold significant positions within the supply chain, following raw material processing particularly in the production of cathode and anode materials. Korea contributes 15% of the total production capacity for cathodes and 3% for anodes. The respective shares for Japan are 14% concerning cathode production and 11% for anode. Emerging strategies to diversify supply and production chains reflect a range of economic, political, and social considerations.

Battery supply chain

Global battery supply chain has become increasingly complex and critical due to the rising demand for batteries driven by ambitious emission reduction targets and decarbonization goals. This demand is further fueled by policies that promote electrification. While these policies have catalysed significant corporate actions, they have also faced challenges and controversies, including automakers revising electrification targets in response to various market pressures.

The secondary battery supply chain is comprised of five stages: mining, refining, cathode production (CAM), cell manufacturing and assembly (LIB cell), and end use applications. The end use stage can also be further broken down into specific sectors: Transportation (including Electric Vehicles), Energy Storage Systems (ESS), Portable Electronics (3Cs). Mining and refining are categorized as "upstream" activities, while stages from CAM to end user are considered "downstream.

In terms of raw material extraction, Chile (34%), Australia (22%), and Argentina (13%) hold the largest global lithium reserves. However, lithium products are primarily refined in China, accounting for more than 50% of the production capacity of lithium carbonate and more than 80% of lithium hydroxide (both lithium chemicals). In terms of volumes of raw materials, Australia takes the lead producing close to 400,000 MT-LCE (42%) in the shape of spodumene concentrate. Nevertheless, spodumene concentrate is only a raw material for the production of lithium chemicals, so 82% of Australian production ends up being refined in China.

Indonesia leads in nickel production with 42% of global reserves, the Democratic Republic of Congo (DRC) is the primary source of cobalt accounting for over 70% of the global extraction, and China dominates the global production of graphite accounting for 57% and 30% of global reserves, respectively. Nickel is found globally, primarily in laterite deposits as is the case of Indonesia's abundant reserves. The largest nickel extraction site is in the Maluku region of Indonesia and cobalt is mainly mined as a by-product of copper and nickel mining, with most of the global production concentrated in the DRC. Graphite, the main anode material, is extracted from both natural deposits and synthetic production, with China accounting for 30% of global reserves. Manganese resources, in contrast, are more widely distributed around the world and remain relatively inexpensive compared to other battery metals.

Once extracted, raw materials undergo refining to achieve the high purity required for battery production, with China dominating this stage. The refining process involves various techniques, including hydrometallurgy and pyrometallurgy, to produce battery-grade materials. Indonesia has also increased its domestic processing capacity for nickel, impacting global supply chains. Indonesia has increased its participation in the refining process 208%, between the introduction of the nickel ban in 2022 and investments in mineral processing and manufacturing.

Cathode active material (CAM) industry, which is the chemistry of the cell, is dominated by China and is expected to remain the same in the short-term. For Asian manufacturers**,** NMC represents between 40% and 60% of the EV manufacturing during the last 5 years. China has almost 79% of the global cathode capacity, followed by South Korea (14%) and Japan (5%). The Chinese cathode market is quite diverse with around 100 traceable players in the production of both LFP and NMC. Over the next five years, China will continue to dominate the cathode landscape, but interesting developments are emerging outside the country: The United States plans to add close to 1.5 million tons of cathode capacity by 2028 with 15 new projects underway. The European Union is also expanding, with Sweden, Poland, Hungary and Finland expected to add almost 1 million tons by 2028. Indonesia will contribute with two new projects, adding 160,000 tons of capacity over the next decade. Indonesia's strategic role in the nickel market, along with its competitive energy and reagent costs, could attract even more projects.

Anode active materials are predominantly composed of graphite, with most of the global production capacity for these materials concentrated in China. The majority of the installed capacity is to produce synthetic graphite, accounting for almost 75% of global output, despite being more expensive than natural flake graphite. Indonesia's participation in the anode industry is quite small, and although there are plans to add new capacity in this and other countries like the US and India, the additional capacity outside of China will not exceed 1 million tons, representing almost 20% of the total anode capacity worldwide. This means that, at least in the next decade, the anode industry will continue to be dependent on China.

The cell manufacturing stage within the battery supply chain is also led by China. This stage involves the production of battery cells and packs including the assembly of cathode and anode materials, electrolytes, separators, and electrical foils into battery cells, which are then combined into modules and packs. Before 2023, the companies with the largest LIB cell manufacturing capacity were CATL with 552GWh, LG Chem with 172GWh and BYD with 148 GWh. Both CATL and LG Chem include Indonesia in their strategy. CATL, particularly, is developing the EV Battery Industrial Chain Project with a USD $6 billion investment intended to lead the battery industry technology for nickel NMC and ensure the cost competitiveness of NMCs in the competition with LFPs. Many Chinese players are mastering the production of NCM811, which explains why the global cell production capacity is biased towards high nickel chemistries and the interest for Chinese players to keep lithium and nickel mining/refining margins under control.

Transportation is the largest end use within secondary batteries' growing markets followed by energy storage systems. Major EV manufacturers like BYD, Tesla, and Volkswagen rely on both nickel-based and iron-based battery chemistry. To develop the EV industry in the country, Indonesia has set the incentive at 0% import duty tariff applicable to Completely Built Up (CBU) and Completely Knock Down (CKD) EVs with a local content value of 20-40%. EV producers BYD, Vinfast, Aion, Volkswagen and Maxus have benefited from such incentives. In addition to EV batteries, the market for stationary energy storage is growing.

Industrial Landscape Perspective in Indonesia

Indonesia's battery supply chain is overseen by three key ministries: the Ministry of Energy and Mineral Resources (MEMR), The Ministry of Industry (MoI), and The Ministry of Investment (MoInv), along with support from other government bodies and state-owned enterprises, like the Indonesia Battery Corporation (IBC). Additional players include private companies, foreign investors, industrial estates, and financial institutions that facilitate growth through funding mechanisms. End-use stakeholders, such as public transport providers and charging station operators, drive demand.

Indonesia's nickel and processing industries are well-developed; however, the latter has been historically focused on the steel sector until recent years, where a rapid development for nickel processing aimed at the battery sector has been established. Regarding the extraction of raw materials, Indonesia also possesses abundant cobalt and manganese mineral resources. Unlike nickel, the manganese production has experienced inconsistent output in recent years. Enhancing the use of domestic resources while reducing reliance on imports remains a priority. In addition, processing of other materials besides nickel is either limited or still in development.

The country's first LFP cathode facility, PT LBM Energi Baru Indonesia, has a production capacity of 30,000 tons of LFP cathodes, and the anode industry is developing, although its capacity remains limited. In addition, Indonesia plans to produce 160,000 tons of NMC cathodes annually in the following decade. The strategic role of Indonesia in the nickel market and its competitiveness in terms of energy/reagent could attract more projects that can accelerate this development. Regarding the anode industry, in Q4 2024, President Joko Widodo inaugurated a new plant built by PT Indonesia BTR New Energy in Central Java, producing anode materials for EV batteries. A new NMC cell manufacturing plant was recently launched in Indonesia, with an annual production capacity of 10 GWh. This facility encourages the use of domestic resources. The company, PT HLI Green Power, is a joint venture between Hyundai Motor Company, LG Energy Solution, and the Indonesia Battery Corporation. LFP battery producers are also present in Indonesia, i.e., PT Gotion Green Energy Solutions Indonesia and PT International Chemical Industry (Intercallin). Battery parts are reportedly imported. According to the Ministry of Investment, the country has the potential to become one of the top 5 global battery manufacturers by 2040 with a total production capacity of 650GWh per year, accounting for 10% of the global battery demand.

Battery production in Indonesia is intended mainly for EV production and incentives for investments in downstream businesses and demand incentives have been implemented to encourage sector growth. These incentives include: (i) 75% loan coverage for EV value chain activities and exemptions from maximum credit limits, and (ii) corporate income tax holidays for EV industry investments. Hyundai and KIA are the only EV manufacturers currently using domestically produced batteries. Demand incentives include loans for EV purchases, a 10% VAT reduction on EVs with at least 40% local components, reduced luxury EV taxes, exemptions from road restrictions, and parking discounts. Indonesia's recent 4W EV production is 15.3% of the 2030 annual target (600,000 units). With its production capacity of 91,661 4W EVs (including BEVs, HEVs, and electric buses) and 100,000 2W EVs, Indonesia has become a net exporter of 4W and 2W EVs. It is heading towards becoming a large regional player.

Although the country aims to address the End of Life (EOL) stage of batteries, currently, the only battery recycling company in Indonesia is PT Indonesia Puqing Recycling Technology. This company can process up to 18,144 mt/year of used lithium batteries. Additional investments in recycling and second-life battery technologies could align Indonesia with global trends in sustainable energy and circular economy principles. Investments in NMC chemistries could increase the country's supply chain sustainability credentials since NMC batteries contain more valuable raw materials compared to iron-based chemistries.

Economic perspective for developing Indonesia's battery supply chain

The Indonesian government has implemented a fiscal and non-fiscal incentive to promote the adoption of EVs including corporate incentives, parking benefits and charging infrastructure development, tax reductions and odd-even license plate policy exemption. The latter being a traffic regulation that restrict vehicle access to certain roads on certain dates based on the last digit of its license plate. The latter, including lower import duties and exemptions from luxury goods tax. Electric vehicles benefit from a reduced Value-Added Tax (VAT) of 1%, compared to 11% for conventional vehicles, and are also exempt from luxury and import taxes. However, in order to encourage local manufacturing, a minimum of 40% of the EV components must be local to access the reduced VAT by 2025 and 60% by 2027. Although currently the local content for EVs is lower than 20%, the Ministry of Investment foresees increases in the local component as a result of the strong support from the government regarding licensing, infrastructure and regulations to attract foreign investors that contribute to the upstream-downstream industrial integration.

Raw materials represent a substantial portion of EV's battery costs, accounting for approximately 70% to 80% of total expenditures. The government has established a monthly domestic trade benchmark price (HPM) for various metal minerals and coal, covering key commodities such as: nickel, cobalt, lead, zinc, aluminium, copper, gold, silver, tin, manganese, iron ore, chrome ore, ilmenite concentrate, and titanium concentrate. The goal of the HPM is to create a fair, competitive, and transparent trade system for miners and smelters.

Indonesian government MEMR's Secretary-General has stated that the government has set the target to expand the EV market, the goal is to reach 2 million electric four-wheel vehicles (E4W) on the road by 2030. The EV market in Indonesia is still far from meeting the targets set, however, sales in 2023 seem encouraging. In 2023, 12,248 units of EVs were sold in the country, which represented a 43% increase from the previous year. To this day, production of E4Ws in Indonesia is low and far from the production target by 2030. Battery and EVs manufacturers have encountered barriers such as high nickel and cobalt prices, high manufacturing costs and slow application processes for permits. Consequently, the government's efforts to develop the supply chain for batteries and the incentive implementation for upstream and downstream investments propose to change this.

The VAT reduction incentive could be the basis to meet adoption and production of EVs' targets. Under two main and broad assumptions: (i) the average price of EVs sold in Indonesia until 2030 behave in line with the global average price projections, and (ii) each EV from 2027 forward will replace one internal combustion engine vehicle (ICEV) of similar price. Under these conditions, the estimated accumulated VAT revenue loss between 2027-2030 rises to USD $8.21 billion. However, meeting those targets could generate 43,060 net new jobs, assuming ICEVs employees could transfer to EV production. Plus, those new jobs would trigger additional tax collection, in turn fuelling economic activity. Meeting these targets, having a VAT revenue decrease would also mean additional tax collection from battery and mining and refining production industries.

Opportunities for investment

Indonesia holds significant potential in the global battery supply chain due to its abundant reserves of nickel, cobalt, and manganese, and, as the world's largest producer of nickel, plays a pivotal role in meeting global demand for lithium-ion batteries, essential for EVs. The battery sector in Indonesia presents considerable investment opportunities along diverse stages of the battery supply chain.

Indonesia possesses vast reserves of key minerals, including 42% of global nickel resources and 2% of global cobalt resources (according to USGS), but challenges remain in scaling up production capacity for these essential minerals for domestic battery production. The following preliminary recommendations have been developed to address these challenges and will be further explored in subsequent workstreams:

- Focusing on securing a reliable supply of lithium ore to develop the national battery industry. Indonesia could leverage its proximity to Asian end markets creating attractive conditions for refining investors.
- Implement international best practices in technological advancements and regulatory reforms within the mining sector that enhance resource efficiency and sustainability to address possible scale back investments from international companies due to concerns over environmental and social impacts.
- Establish multilateral and bilateral partnerships to diversify suppliers and attract investment in domestic refining operations. This approach will minimize reliance on a single supplier for lithium and graphite, mitigating risks from geopolitical tensions or trade disruptions.
- Encouraging multilateral and bilateral cooperation to strengthen domestic manganese refining operations in NTT and reinforcing monitoring mechanisms, reporting to MEMR.

When key battery materials are secured, investments in the manufacturing supply chain must increase to create a fully integrated and connected system. The preliminary recommendations to tackle challenges at each stage of the supply chain are the following:

- International stakeholders have raised concerns over environmental and social impacts, resulting from the extraction of minerals. The government should enforce stricter regulations and policies to ensure operations comply with green mining standards and effectively address social impact.
- The government should explore strategies to reduce reliance on China in the refining and CAM sectors, while also developing domestic refining capabilities, the government should consider revising tax incentives, such as tax holidays for pyrometallurgy,

and support the development of robust manganese smelter operations, particularly in NTT.

- Indonesia should prioritize investments in and the promotion of the NMC/NCA battery supply chain to fully capitalize on its domestic nickel and cobalt resources. This includes developing the country's production capacity for NMC batteries.
- Encourage investment in anode manufacturing facilities, focusing on both synthetic and natural graphite options, to reduce dependence on China and support domestic production.
- Strengthen partnerships between battery material producers and companies like LG Chem to diversify manufacturing capacity and reduce reliance on Chinese players.
- It is also recommended that the country develops urban mining to promote the circular economy by enhancing resource recovery and reducing waste, to support resource security by providing a more independent source of raw materials and to minimize transportation costs.

Finally, the market penetration of domestically ensembled EVs has yet to reach its full potential. It is recommended that Indonesia expand infrastructure for EVs, particularly the establishment of EV charging stations across urban and rural areas.

1 Battery technologies

1.1 Introduction

Batteries are devices formed by cells that store chemical energy from various sources and convert it into electrical energy when needed. The operation of a battery cell involves chemical reactions that facilitate the flow of electrons between two electrodes: the anode (negative electrode) and the cathode (positive electrode). As electrons move from the anode to the cathode through an external circuit, they generate an electric current. To maintain a balance in the flow of electrons, charged ions move through an electrolyte solution that is in contact with both electrodes.

This movement is essential for completing the electrical circuit. The chemical reactions in a battery are classified as reduction-oxidation (redox) reactions. When cells use appropriate electrode materials, the chemical reactions can be reversed during charging, restoring the cell's energy storage capability. However, each charge cycle leads to gradual degradation of the electrodes, resulting in diminished performance over time.

Based on the above, cells can be classified in two basic types: primary and secondary.

- **Primary cells**: In these cells, the electrode and the reactions cannot be reversed by passing an external electrical energy. Thus, the reactions occur only once. Batteries formed by this type of cells are not chargeable and must be discarded after they have been discharged.
- **Secondary cells**: In these cells, the redox reactions can be reversed by passing an external electrical energy Global demand has increased for this type of cell, driven by decarbonization policies and the electrification of transportation and energy storage systems that promote the use of renewable energy sources.

Companies and research centers are looking for secondary battery technologies that improve performance, capacity, power and energy density, speeding charging time, lower costs and greater lifetime. The following section analyses two types of secondary batteries: Lithium-ion and Sodium ion.

1.2 Lithium-ion secondary batteries (LIBs)

Currently, lithium-ion secondary batteries dominate the global market, serving in applications from consumer electronics to transportation and grid-scale energy storage. These batteries are the preferred choice for electric vehicles (EVs) due to their high energy density and efficiency. Notably, a typical lithium-ion battery pack for a single electric vehicle contains about 8 kilograms of lithium[2]. Current global reserves are projected to be sufficient to produce nearly 2.5 billion batteries, supporting the anticipated growth in the EV market. The lithium-ion battery market was valued at USD $70 billion in 2022 and projected to exceed USD $387.05 billion by 2032.

Most commercial lithium-ion batteries today use graphite for the anode and lithium salt (Lithium Hexafluorophosphate $LiPF_6$) for the electrolyte. The cathode, which is also the most intensive part of the battery, requires other raw materials besides lithium and its

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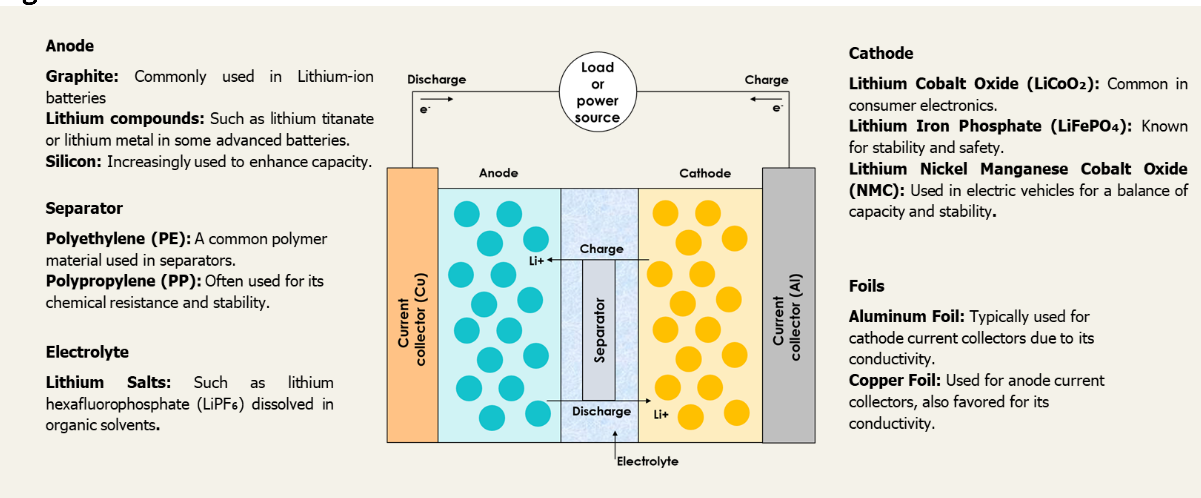
[2] According to figures from US Department of Energy science and engineering research centre Argonne National Laboratory. WEF, 2022. The world needs 2 billion electric vehicles to get to net zero. But is there enough lithium to make all the batteries? Available at: [Electric vehicle demand – has the world got enough lithium? | World Economic Forum (weforum.org)]

composition varies across different sub-chemistries of the lithium-ion technology. The selection of chemistries used in the production of batteries depend on resource availability, costs and even geopolitical aspects discussed further in this report. Figure 1.1 illustrates the essential components of a lithium-ion cell, along with the key minerals and materials associated with it.

Figure 1.1 Schematic of the Lithium-ion cell



Source: Own elaboration

1.2.1 Chemistries

Battery technologies can be analyzed based on their chemistry type (various material combinations), each one with unique performance, cost and safety characteristics. Other features typically involve energy density, power density, thermal stability, and cycle life, which manufacturers optimize based on the specific application of the battery. Thus, these characteristics represent pros and cons depending on the application of the battery. The description of the technical concepts used as specifications to describe battery cells, modules and packs can be found in Annex 1. Battery technologies technical specifications and Technological Readiness Levels.

The nomenclature of lithium-ion batteries depends on the composition of the cathode materials used, specifically the ratios of the main raw materials. For instance, nickel (N), manganese (M) and cobalt (C) combination ratios are referred to as NMC. While the digits following the code letters represent the relative proportions of each one of the materials in the cathode. Each number corresponds to the percentage of the respective metal in the total cathode composition, scaled to a total of 1 (or 100%).

- **Lithium Nickel Manganese Cobalt Oxide ($LiNiMnCoO_2$) – NMC**

Cathodes of NMC batteries are formed by $LiNi_xMn_yCo_zO_2$ (x + y + z = 1), also termed NMCXYZ, are widely commercialized cathode materials[3]. Nickel (N), manganese (M) and cobalt (C) can be altered to obtain different properties for specific applications. For instance, NMC811 has 80% nickel, 10% cobalt, and 10% manganese. NMC cathodes other common formulations are NMC532, NMC622, and NMC111, where 111 means the NMC cell has equal parts nickel, manganese and cobalt.

[3] *Aleksandra A. Savina, Artem M. Abakumov, Benchmarking the electrochemical parameters of the LiNi0.8Mn0.1Co0.1O2 positive electrode material for Li-ion batteries, Heliyon, Volume 9, Issue 12, 2023, e21881, ISSN 2405-8440, Available at: https://www.sciencedirect.com/science/article/pii/S2405844023090898)*

Higher nickel content, such as in NMC811, enhances energy density and reduces costs by decreasing the cobalt content[4] - Cobalt is used in smaller quantities due to its high cost and ethical concerns, with ongoing efforts to reduce its proportion in these batteries -. However, high-nickel NMCs face challenges related to thermal stability and structural degradation, which require advanced stabilization techniques like structural doping and interfacial coatings. Indonesia could leverage from its nickel reserves and refining capabilities to develop NMC cells' supply chain.

The NMC battery market was valued at USD $25.8 billion in 2023 and is projected to grow at a compound annual growth rate (CAGR) of over 15.7% from 2024 to 2032. This growth is driven by increasing demand for electric vehicles (EVs) and advancing technological trends across various industries[5].

- **Nickel Cobalt Aluminium Oxide - NCA**

Lithium-nickel-cobalt-aluminium oxide $LiNi_{1-x-y}Co_xAl_yO_2$ (NCA) batteries, typically consist of approximately 80% nickel, 15% cobalt, and 5% aluminium. They offer high energy density and long cycle life compared to NMC, making them suitable for high-performance EVs. However, similar to NMC, they require effective thermal management due to safety concerns associated with high nickel content. This type of cathode is used by Tesla in the US market[6].

- **Lithium Iron Phosphate (LiFePO4) – LFP**

Lithium iron phosphate ($LiFePO_4$ or LFP) is a widely used iron-based cathode material in lithium-ion batteries. The key materials of these types of cathodes include iron, lithium, and phosphate. Iron is abundant and inexpensive, significantly lowering the cost compared to nickel and cobalt. Lithium remains a core component, though in lesser amounts compared to nickel-based batteries

LFP batteries are known for their safety, long cycle life, and thermal stability, which make them a reliable choice for various applications. These types of battery do not suffer from thermal runaway and can operate at high temperatures without decomposing. Although they have a lower energy density compared to nickel-based cathodes, they provide better power density and are more environmentally friendly due to the abundance and low cost of iron. Chinese battery manufacturers account for 90% of the global production of LFP batteries. According to MarketsandMarkets Research, the LFP battery market is projected to reach over USD $13 billion in 2024, with potential growth to USD $24.6 billion by 2027, reflecting a compound annual growth rate (CAGR) of 13.7%.

- **Lithium Manganese Iron Phosphate - LMFP**

LMFP batteries are a development of LFP batteries since manganese replaced some of the iron used as the cathode material. It has a higher energy density (15-20%) than LFP while keeping the cost and level of safety. LMFP batteries are a promising successor to LFP batteries in China, where LFP batteries account for 60% of the domestic market share. Comparing costs, as this type of battery does not use cobalt or other rare metals, the costs are expected to be equal to or lower than that of LFP.

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[4] *Journal of Materials Chemistry A: "Structure/interface synergy stabilizes high-nickel cathodes for lithium-ion batteries". https://pubs.rsc.org/en/content/articlelanding/2024/ta/d4ta01230e*

[5] *Global market insights. Nickel Manganese Cobalt (NMC) battery Market Size - By Application (Automotive, Energy Storage, Industrial), By Regional Outlook & Forecast, 2024 – 2032. Available at: Nickel Manganese Cobalt (NMC) Battery Market Size, 2032 Report (gminsights.com)*

[6] *Tesla has used three main cathode types: NCA, NMC, and LFP depending on the battery pack production company and its location and market. The latest development shows that LFP are a leading alternative due to the costs of Cobalt.*

- **Lithium Nickel Manganese Spinel ($LiNi_{0.5}Mn_{1.5}O_4$) - LNMO**

This type of battery is cobalt free and low in nickel content. The cathode is formed by Lithium nickel manganese oxide. The battery offers high energy density and a high voltage plateau, while it has good thermal stability. It possesses a three-dimensional spinel structure that improves the flow of lithium-ions, enabling high discharge rates and fast charging. Research is ongoing to improve the performance of this battery chemistry.

- **Lithium Cobalt Oxide ($LiCoO_2$) - LCO**

The cathode in LCO batteries is a lithium compound of cobalt oxide and the anode is a graphite/carbon material. This type of battery has high specific energy, relatively low thermal stability, and limited lifespan. LCO batteries tend to be more expensive than other chemistries due to the high cost of cobalt.

- **Lithium Titanate ($Li_4Ti_5O_{12}$) – LTO**

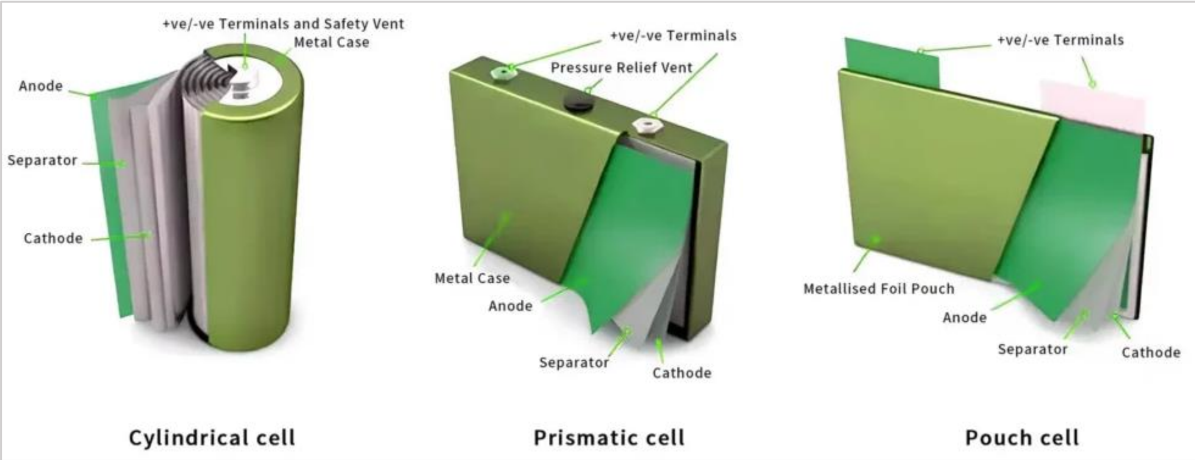
Lithium titanate batteries typically use NMC as the cathode material and lithium titanate nanocrystals for the anode, though, alternative chemistries such as LMO and LFP can also be employed. These batteries provide fast charging, high discharge current, and excellent low temperature discharge characteristics. While they have lower energy density and higher manufacturing costs compared to conventional Li-ion batteries, they boast a significantly longer lifecycle. Additionally, their better thermal tolerance makes them extremely safe for use in EVs and e-bikes, with potential use in the military and aerospace industries.

1.2.2 Formats

The different chemistries can be produced using one of three types of cell forms: cylindrical, prismatic and pouch (Figure 1.2). However, there is no one standardized format for a lithium-ion secondary battery, as it is based on the specific requirements of the final application.

- **Cylindrical type:** It comprises an electrode assembly, a case for receiving the electrode assembly, and a cap assembly for sealing the top opening of the case. This format is the oldest in the market and possess a higher degree of standardization. Most common chemistries for cylindrical battery cathode materials are LCO, LMO, NMC and LFP.
- **Pouch cells in secondary batteries:** The battery is made by laminating flat electrodes and separators, then sealing them in a flexible, heat-sealed pouch or bag made of a flexible material, often aluminium or other polymers. However, this type of cell is prone to swelling over time, affecting performance and safety of the battery pack. The most common chemistries for pouch cell type batteries are: LCO, LFP, LMO.
- **Prismatic cells:** With its rectangular or square flat shape t cells are stackable which improves space efficiency is some appliances. The electrode materials are arranged in layers, and the cell is enclosed in a sturdy metal casing. The casing shape and thickness allow better heat management than cylindrical cells. The preferred cell chemistry for these batteries is LFP.

Figure 1.2 Types of cell forms



Source: LiYue New Energy. Learn about pouch cell batteries (2023)

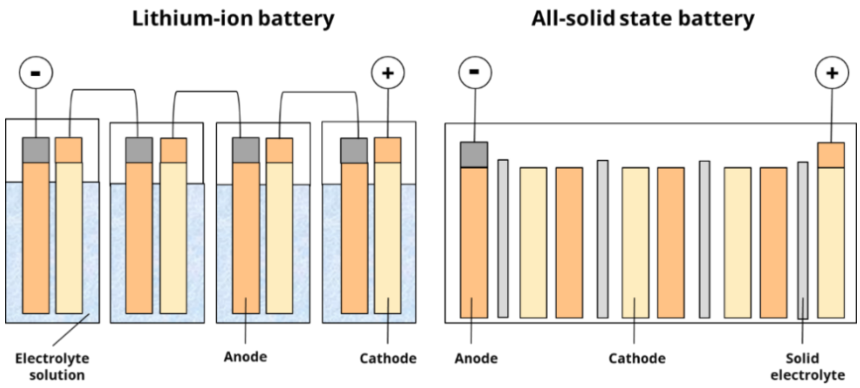
1.2.3 Solid State batteries

Unlike conventional lithium-ion batteries, which use liquid electrolytes, solid-state lithium-ion batteries (SSLBs) employ solid electrolytes (See Figure 1.3). This change enhances safety by reducing the risk of leakage and combustion associated with liquid electrolytes, and potentially increases energy density, making this type of battery safer for automotive applications.

SSLBs often use lithium metal anodes, which offer a higher energy density compared to graphite anodes. However, this requires high-purity lithium, which could increase the demand for this type of refined mineral. In terms of performance, challenges such as dendrite formation and interfacial stability need to be addressed to ensure reliable long-term performance.

SSLBs represent an advanced and promising technology for next-generation energy storage. For the solid electrolytes, various types are being explored, including sulphide-based, oxide-based, and polymer-based materials. The global solid-state battery market was valued at approximately USD $85.13 million in 2023 and is projected to grow to USD $1.4 billion by 2032, reflecting a compound annual growth rate (CAGR) of 38.75% during this period. This growth, particularly in the Asia Pacific region, is driven by strategic partnerships among solid-state battery companies and the increasing demand for consumer electronics.

Figure 1.3 Solid state vs conventional lithium-ion batteries



Source: Own elaboration

1.3 Lithium metal batteries

Lithium metal batteries have lithium metal anodes and have the potential to replace traditional graphite anodes, offering the promise of more energy-dense battery architectures and faster charging speeds. For this reason, Lithium metal is widely regarded as the ideal anode material for next generation secondary batteries.

However, integrating lithium metal anodes into battery systems requires a complete redesign of the battery cell. Currently, the use of Li-metal anodes result in several challenges, including degradation, instability in non-aqueous solvents, incompatibility with solid electrolyte chemistries, and the formation of lithium dendrites. These dendrites can crack the anode and disrupt the electrolyte interphase, among other issues, which have hindered the commercial adoption of this technology.

To address these challenges, research on modified solid electrolyte must be robust, focusing on improving safety, ensuring dendrite free performance, and extending the lifespan of lithium metal-based batteries. One potential solution is the reinforcement of the solid electrolyte layer with protective coatings to enhance stability.

The shift from graphite to lithium metal anodes could also significantly disrupt the global supply chain. As China is the world's largest producer of graphite, accounting for more than 77% of global production in 2023[7], replacing graphite with lithium metal would diminish China´s dominant position in the supply chain.

To advance the development of solid-state batteries with lithium metal anodes, substantial investment is needed. This includes tens of millions of dollars in grants and low-cost loan financing to establish pilot production lines and accelerate the path to commercialization.

1.4 Sodium-Ion Batteries (SIBs)

Initially developed in the United States and Europe, SIB´s are emerging again as a promising alternative to lithium-ion batteries, due to the abundant availability and lower cost of sodium compared to lithium (Sodium is about 1000 times more abundant than lithium). Valued at USD $0.86 billion in 2022, the sodium-ion battery market is expected to reach around USD $4.8 billion by 2032[8]. However, the industry lacks scale and maturity relative to lithium-ion batteries. Therefore, a winning set of sub-chemistries is yet to be determined for this type of batteries.

Hard carbon is the most commonly used anode material for SIBs. Other key components of SIBs cathodes include:

Sodium based layered transition metal oxides. Typically, the chemical formula of transition metal oxides is generally Na_xMO_2 where M is one or more of the 3d transition metal elements such as nickel, manganese, iron, cobalt and copper (in which $0 < x \leq 1$[9]). Recent

[7] *Statista, 2023. [Leading countries in based on mine production of graphite worldwide in 2023](#).*
[8] *Xiaoying, Y. (2024). China's position in the global race for alternative EV batteries. Dialogue Earth. Available at: https://dialogue.earth/en/business/chinas-position-in-the-global-race-for-alternative-ev-batteries/#:~:text=From%20UK%2Dbased%20Faradion%20to,to%20market%20analyst%20Precedence%20Research.*
[9] *Mingyi He, Shaomin Liu, Jiating Wu, Jinglin Zhu, Review of cathode materials for sodium-ion batteries, Progress in Solid State Chemistry, Volume 74, 2024, 100452, ISSN 0079-6786, https://doi.org/10.1016/j.progsolidstchem.2024.100452. (https://www.sciencedirect.com/science/article/pii/S0079678624000153)*

research has focused on improving the cycle life and performance of these materials. For instance, layered oxide cathodes are being optimized to address issues like irreversible phase transformation[10].

Sodium-based polyanionic compounds. These are special materials made up of sodium and certain types of negatively charged groups (polyanions) that contain metals and non-metals. Its structure is formed by strong covalent bonds with a three-site network structure, where sodium (Na+) is distributed in the network gap. The chemical formula is $Na_xM_y(XaOb)_zZw$, where:

> **M** is one or more of the valence metals including titanium, vanadium, chromium, manganese, iron, cobalt, nickel, calcium, magnesium, aluminium, niobium;
> **X** is phosphorus, sulphur, arsenic, silicon, boron, molybdenum, tungsten, germanium, etc.,
> **Z** is Fluorine, hydroxide, etc.

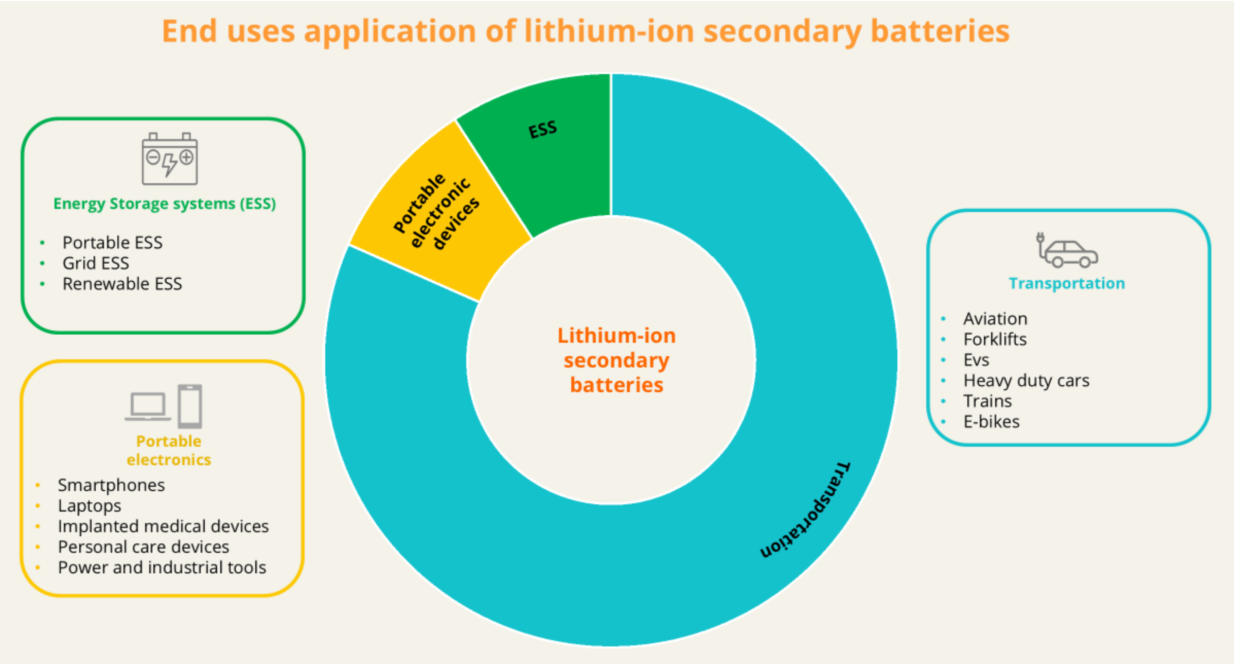
Polyanion cathode materials have strong application potential due to their strong three-dimensional arrangement which allow them to transfer energy effectively.[9]

SIBs are particularly attractive for large-scale energy storage and low-speed electric vehicle applications. They generally require more volume to achieve the same energy density as lithium-ion batteries.

1.5 End uses

The end use markets and their growth drive demand for new materials. The most common applications for secondary batteries include: i) Transportation; ii) Energy Storage Systems; and iii) Portable electronics, also referred to as the "3Cs" - computing, communications and consumer electronics. (See Figure 1.4)

Figure 1.4. End uses application for lithium-ion secondary batteries



Source: Own elaboration

[10] *When a transition metal ion exhibits Jahn-Teller distortion, it affects how well sodium ions can move around in the cathode during charging and discharging cycles. Li, Xin, Wang, Yan, Wu, Di, Liu, Lei, Bo, Shou-Hang, & Ceder, Gerbrand. Jahn–Teller Assisted Na Diffusion for High Performance Na Ion Batteries. United States. https://doi.org/10.1021/acs.chemmater.6b02440*

Although this project will focus on battery supply chain of EVs due to its dominance in the market, the following section provides a detailed overview of these applications.

1.5.1 Transportation

The electrification of the transportation sector has driven the widespread adoption of lithium-ion batteries (LIBs) across various subsectors, including aviation, electric vehicles (EVs), heavy-duty vehicles, trains, and two-wheelers. Each battery chemistry has distinct benefits and drawbacks depending on the specific application. For example, NMC batteries are favored for their high energy density, which enables longer driving ranges—an essential feature for EVs. In contrast, NCA batteries are preferred for their ability to support extended driving ranges, offering up to 1,000 charge cycles.

LFP batteries, while generally having shorter driving ranges due to their lower energy density compared to NMC and NCA, are expected to play a significant role in Asian markets, where daily driving ranges tend to be shorter than in the US and European markets. Recent advancements, such as solid-state lithium batteries (SSLBs) combined with lithium metal anodes, offer the potential for higher energy densities, significantly extending EV driving ranges.

Finally, SIBs (Sodium-Ion Batteries) are well-suited for low-speed electric vehicles like e-bikes, electric scooters, and certain types of electric buses due to their relatively low energy density compared to traditional LIBs.

1.5.2 Energy storage systems

These systems help balance supply and demand and are critical for integrating intermittent renewable resources into the power system by providing applications in energy and capacity management, ancillary services, and grid stability enhancement. Grid storage batteries are generally less sensitive to density, given that they are housed in large containers and are stationary. The most used battery chemistry in the ESS sector is LFP, primarily due to its lower cost and reliable performance. NMC batteries are expected to play a smaller role in grid energy storage due to the significant cost difference compared to LFP.

SSBs are particularly suitable for storing energy from intermittent sources like solar and wind, owing to their long cycle life and high energy density. Additionally, SSBs offer the advantage of operating safely at higher voltages and temperatures, without the risks of leakage or combustion, making them highly attractive for large-scale energy storage applications. SIBs are also well-suited for large-scale ESS, due to their cost-effectiveness and the abundance of sodium. They provide a long cycle life and stable performance under varying environmental conditions, further enhancing their potential in energy storage systems.

1.5.3 Portable Electronics (Computing, Communications and Consumer Electronics)

The consumer electronics sector encompasses a wide range of devices, including smartphones, tablets, laptops, power tools, industrial equipment, and medical and personal care devices. These technologies are widely used in applications ranging from household settings to industrial facilities, highlighting their versatility and ubiquity in modern life. Battery chemistries commonly used in this sector include LCO, NMC and others. The primary requirements for batteries in this sector are high energy density, followed by cost-effectiveness, as these factors directly impact device performance and affordability.

LCO batteries dominate the consumer electronics sector, accounting for 48% of the installed capacity, thanks to their cost effectiveness and high energy density. NMC batteries follow closely, representing 42% of the market share. They are increasingly utilized in power tools, where high performance in a compact size is crucial, along with their low self-discharge rate. LFP batteries are favoured in applications requiring reliable and durable power sources, especially in industrial settings. Their superior safety profile, resistance to thermal runaway, and ability to operate safely at high temperatures make them an ideal choice for such environments.

SSBs offer significantly higher energy densities and longer cycle lives, which translates into longer battery life and faster charging times. With the growing demand for miniaturized devices and higher battery capacities, SSBs are becoming an attractive option for smartphones, laptops, wearable devices, and implantable medical devices. Their compact size, enhanced energy density, and superior safety features align well with the needs of these advanced applications. The solid-state design also reduces the risk of fires or explosions, offering improved safety.

SIBs present a low-cost, safe alternative, particularly for applications where size and weight are less critical. These include household appliances, certain portable devices, power tools, forklifts, and industrial equipment, where their affordability and reliability make them an excellent choice. SIBs are also well-suited for use in uninterruptible power supplies (UPS) for data centers and hospitals, ensuring continuous power during outages[11].

1.6 Research and development

Research and development in the secondary battery industry focus on improving energy density, lifespan, safety, and cost-effectiveness, alongside advancements in manufacturing processes to enable scalable production. Increasing attention is also being given to reducing environmental impact through the development of efficient recycling technologies and the minimization or elimination of materials that compromise social and environmental wellbeing.

These efforts are driven by a collaborative ecosystem of private companies, academic institutions, government initiatives, and national agencies, all working together to innovate and meet the evolving demands of the industry. Indonesia could benefit from establishing partnerships with global players to help acquire the necessary technological expertise for producing advanced battery technologies. Such partnerships could support and promote nickel-based cell chemistries, rather than LFP chemistries.

There are multiple areas of research focused on exploring and advancing different battery chemistries. The following Table 1.1 presents strategic focus areas and advances:

Table 1.1 Summary of strategies and advances on battery chemistries

Focus areas	Advances
Research lines	• Development of nickel and cobalt free cathode materials[12] beyond the current generation of lithium batteries. • Enhancing the energy density of LFP batteries. • Improving safety through advancements in thermal stability for lithium-ion batteries • Extending battery lifespan by reducing anode and cathode degradation

[11] *Acculon energy. Sodium-Ion Batteries: A Sustainable Solution for Telecom Backup Power in the 5G Era. Available at: Sodium-Ion Batteries: A Sustainable Solution for Telecom Backup Power in the 5G Era - Acculon Energy*

[12] *Federal Consortium for Advanced Batteries. National blueprint for lithium batteries. Executive summary. Available at: National Blueprint for Lithium Batteries 2021-2030 (energy.gov)*

Focus areas	Advances
	• Improve the stability of Li-metal anodes for all working conditions • Development of solid-state battery technology to overcome limitations of current LIBs.[13] Major companies involved in R&D of SSLB + lithium metal anodes include: Illika, QuantumScape Corporation, Toyota motor corporation, TDK Corporation, Solid Power, LG, Chem, Panasonic Corporation, Samsung SDI Co. • Innovative battery recycling methods and materials, focusing on extracting valuable materials (e.g. lithium, iron, and phosphate [14]) from used batteries
Innovation hubs supported by governments	Germany • Fraunhofer Institute for Systems and Innovation Research ISI, supported by the Federal Ministry of Education and Research U.S. (Department of Energy) • Energy Storage Research Alliance (ESRA): Led by Argone National Laboratory • Aqueous Battery Consortium (ABC): Led by Standford University[15]. China • Energy Storage R&D Center at the Institute of Engineering Thermophysics. Chinese Academy of Sciences. • Over USD $830 million in grants for solid-state battery technology projects in 2024, benefiting six companies: CATL, BYD, Tesla, FAW, SAIC, and Geely.
Strategic Alliances	USA • BlueOval Battery Park: A collaboration between Ford and CATL, involving a 3.5 billion of investment in Michigan, USA. The facility will focus on LFP battery manufacturing creating 2500 jobs commencing production in 2026 [16] • General Motors and CATL partnership: Joint development of an ultra-fast charging LFP battery[17] to be launched in 2025. China • Multiple joint ventures between automakers and battery manufacturers, aimed at accelerating the adoption and development of cutting-edge battery technologies.

1.7 Battery technologies comparison and future state

Among the various types of LIBs, NMC and NCA are currently the most material-intensive, relying on scarce and expensive elements such as nickel and cobalt. As a result, batteries using these chemistries face higher production costs and potential supply chain risks due to the materials involved.

In contrast, LFP batteries offer a more sustainable and cost-effective alternative to NMCs and NCAs, especially in markets focused on affordability and safety. This is due to the abundance and low costs of iron.

SSLBs, which utilize solid electrolytes, promise higher energy density and enhanced safety, potentially revolutionizing the battery market once technical and manufacturing challenges are overcome. SSLBs could deliver superior performance in EVs and other high-demand applications. However, similar to conventional LIBs, SSLBs still rely on the same key minerals, which exposes them to supply chain risks. While technologies such as NMC, NCA, and LFP have reached full maturity with a technology readiness level (TRL) of 9, SSLBs are still in the development phase, with a TRL of 5. Ongoing advancements in

[13] *TopSpeed, 2024. The Real Story Behind Toyotas 745-Mile Solid-State Battery. Available at: [The Real Story Behind Toyotas 745-Mile Solid-State Battery (msn.com)]*

[14] *Energy Central 2024. Latest Battery Breakthroughs: The Role of LFP Technology in Sustainable Energy. Available at: [Latest Battery Breakthroughs: The Role of LFP Technology in Sustainable Energy | Energy Central]*

[15] *USCOE. Department of Energy Awards $125 Million for Research to Enable Next-Generation Batteries and Energy Storage. Available at: https://www.energy.gov/science/articles/department-energy-awards-125-million-research-enable-next-generation-batteries-and*

[16] *Ford, 2023. BLUEOVAL Battery Park Michigan. Available at: https://corporate.ford.com/operations/blue-oval-battery-park-michigan.html*

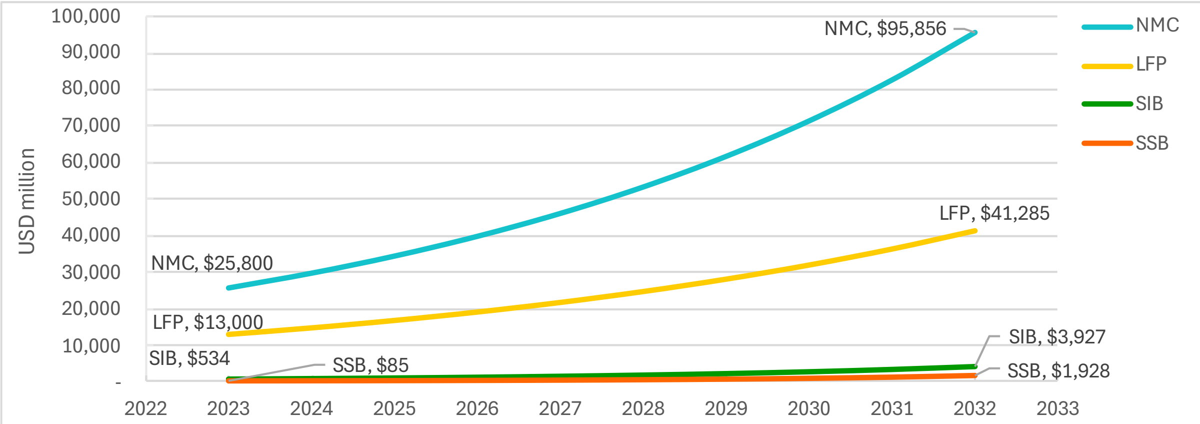
[17] *GMAuthority, 2024. SAIC-GM and CATL launch fastest-charging EV battery so far. Available at: https://gmauthority.com/blog/2024/09/saic-gm-and-catl-launch-fastest-charging-ev-battery-so-far/*

battery technology aim to balance performance, cost, and environmental impact. Both SSLB and SIB remain in early stages of market development, with market sizes still relatively small compared to NMC and LFP.

Currently, LIBs dominate the global market, particularly in electric vehicles (EVs) due to their high energy density and efficiency. On the other hand, SIBs offer advantages such as lower cost, reduced risk of thermal runaway, and a lower environmental impact compared to traditional LIBs. However, the SIBs industry lacks the scale and maturity necessary to compete with established LIB technologies.

When comparing the market size of LIBs and SIBs, it is clear that, despite the technical advantages of SIBs, they are still far from competing with LIBs on a commercial scale. As shown in Figure 1.5, projections indicate that while the market size for both SSLB and SIB will continue to grow, they are unlikely to become competitive with NMC and LFP over the next decade.

Figure 1.5 Global market size for selected batteries, outlook and forecast (2023-2032)



Source: Own elaboration[18]

Despite the growing popularity of iron-based lithium-ion batteries like LFP and LMFP, especially in cost-sensitive and safety-critical applications, the figure suggests that LIBs, particularly nickel-based chemistries like NMC and NCA, will continue to dominate the market. This is driven not only by demand but also by the availability of resources, with current global reserves projected to be sufficient to produce nearly 2.5 billion batteries.

Finally, while SIBs are being explored as a sustainable and cost-effective alternative—especially for large-scale energy storage systems—their market size is expected to remain relatively small in the foreseeable future.

[18] *Data sources for each battery market: **LFP**. MarketsandMarkets, 2023. Lithium Iron Phosphate Batteries Market Size to Reach USD $24.6 Billion, at a 13.7% CAGR by 2027. Lithium Iron Phosphate Batteries Market Size to Reach USD $24.6 (globenewswire.com). **NMC.** Global market insights. Nickel Manganese Cobalt (NMC) battery Market Size - By Application (Automotive, Energy Storage, Industrial), By Regional Outlook & Forecast, 2024 – 2032. Available at: Nickel Manganese Cobalt (NMC) Battery Market Size, 2032 Report (gminsights.com). **SIB.** Sodium-Ion Battery Market Size, Share & Trends Analysis Report By Type (Sodium-Sulfur Batteries, Sodium-Salt Batteries (Zebra Batteries), Sodium-oxygen (Sodium Air) Batteries), By Technology (Aqueous, Non-aqueous), By Application (Energy Storage and Grid Integration, Electric Vehicles (EVs), Residential Energy Storage, Emergency Backup And UPS, Others) and By Region(North America, Europe, APAC, Middle East and Africa, LATAM) Forecasts, 2024-2032. **SSB.** Fortune Business insights. Solid-state battery market size, share and Industry analysis, by type (single layer and multilayer), by application (consumer electronics, electric vehicles, medical devices, and others), and regional forecast, 2024-2032. Available at: Solid-State Battery Market Size, Share, Growth | Forecast [2032] (fortunebusinessinsights.com)*

2 Battery Supply Chain

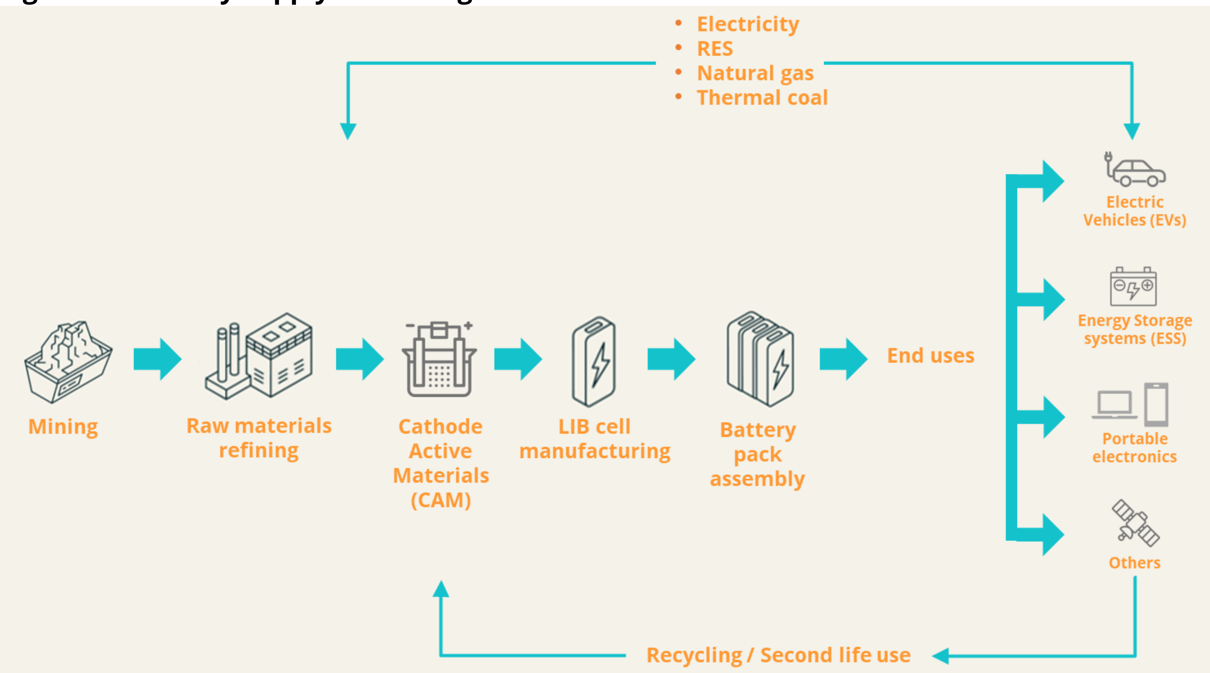
2.1 LIB Supply Chain Structure

The following section provides an overview of the current global state-of-play of the battery supply chain, with main players along the supply chain identified where possible.

2.1.1 Features of the Supply Chain

Lithium-ion battery (LIB) supply chain comprises five stages: mining, refining, cathode production (CAM), cell manufacturing and assembly (LIB cell), and finally end uses (See Figure 2.1). This last link of the supply chain can also be broken down into uses: Transportation (also Electric Vehicles), Energy Storage Systems (ESS), Portable Electronics (3Cs) and finally other uses. LIB supply chain can also be described as "upstream" and "downstream". Typically, mining and refining are considered "upstream" activities, while from CAM to end uses are considered "downstream".

Figure 2.1 Battery supply chain stages



Source: Own elaboration

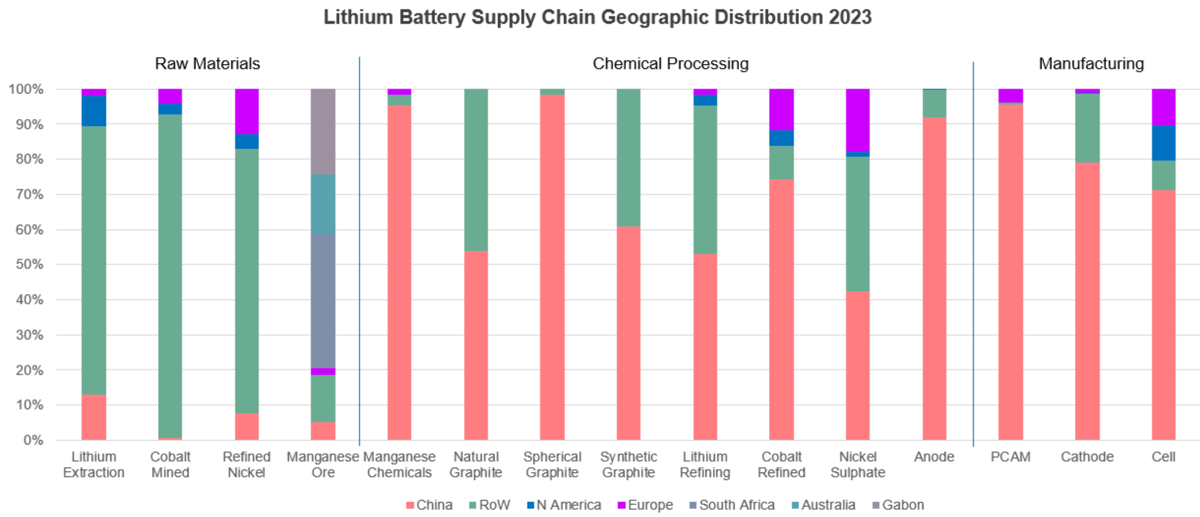
The conventional lithium-ion battery supply chain is characterized by its complexity and geographical concentration, especially in Asia. Due to the high level of concentration on several nodes of the battery supply chains, they can rapidly be disrupted by regulatory changes, trade restrictions, or political instability in a few countries. Export bans like the one implemented on nickel ore from Indonesia or by Zimbabwe on chromium ore are examples of how policy changes affect production, trade and investment[19].

Each key mineral has a unique trade geography, creating a web of interdependence among nations. Countries depend on a global market for key materials and technologies, either through imports or steady demand for their products. Trade patterns vary widely,

[19] *U.S. International Trade Commission (USITC) (2024) Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel. Available at: https://www.usitc.gov/publications/332/working_papers/ermm_indonesia_export_ban_of_nickel.pdf*

highlighting the interdependence in mineral supply and demand.[20] However, it is the geographical concentration of refining, cathode production and cell manufacturing in China (Figure 2.2) which represents the largest challenge concerning resources security and geopolitical dynamics.[21]

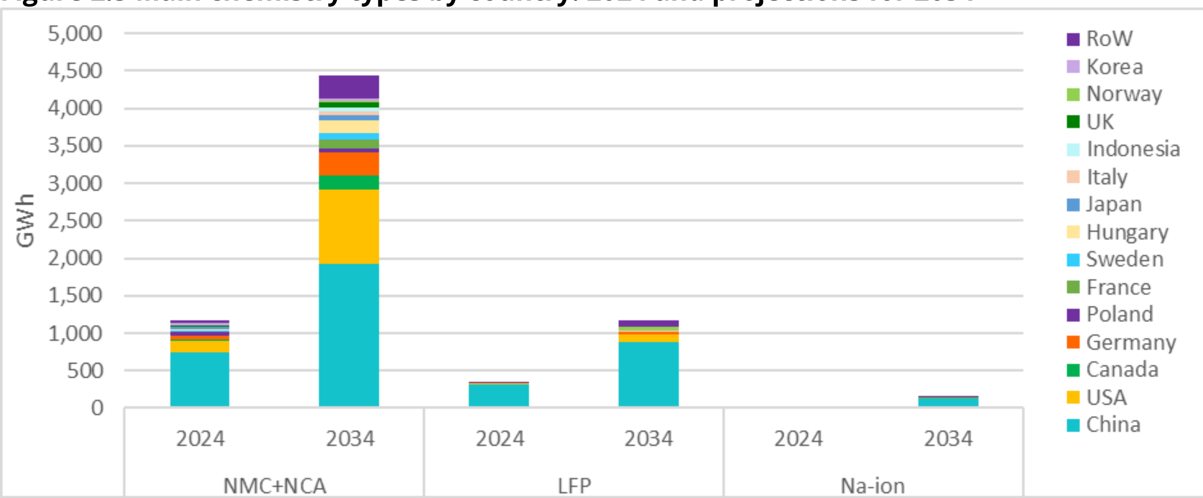
Figure 2.2 Geographic Distribution of LIB Supply Chain



Source: Supply Chain Insights 2024, 'Lithium Battery Supply Chain Geographic Distribution 2023'. China currently dominates the Lithium-ion supply chain in processing and manufacturing.

As elaborated in Section 0 above, nickel-based (NMC and NCA) and iron-based (LFP) lithium-ion batteries are categorized as conventional lithium-ion batteries. In contrast, lithium-metal batteries have not yet reached the same level of maturity as these conventional batteries. The same applies to sodium-ion and solid-state battery technology. This situation is presented in the next figure, that clearly portrays the share of the most significant chemistries in the market: NMC and LFP. For the transportation sector, NMC represents more than 60%, while LFP represents 30% of the market. The figure also shows how China dominates and will continue to dominate the NMC/NCA and LFP market, however, it also shows Indonesia's opportunity to play a role in the NMC/NCA market in the next decade.

Figure 2.3 Main chemistry types by country: 2024 and projections for 2034

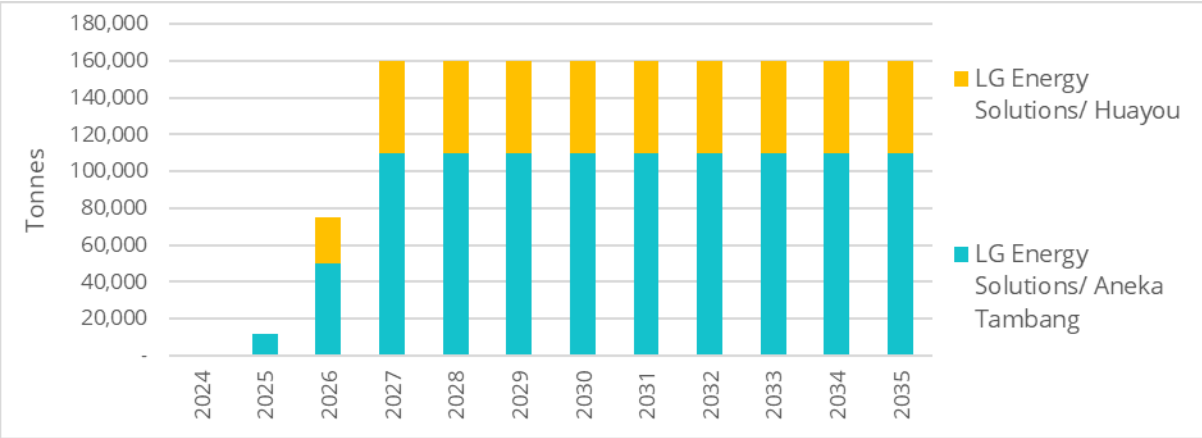


Source: SC Insights

[20] *International Renewable Energy Agency (IRENA), Geopolitics of the Energy Transition: Critical Materials (IRENA 2023), p. 16.*
[21] *ibid., p. 23.*

The Indonesian cathode space has an enormous potential, with very limited installed cathode capacity. This is a significant concern since the sector procuring battery materials is cathode space. However, two interesting projects in Indonesia will add a combined capacity of close to 160,000 tons of cathode during the next ten years, the largest one being LG Energy Solutions/Aneka Tambang (Figure 2.4). The cathode space will be analyzed in detail in the following sections.

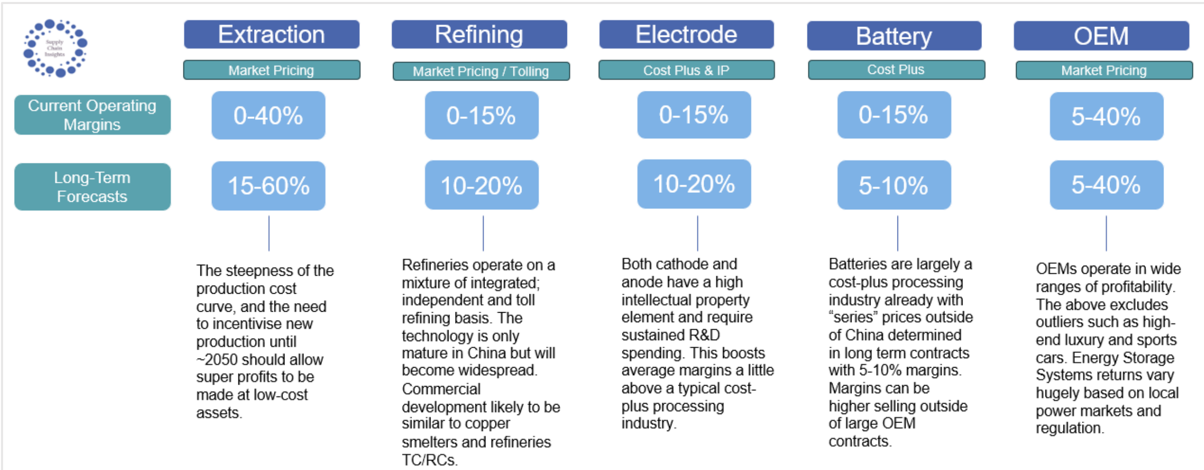
Figure 2.4 LG Energy Solution announced NMC cathode production in Indonesia



Source: SC Insights

Additionally, the estimated operating margins throughout LIB supply chains show that both the extraction and the original equipment manufacturing (OEM) operate under wider profitability ranges, as shown in Figure 2.5. The notable upsurge of margins on both ends of the LIB supply chain (Extraction and OEMs), make increasable important for large car corporations to monitor price of battery materials. Historic price upsurge of cobalt, then nickel and finally lithium have created incentives for OEMs so integrate themselves upstream. This has been the case of emblematical Chinese players such as CATL and BYD, whose role in securing raw materials has increase in the last years. Similarly, these companies pay extra care to keep the margins of refining and CAM under control.

Figure 2.5 Margin estimation for the entire LIB Supply Chain



Source: SC Insights

2.1.2 Decarbonization targets

Global battery demand has risen significantly over the last decade[22], primarily driven by ambitious emission reduction targets and decarbonization objectives. This shift has led to the implementation of favourable policies and legislative frameworks that promote electrification as a key strategy for achieving decarbonization. In this context, electrification refers to replacing fossil fuel-based technologies with electric alternatives, which are generally more efficient and help reduce energy consumption. As the electricity grid becomes greener with increasing amounts of renewable energy sources, these electric replacements also lead to substantial emissions reductions.[23]

For example, the European Union (EU) has enacted legislation banning the sale of new internal combustion engine vehicles[24], while the United States (US) has set a target for electric vehicles to make up 50% of new sales by 2030[25]. These ambitious goals have spurred action at the corporate level, with several automakers announcing their own electrification targets. [26]

However, these policies are not without controversy. The EU's ban on internal combustion engine cars is currently facing challenges, particularly from Germany, which is advocating for an exception that would permit the sale of internal combustion engine vehicles powered by synthetic fuels.[24]

Recently, many global automotive manufacturers have been revising their electrification targets downward, due to a moderate growth of demand and the unexpected growth in PHEV sales (compared to BEV sales). This decline can be attributed to a lack of affordable models, slow progress in charging infrastructure deployment, escalating trade tensions, and increased competition from more cost-effective Chinese manufacturers, as further examined in this section. Additionally, similar policy and legislative measures have been implemented to support the uptake of battery energy storage systems, facilitating the integration of variable renewable energy sources into the electricity grid.[27]

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[22] *See, inter alia, International Energy Agency (IEA), Global EV Outlook 2024 (IEA Publications 2024), p. 78; J Fleischmann, P Schaufuss, M Linder, M Hanicke, E Horetsky, D Ibrahim, S Jautelat, L Torscht and A van de Rijt, 'Battery 2030: Resilient, sustainable, and circular', January 16, 2023, McKinsey & Company, available at https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-2030-resilient-sustainable-and-circular#/; E Silva, 'Competition for lithium supply heating up between stationary storage, EVs' October 24, 2023, S&P Global, available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/competition-for-lithium-supply-heating-up-between-stationary-storage-evs-77931334*

[23] *One such example is replacing internal combustion engines with electric vehicles. See, e.g., P Aalto (ed.), Electrification: Accelerating the Energy Transition, 1st edition (Elsevier 2021). See also IEA, Global EV Outlook 2024 (IEA Publications 2024), p. 12.*

[24] *Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increase climate ambition, OJ L 110, 25.4.2023, p. 5-20. See, e.g., T Lecca, 'EU should allow 'climate-friendly' fuel cars after 2035, says Germany's Lindner' April 10, 2024, Politico.*

[25] *Executive Order 14037 on Strengthening American Leadership in Clean Cars and Trucks, August 05, 2021.*

[26] *IEA, Global EV Outlook 2023 (IEA 2023), pp. 90-91. See, e.g., 'Carmakers scale down electrification plans as EV demand slows' September 12, 2024, Reuters, available at https://www.reuters.com/business/autos-transportation/carmakers-adjust-electrification-plans-ev-demand-slows-2024-09-06/; M Wayland, 'EV euphoria is dead. Automakers are scaling back or delaying their electric vehicle plans' March 13, 2024, CNBC, available at https://www.cnbc.com/2024/03/13/ev-euphoria-is-dead-automakers-trumpet-consumer-choice-in-us.html*

[27] *For example, in the US see FERC Order No. 841, Electric Storage Participation in Markets operated by Regional Transmission Organizations and Independent System Operators (issued February 15, 2018); in the EU, see Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, OJ L 158, 14.6.2019, p. 125-199 and Commission Recommendation of 14 March 2023 on Energy Storage – Underpinning a decarbonised and secure EU energy system C(2023)1729, OJ C 103, 20.3.3023, p. 1-5.*

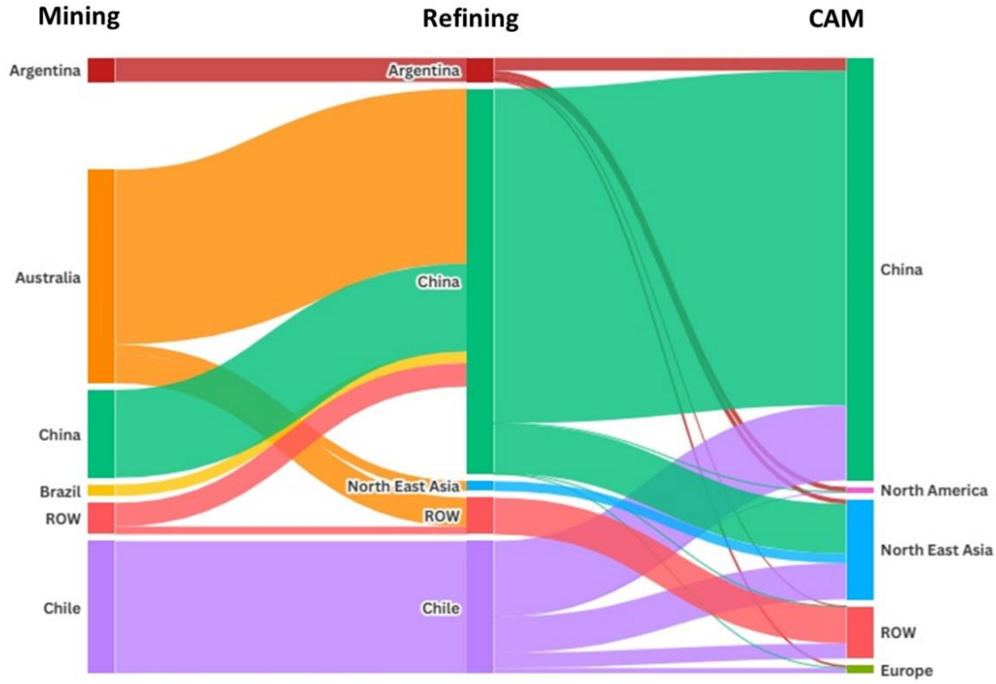
Decarbonization targets, coupled with challenges arising from the post-COVID-19 landscape and concerns over Russian nickel sources amidst Russian invasion of Ukraine and western sanctions have placed significant stress on the conventional lithium-ion battery supply chain over the years[28]. The situation has been further exacerbated by a persistent lack of investment in expanding supply capacity.

2.2 Trade flows for critical materials

This section presents the trade flows throughout the LIBs supply chain stages the critical minerals i.e., lithium, cobalt, manganese, nickel and graphite. In addition, the global import-export trade flows of materials without filtering the volumes destined exclusively to the battery industry are presented in Annex 3. Sankey diagrams for overall trade flows of materials. In that Annex the Sankey diagrams for materials like Aluminium, Iron and Sodium can be found. It is important to notice that such materials are considered commodities since its usage ranges within many industries and the volumes destined to battery production are quite small compared to the total globally traded volume.

Lithium feedstock comes primarily from Australia, in the form of spodumene concentrate, then Chile. The particularity of Australia is that spodumene concentrate gets further refining in China, as opposed to Chile, where refining capacity for both lithium carbonate and lithium hydroxide has been built accordingly throughout the years. In the case of lithium, Energy Storage represents 82% of the total demand. Lithium trade flows using trade stats are depicted below:

Figure 2.6 Trade flows of Lithium throughout LIBs supply chain stages



Source: Own elaboration

[28] *International Energy Agency (IEA), Global Supply Chains of Batteries (IEA Publications 2022), p. 15.*

In line with the latter flow diagram, the evolution of lithium supply has been the following:

Table 2.1 Lithium supply and growth rate

Item	Unit	2018	2019	2020	2021	2022	2023	CAGR
Lithium Supply	kMT-LCE	202	290	333	479	620	844	-
Growth Rate	%	-	43%	14%	43%	29%	36%	33%

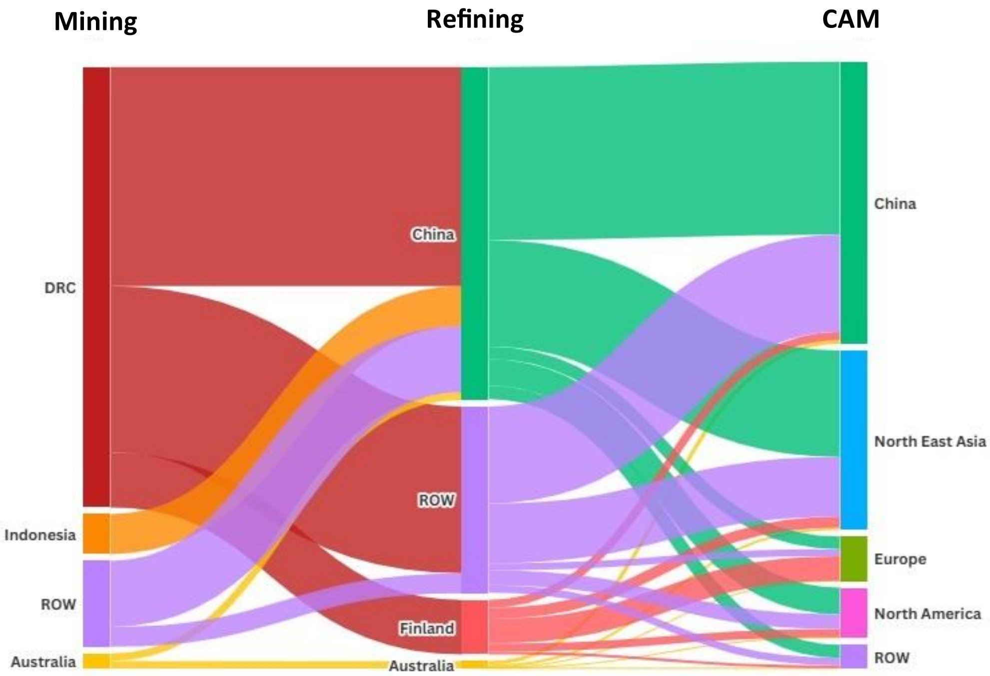
The three largest producers of lithium feedstock are Australia (42%), Chile (26%) and China (18%). In terms of exports, Australia exports 82% of its spodumene concentrate to China (302 kMT-LCE of spodumene concentrate), while the remaining 18% is split between RoW and internal consumption. In the case of Chile, the country exports 57% to China (130 kMT-LCE) and 27% to Northeast Asia (62 kMT-LCE to NEA). The case of China is different since from the production of lithium chemicals only a 13% gets exported (88 kMT-LCE), while the rest remains inland (577 kMT-LCE). The raw material codes used on several trade databases for its Sankey diagram are the following:

Table 2.2 Lithium codes used for Sankey diagram

Source	Code	Description	LIB Supply chain	Finished product	Notes
AHECC	25309011	Lithium concentrates	Lithium feedstock	No	Australian code for spodumene concentrate
HS	25309093	Mineral substances not elsewhere specified or included	Lithium feedstock	No	Former Australian code for spodumene concentrate
HS	26179000	Spodumene concentrate grade	Lithium feedstock	No	SC7%
NCM-SIM	2836.91.00.000G	Lithium carbonate	Lithium feedstock	No	Argentinian customs
SACH	28369130	Lithium carbonate	Battery Grade and Technical Grade	Yes	Chilean customs
SACH	28252011	Lithium hydroxide	Battery Grade and Technical Grade	Yes	Monohydrate

Cobalt feedstock production is concentrated in the Democratic Republic of Congo (DRC), accounting for more than three quarters of the total global supply of ore. This supply is quite scattered in the country, but most importantly, it does not have the adequate refining capacity inside the country. Therefore, it has to be further refined primordially in China and Finland. After refining there is an important portion that stays in China (73,000 MT-Co), although a significant flow stream (45,000 MT-Co) ends up in Korea and Japan. In addition, Northeast Asia also obtains refined cobalt from other suppliers globally. In the case of cobalt, Energy Storage represents 49% of total demand. Cobalt trade flows using trade stats are depicted below:

Figure 2.7 Trade flows of Cobalt throughout LIBs supply chain stages



Source: Own elaboration

In line with the latter flow diagram, the evolution of cobalt supply has been the following:

Table 2.3 Cobalt supply and growth rate

Item	Unit	2018	2019	2020	2021	2022	2023	CAGR
Cobalt Supply	kMT-Co	118	137	134	153	165	180	-
Growth Rate	%	-	16%	-2%	14%	8%	9%	9%

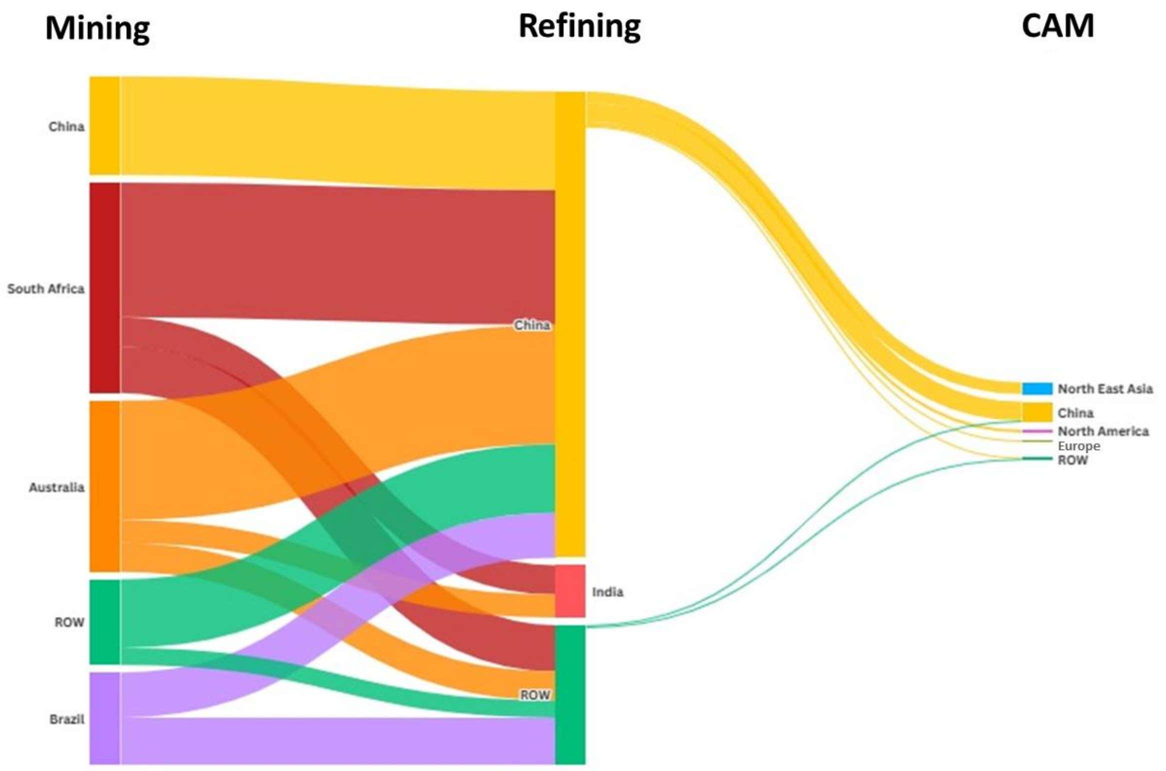
The three largest producers of cobalt feedstock are the Democratic Republic of Congo (DRC) (76%), then Indonesia (7%) and finally Australia (3%). According to trade data, the DRC exports to China account for 49% of the total (92 kMT-Co), with other exports being shipped to Finland (12% equivalent to 23 kMT-Co), and the remaining to the RoW (37% equivalent to 70 kMT-Co). Next, Indonesia accounts for 17 kMT-Co that are mainly destined to China. Third, Australia which brings 6.3 kMT-Co to the market, evenly split by destination (China and Australia for further refining). The raw material codes used on several databases for its Sankey diagram are the following:

Table 2.4 Cobalt codes used for Sankey diagram

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	26050000	Cobalt ores and concentrates	PCAM/CAM feedstock	No	-
HS	28332990	Cobalt sulphate	PCAM/CAM feedstock	Both	Inorganic chemicals; organic or inorganic compounds
HS	282200	Cobalt oxides and hydroxides	Cobalt feedstock	No	Includes commercial oxides
HS	8105 2000 00	Cobalt mattes and other intermediate	Feedstock for CoSO4	No	Products of cobalt metallurgy and powders

Manganese feedstock production is concentrated among four countries: South Africa (32%), Australia (26%), China (15%) and Brazil (14%). As opposed to lithium and cobalt markets, Energy Storage is just a minor share of total demand, accounting for only 6% of total consumption. The main producer of Medium-Purity Manganese Sulfate Monohydrate (MPMSM) for cathode production is China, with a small portion coming from Europe and Mn recycling. Manganese trade flows using trade stats are depicted below:

Figure 2.8 Trade flows of Manganese throughout LIBs supply chain stages



Source: Own elaboration

In line with the latter flow diagram, the evolution of manganese MPMSM supply has been the following:

Table 2.5 Manganese MPMSM supply and growth rate

Item	Unit	2018	2019	2020	2021	2022	2023	CAGR
Manganese MPMSM Supply	kMT-Mn	33.8	36.5	62.0	91.8	105.5	121.0	-
Growth Rate	%	-	8%	69%	41%	15%	15%	29%

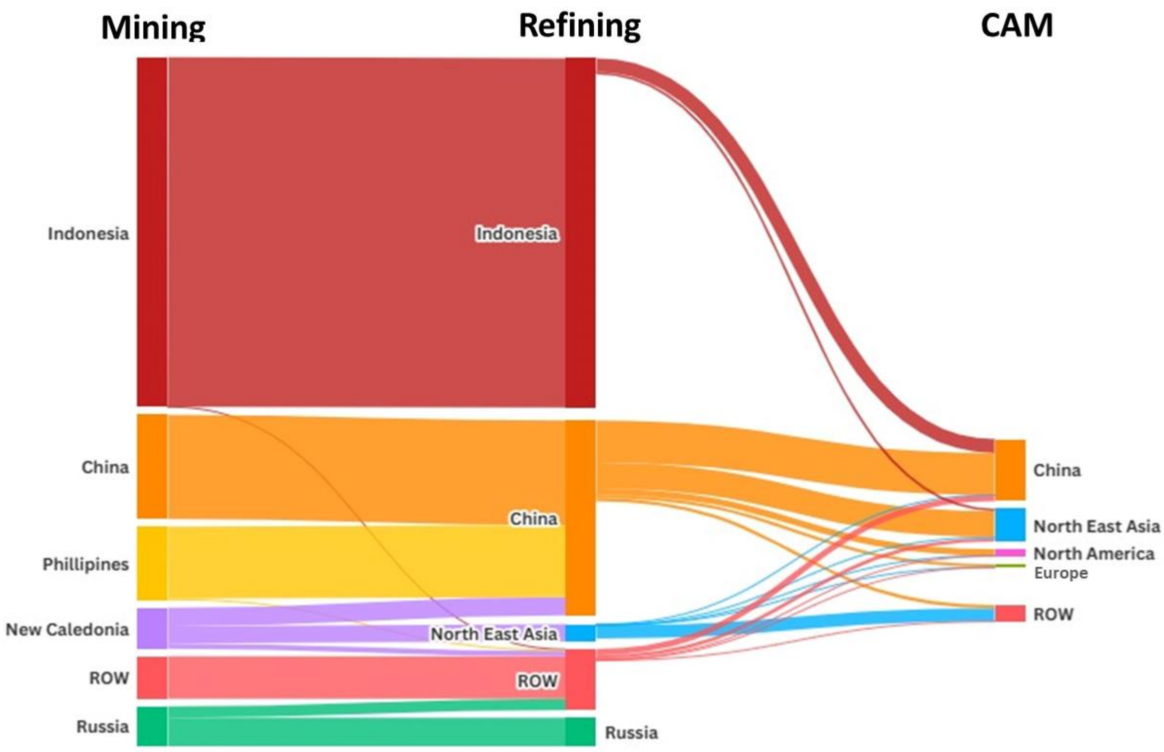
From a total production of 644 kMT-Mn, South Africa exports 64% of those raw materials to China (412 kMT-Mn). Secondly, Australia is the second largest producers accounting for 524 kMT-Mn of manganese ores and exporting 69% if their production to China (365 kMt-Mn). Finally, China who produces a bit more than 300 kMT-Mn but received more than 1,125,000 kMT-Mn from other locations. However, the amount converted to manganese sulphate for battery applications is way less than what China received, only accounting for 110 kMT-Mn. The raw material codes used on several databases for its Sankey diagram are based on ores and sulphates, with their correspondent detail below:

Table 2.6 Manganese codes used for Sankey diagram

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	260200	Manganese ores and concentrates	Feedstock for MnCO3, MnSO4	No	-
HS	283322940	Manganese sulphate	PCAM/CAM feedstock	Yes	Hydrate, monohydrate, tetrahydrate

The nickel market for Energy Storage is quite similar to manganese; only a small portion of refined products end up consumed by this specific sector (18%). The latter means that in case of a sudden shock of demand, there is no bottleneck to source feedstock of nickel for producing nickel sulphate. Plenty of pellets, brickettes, matte, oxides and even powders can be reconverted into sulphate, where countries like Indonesia, China, Russia and Philippines have a leading role. Nickel trade flows using trade stats are depicted below:

Figure 2.9 Trade flows of Nickel throughout LIBs supply chain stages



Source: Own elaboration

In line with the latter flow diagram, the evolution of nickel sulphate has been the following:

Table 2.7 Nickel sulphate supply and growth rate

Item	Unit	2018	2019	2020	2021	2022	2023	CAGR
Nickel Supply	kMT-Ni	191	220	356	498	572	639	-
Growth Rate	%	-	15%	62%	39%	15%	12%	27%

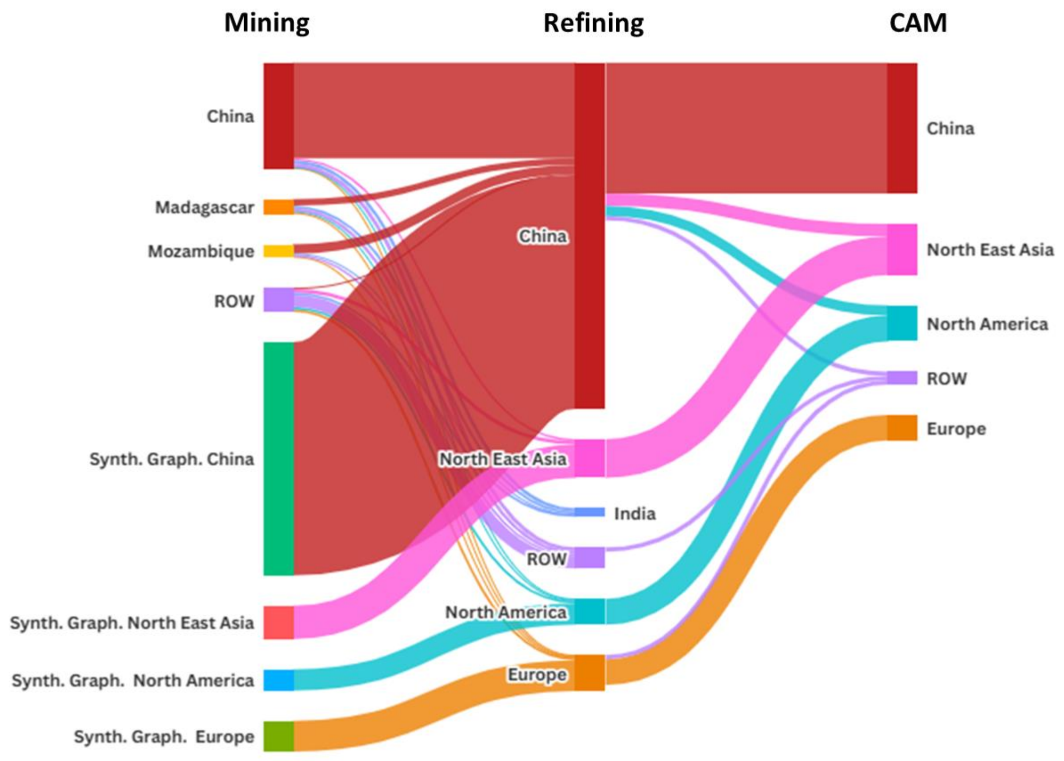
The nickel is significantly larger in volumes compared to lithium, cobalt and manganese, consequently with a significantly larger portion of raw material consumed by the industrial sector. The raw material nickel market in 2023 reached 3,400,000 MT-Ni contained, with the battery sector only reaching 640,000 MT-Ni contained in the shape of nickel sulphate. The largest producers are Indonesia (1,830,000 MT-Ni), followed by China (550 kMt-Ni), and finally Phillipines (384 kMT-Ni). China produces 420 kMT-Ni in the shape of nickel sulphate for the battery market, however 52% of that stays in China for local consumption (220 kMT-Ni of Ni2SO4). The raw material codes used on several databases for its Sankey diagram are based on ores and sulphates, with their correspondent detail below:

Table 2.8 Nickel codes used for Sankey diagram

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	26040000	Nickel ores and concentrates	Feedstock	No	Saprolite and limonite should go under this category
HS	28332400	Nickel sulphate	PCAM/CAM feedstock	Both	Other sulphates of nickel

The graphite market is quite a particular one, in the sense that feedstock material can be sourced either from natural (natural flake graphite) or synthetic sources (refining of pet coke). Despite having a smaller portion of the supply, the production of flake graphite can be traced using trade stats, as opposed to synthetic refined graphite which process is competed in the country of origin. Similarly, the demand of graphite for battery applications (basically the production of anodes) tends to be biased towards synthetic (68%), while demand for graphite using further refined natural flake has a smaller share (27%). Graphite trade flows using trade stats are depicted below:

Figure 2.10 Trade flows of Nickel throughout LIBs supply chain stages



Source: Own elaboration

With regards to natural graphite, the main producer globally is China (67%), then followed by Madagascar (9%) and Mozambique (8%). From a total production of 920-kMT, China only exports 90 kMT abroad (10% of production). The latter is important since Chinese exports are well diversified between Northeast Asia, India, Europe and North America. Next, Madagascar and Mozambique export close to 280 kMT combined. For artificial or synthetic graphite, the volumes produced by China are significantly larger reaching 2,000,000 MT, while Northeast Asia, North America and Europe produce above 700 kMT combined. Sankey diagram are based on both natural flake and synthetic graphite:

Table 2.9 Graphite codes used for Sankey diagram

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	250410	Flake or Powder graphite	Feedstock for Anode	Both	Natural graphite
HS	25041010	Flake or Powder graphite	Feedstock for Anode	Yes	Crystaline
HS	25041020	Flake or Powder graphite	Feedstock for Anode	No	Amorphous
HS	38011000	Artificial graphite	Related	No	Paste, block, plates, or other-semimanufactures
HS	38012000	Artificial graphite	Related	No	Colloidal or semi-colloidal
HS	38013000	Artificial graphite	Related	No	Carbonaceous paste

2.3 Battery Materials

This section focuses on lithium, nickel, cobalt, graphite and manganese – the main battery materials required for lithium-ion batteries as identified above in Section 1.

2.3.1 Lithium mining

Lithium is traditionally extracted from two main sources: brine processing and hard rock mining.[29] Lithium-rich brine is found in underground reservoirs beneath salt flats, primarily in South America (Chile, Argentina and Bolivia), North America and China (Qinghai–Tibet Plateau).[30]

Brine is pumped and concentrated in large ponds in order to extract valuable salts: halite, bischofite, sylvinite, and finally lithium chloride in solution. The latter is further purified and carbonated to produce lithium carbonate (battery grade), which can be further processed to lithium hydroxide.

In hard rock mining, lithium is preferably extracted from spodumene, due to the high grade and competitive cost. This mineralogy species is quite abundant, and globally widespread. Close to half of the raw materials for the production of lithium chemicals come from Australia, with additional spodumene concentrate being produced in South America (Brazil), Africa (Zimbabwe and others), China, and North America.[31] Production process involves concentration, calcination, purification and chemical precipitation (lithium carbonate and/or hydroxide.

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[29] *B Tadesse, F Makuei, B Albijanic, L. Dyer, 'The beneficiation of lithium minerals from hard rock ores: a review' 131 Minerals Engineering (2019), pp. 170-184.*
[30] *See, e.g., S Agmad, 'The Lithium Triangle: Where Chile, Argentina, and Bolivia Meet' January 15, 2020, Harvard International Review, available at https://hir.harvard.edu/lithium-triangle/*
[31] *IEA, Global Supply Chains of Batteries (IEA Publications 2021), p. 21.*

In addition to these two main sources, lithium chemicals can also be obtained from clays or low-grade ores such as lepidolite. The Chinese refining industry is highly specialized in the refining of lepidolite in Yichun, nevertheless with high cost.

Table 2.10 The world's 9 largest lithium mines

Rank	Asset Name	Geographical sub-region	Location	Owner	Production in 2023
1	Greenbushes Lithium Operations	Australia and New Zealand	Western Australia, Australia	Albemarle	176 kt-LCE
2	Salar de Atacama Mine	South America	Antofagasta, Chile	SQM	170 kt-LCE
3	Pilgangoora	Australia and New Zealand	Western Australia, Australia	Pilbara Minerals	78 kt-LCE
4	Salar de Atacama Mine	South America	El Loa, Chile	Albemarle	53 kt-LCE
5	Mount Marion	Australia and New Zealand	Western Australia, Australia	Mineral Resources	52 kt-LCE
6	Wodgina	Australia and New Zealand	Western Australia, Australia	Albemarle	28 kt-LCE
7	Salar de Hombre Muerto	South America	Catamarca, Argentina	Arcadium Lithium	22 kt-LCE
8	Mt Cattlin	Australia and New Zealand	Western Australia, Australia	Tianqi Lithium	18 kt-LCE
9	Salar de Olaroz	South America	Jujuy, Argentina	Arcadium Lithium	14 kt-LCE

[Mtpa]: million tonnes per annum; [kt]: Thousand tonnes

In terms of global lithium reserves, Chile, Australia, and Argentina have the largest deposits. Most Australian lithium goes directly to China; however, Indonesia could benefit from focusing on securing a reliable supply of lithium ore to develop the national battery industry.

Table 2.11 Lithium reserves

Rank	Country/Region	Global reserves [%]	Metric tonnes
1	Chile	34%	9,300,000
2	Australia	22%	6,200,000
3	Argentina	13%	3,600,000
4	China	11%	3,000,000
5	US	4%	1,100,000
6	Canada	3%	930,000
7	Brazil	1%	390,000
8	Zimbabwe	1%	310,000
9	Portugal	0.2%	60,000
10	Other countries	10%	2,800,000
	World total (rounded)	**100%**	**28,000,000**

Source: U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geologigal Survey 2024).

2.3.2 Nickel mining

Nickel is found in various locations around the world, primarily in two types of ore deposits: sulfide deposits and laterite deposits.[32] Sulfide deposits usually contain higher grade nickel and is therefore more efficiently refined into high-grade nickel suitable for batteries. Sulfide deposits include Sudbury in Canada, Norilsk in Russia and Western Australia. Laterite deposits require a more intensive refining to be converted into battery-grade

[32] *See, e.g., Nickel Institute, 'Nickel industry – Part 1 – Processing nickel laterites and sulfides' May 03, 2024, available at https://nickelinstitute.org/en/blog/2024/may/nickel-industry-part-1-processing-nickel-laterites-and-sulfides/*

nickel. Laterite deposits are found in tropical regions: Indonesia,the Philippines and New Caledonia (See Table 2.12).[33]

Table 2.12 The world's ten largest nickel mines

Rank	Mine	Geographical subregion	Location	Owner	Production in 2023
1	Weda Bay Project	South-eastern Asia	Maluku, Indonesia	Tsingshan Holding Group	517 kt
2	PT Halmahera Persada Lygend Project	South-eastern Asia	Maluku, Indonesia	Ningbo Lygend Mining	95 kt
3	Taganito Mine	South-eastern Asia	Surigao del Norte, Philippines	Nickel Asia	70 kt
4	Sorowako Mine	South-eastern Asia	South Sulawesi, Indonesia	Vale	64 kt
5	PT Huayue Nickel Cobalt Project	South-eastern Asia	Central Sulawesi, Indonesia	Huayou Cobalt	42 kt
6	Ambatovy Project	Eastern Africa	Atsinanana, Madagasgar	Sumiotmo	41 kt
7	Cerro Matoso Mine	South America	Cordoba, Colombia	South32	41 kt
8	Rio Tuba Mine	Eastern Africa	Palawan, Philippines	Nickel Asia	39 k
9	Oktyabrsky Mine	Eastern Europe	Karsnoyarsk Krai, Russia	MMC Norilsk Nickel	36 kt
10	Pakal Island Mine	South-eastern Asia	Maluku, Indonesia	Mining Industry Indonesia	36 kt

[kt]: Thousand tonnes

In terms of global nickel reserves, as it has been mentioned, Indonesia has the largest deposits, followed by Australia and Brazil. This turn Indonesia into a key player in the development of the NMC and NCA market.

Table 2.13 Nickel reserves

Rank	Country/Region	Global reserves [%]	Metric tonnes
1	Indonesia	42%	55,000,000
2	Australia	18%	24,000,000
3	Brazil	12%	16,000,000
4	Russia	6%	8,300,000
5	New Caledonia	5%	7,100,000
6	Philippines	4%	4,800,000
7	China	3%	4,200,000
8	Canada	2%	2,200,000
9	US	0.3%	340,000
10	Other countries	7%	9,100,000
	World total (rounded)	**100%**	**130,000,000**

Source: U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geological Survey 2024).

2.3.3 Cobalt mining

Cobalt extraction involves several methods, mainly depending on the type of ore and its composition. The main techniques are recovery from copper-cobalt sulfide concentrates and the Sherritt process for nickel-cobalt sulfide concentrates. The majority of global cobalt mining, over 70%, takes place in the Democratic Republic of Congo (DRC).[34] Cobalt

[33] *IEA, Global Supply Chains of Batteries (IEA Publications 2021), p. 21.*

[34] *W4orld Bank, Cobalt in the Democratic Republic of Congo (June 2021), available at https://documents1.worldbank.org/curated/en/099500001312236438/pdf/P1723770a0f570093092050c1bddd6a29df.pdf*

extraction is therefore highly concentrated, as is also illustrated below in Table 2.14. Yet, cobalt is often mined as a by-product of copper and nickel mining, which is followed by a refining process of several steps to reach a final product with high purity levels. This means that Indonesia could also be set on the map for cobalt mining and develop its capabilities for processing. In the ISIC system this activity is classified in Mining and quarrying, Section: B, Division 07, Group: 072, Class: 0729.[35]

Table 2.14 The world's ten largest cobalt mines

Rank	Mine	Geographical subregion	Location	Owner	Production in 2023
1	Kisanfu Mine	Middle Africa	Katanga, DRC	CMOC Group	33 kt
2	Katanga	Middle Africa	Katanga, DRC	Glencore Plc	28 kt
3	Metalkol RTR Project	Middle Africa	Katanga, DRC	Eurasian Resources Group	20 kt
4	Tenke Fungurume Mine	Middle Africa	Katanga, DRC	CMOC Group	19 kt
5	Mutanda Mine	Middle Africa	Katanga, DRC	Glencore Plc	10 kt
6	Deziwa Project	Middle Africa	Katanga, DRC	China Nonferrous Metal Mining Group	8 kt
7	Congo Donfang	Middle Africa	Katanga, DRC	Huayou Cobalt	6 kt
8	Coral Bay/Taganito	South-eastern Asia	Indonesia	Sumitomo Metal Mining (SMM)	6 kt
9	Somika	Middle Africa	Katanga, DRC	SPRL	5 kt
10	Kamoya	Middle Africa	Katanga, DRC	Wanbao mining	4 kt

[kt]: Thousand tonnes

In terms of global cobalt reserves, Congo, Australia, Cuba and Indonesia a have the largest deposits (Table 2.15).

Table 2.15 Cobalt reserves

Rank	Country/Region	Global reserves [%]	Metric tonnes
1	Congo (Kinshasa)	57%	6,000,000
2	Australia	16%	1,700,000
3	Other countries	5%	780,000
4	Cuba	5%	500,000
5	Indonesia	2%	500,000
6	Philippines	2%	260,000
7	Russia	2%	250,000
8	Canada	1%	230,000
9	Madagascar	1%	100,000
10	Turkey	1%	91,000
11	US	0.5%	69,000
12	Papua New Guinea	7%	49,000
	World total (rounded)	**100%**	**11,000,000**

Source: U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geological Survey 2024).

2.3.4 Graphite mining

Graphite is the dominant anode material. It can either be found in natural deposits or produced synthetically by high-temperature treatment of carbon materials such as petroleum coke or coal tar pitch. Natural graphite requires refining to remove impurities whereas controlled synthetic graphite production processes result in higher purity.

[35] *Data available at https://www.mining-technology.com/marketdata/ten-largest-cobalts-mines/?cf-view*

Graphite production is led by China, followed by Madagascar, Mozambique, Brazil, Canada and South Korea.[36] The larger deposits of graphite are in China, Brazil, Mozambique and Madagascar (Table 2.16). Many new projects are being developed that contribute to diversifying global production.[37]

Table 2.16 Graphite reserves

Rank	Country/Region	Global reserves [%]	Metric tonnes
1	China	30%	78,000,000
2	Brazil	28%	74,000,000
3	Mozambique	10%	25,000,000
4	Madagascar	9%	24,000,000
5	Tanzania	7%	18,000,000
6	Russia	5%	14,000,000
7	India	3%	8,600,000
8	Turkey	3%	6,900,000
9	Canada	2%	5,700,000
10	Mexico	1%	3,100,000
11	Republic of Korea	1%	1,800,000
12	Sri Lanka	1%	1,500,000
13	Norway	0.2%	600,000
14	North Korea	0.1%	200,000
	World total (rounded)	**100%**	**280,000,000**

Source: U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geological Survey 2024).

2.3.5 Manganese mining

Manganese resources are more globally dispersed compared to other battery metals and remain relatively inexpensive. It is generally anticipated that there will not be a shortage of ore in the near future.[38] Regarding manganese reserves, Ukraine, Australia, China and Brazil have the largest deposits.

Table 2.17 Manganese reserves

Rank	Country/Region	Global reserves [%]	Metric tonnes
1	South Africa	32%	600,000
2	Australia	26%	500,000
3	China	15%	280,000
4	Brazil	14%	270,000
5	Ukraine	7%	140,000
6	Gabon	3%	61,000
7	India	2%	34,000
8	Ghana	1%	13,000
9	Kazakhstan	0.3%	5,000
	World total (rounded)	**100%**	**1,900,000**

Source: U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geological Survey 2024).

2.3.6 Mining of other commodities

Other materials such as aluminium or sodium are also used in small portions in secondary batteries, which is the case of NCA and SIBs. They are considered commodities; since they are traded, bought or sold despite the end-use specification.

[36] *https://www.statista.com/statistics/267366/world-graphite-production/*

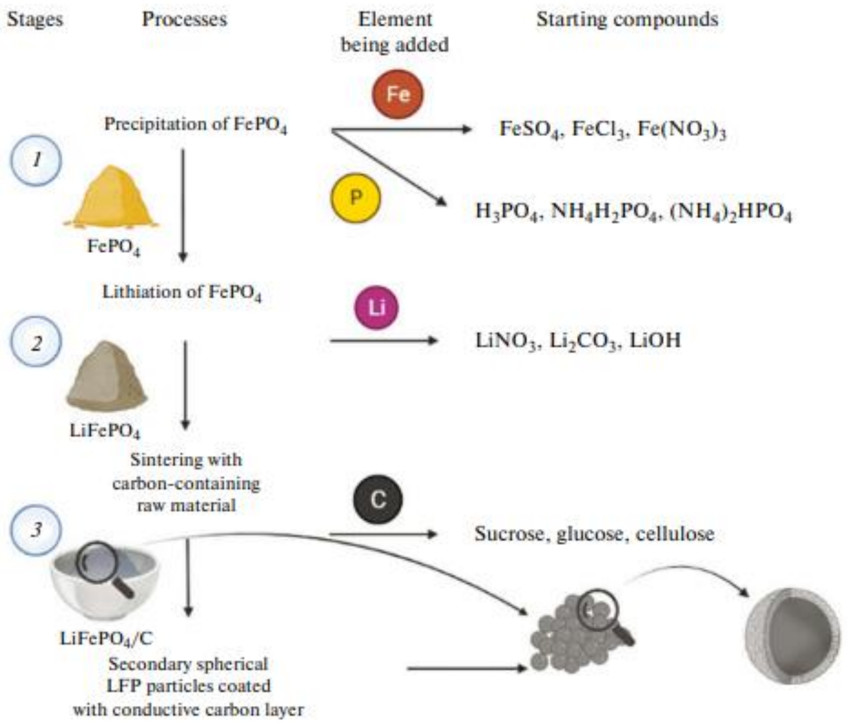
[37] *International Energy Agency (IEA), Global Supply Chains of Batteries (IEA Publications 2022), p. 22.*

[38] *ibid.*

- **Iron phosphate**

Iron phosphate (FePO4) is a key constituent of LFP, a cathode active material, synthetized through a sintering-calcination process. The most used method of producing iron phosphate is through precipitation of iron sources (iron sulphate, iron chloride or iron nitrate) with phosphorus. The result of mixing two saturated solutions (raw materials of an iron compound with phosphorus) results in a supersaturated solution high in iron phosphate. The efficiency of the precipitation process will strongly depend on the duration of the process, same as with temperature, pH, and the addition of reagents. From a schematic point of view, Figure 2.11 depicts the four (4) stages of LFP production: i) Precipitation of raw materials, ii) Lithiation of FePO4, iii) Sintering of lithium-iron phosphate (LiFePO4) and iv) Spherical coating of LFP.

Figure 2.11 Synthesis of LFP by the precipitation method: main stages



Source: "Preparation of battery-grade LiFePO4 by the precipitation method: a review of specific features "

From reagents point of view, precipitating iron phosphate and then sintering stands for the most cost-effective for synthetizing LFP. Table 2.18shows the raw materials involved in this process, which can be sourced conveniently without any foreseen supply impediments:

Table 2.18 Raw material sources for LFP

Iron sources	Phosphorus source	Lithium source	Carbon source
Fe(NO3)3	(NH4)2HPO4	Li2CO3	Glucose
FeSO4	NH4H2PO4	Li2CO3	Glucose
FeSO4	H3PO4	Li2CO3	Glucose
FeSO4	LiH2PO4	LiH2PO4	Glucose
FeSO4	H3PO4	Li2CO3	Oxalic acid
(NH4)2Fe(SO4)2	NH4H2PO4	LiOH	Graphene
Fe(NO3)3	Na2HPO4	LiI	Glucose
FeSO4	(NH4)2H2PO4	Li2CO3	Glucose

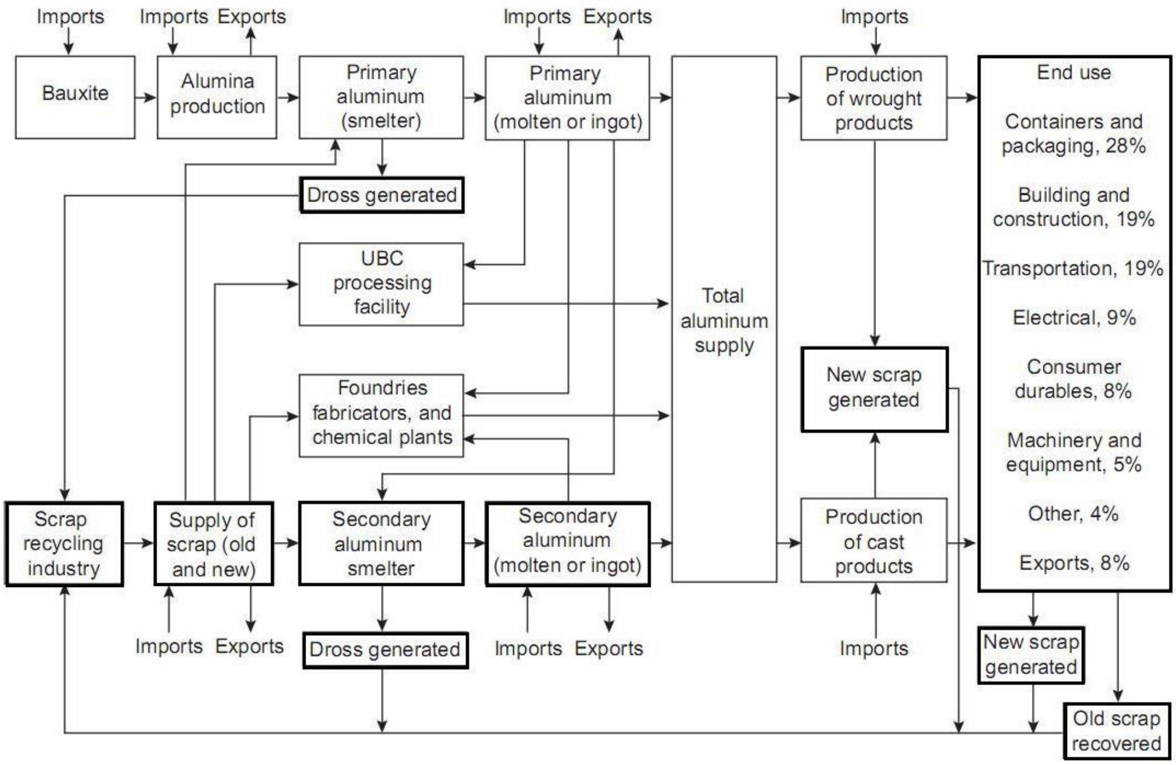
FeSO4	NH4H2PO4	Li2NO3	Activated carbon
FeSO4	NH4H2PO4	Li3PO4	Citric acid
FeSO4	H3PO4	Li2CO3	Glucose
FeSO4	NaH2PO4	Li2CO3	Glucose
FeSO4	H3PO4	LiOH	Glucose
FeSO4	(NH4)2HPO4	LiNO3	Stearic acid
FeCl3	H3PO4	LiOH	Glucose
Fe(NO3)3	H3PO4	Li2CO3	Glucose

Source: "Preparation of battery-grade LiFePO4 by the precipitation method: a review of specific features "

- **Aluminium**

From a mining perspective, aluminium is typically found in bauxite, which is the most common ore of aluminium. This sedimentary rock is the world's main source for aluminium and gallium. The typical production process consists of mining bauxite ore, then refining the ore to recover alumina, and finally smelting alumina to produce aluminium. The latter is depicted in the next figure:

Figure 2.12 Material flow diagram of the aluminium global industry[39]



Source: Aluminium Guide

It is important to notice that in terms of uses, aluminium is mainly employed in "containers and packaging" (28%), then "building and construction" (19%), and "transportation" (19%). The use in energy storage is included in "other", which accounts for 4% of total uses. Hence, the volume of aluminium destined for the battery industry is not relevant when compared to the other critical minerals and is not a key factor within the battery supply chain.

An important source of aluminium supply is the addition of "new scrap" and "old scrap". As of 2023, recycled aluminium makes up about one-third of the global aluminium supply.

39 *Aluminium guide (2023) Material flows in the global aluminum industry: the role of secondary aluminum. Available at: https://aluminium-guide.com/production-recycled-aluminium/*

And recycled aluminium produced from old scrap originates 33% from transport, 26% from packaging, 13% from engineering and cables and 16% from building applications, due to its long lifetime.

- **Sodium salts**

From a mining and refining perspective, sodium compounds are of immense importance. Some specific compounds like salts and oxides have a historic bond with industrial uses such as glass, paper, textiles among others. The most important sodium compounds are table salt (NaCl), soda ash (NaCO3), baking soda (NaHCO3), caustic soda (NaOH), sodium nitrate (NaNO3), and others.

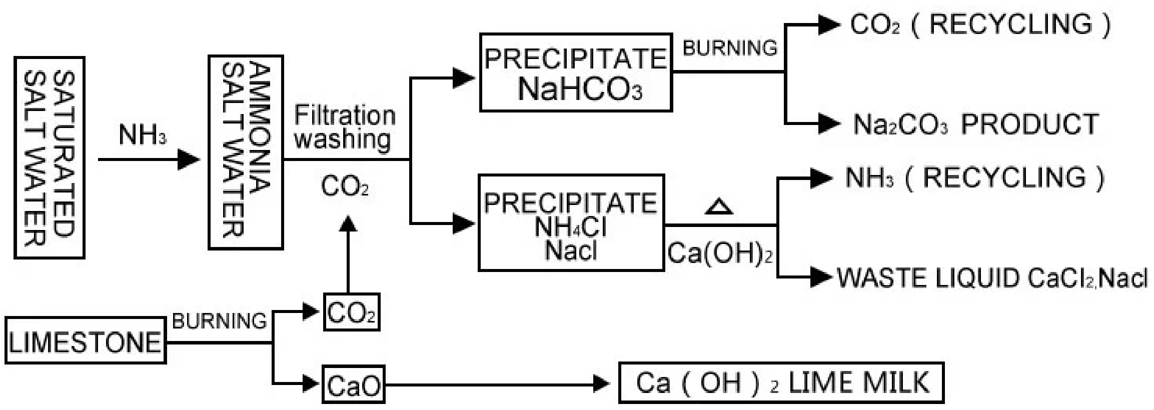
Table 2.19 Main sodium salts and their application

Sodium salts	Formula	Uses
Sodium chloride	NaCl	Common table salt, other chemical processes
Sodium Hydroxide	NaOH	Base in industrial applications: soap manufacturing, paper manufacturing. And as chemical reactant
Sodium Carbonate	Na2CO3	Used in glassmaking, detergent markets and as water softener
Sodium Bicarbonate	NaHCO3	Baking soda and other chemical processes
Sodium Sulphate	Na2SO4	Used in detergents, paper pulping and textile manufac-turing
Sodium Nitrate	NaNO3	Used as fertilizer, in food preservation and in explo-sives

Source: SC-Insights

Many of these sodium compounds are produced with sodium chloride as the starting material. About 50% of the NaCl is consumed in the process to produce sodium hydroxide and sodium chlorine. In the case of SIBs production, the sodium cathode is mainly syn-thetized using sodium carbonate or purified sodium chloride. The production of soda ash is depicted in the next figure:

Figure 2.13 Soda Ash production process flowsheet[40]



Source: Goldsione Group LTD

[40] *Goldsione Group LTD (2023) Soda Ash Dense Production Process. Available at: https://www.evvchem.com/soda-ash-dense.html*

2.4 Refining

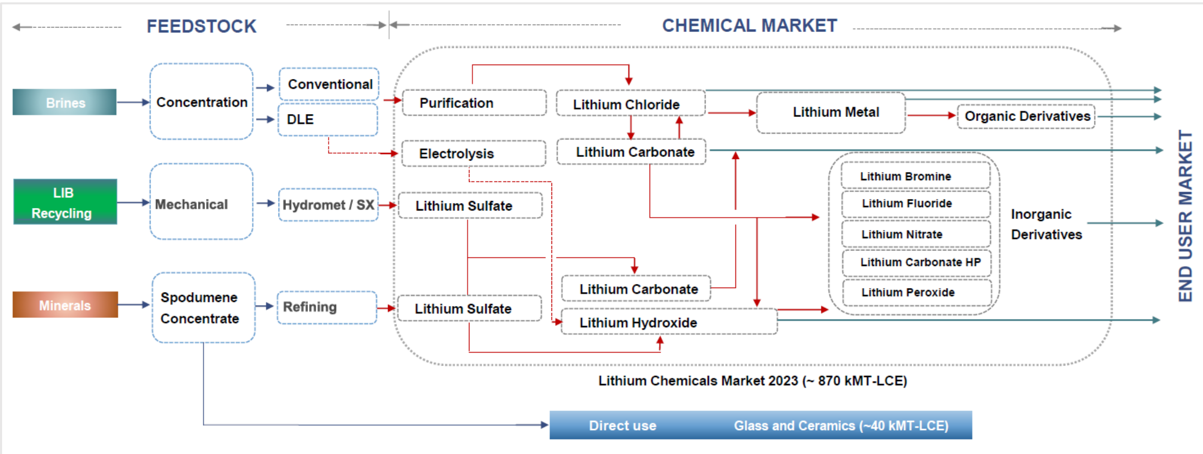
Following the extraction of raw materials by mining operations, which constitute the upstream segment of the battery supply chain, these materials undergo processing and refinement. This is generally considered as the midstream phase of the battery supply chain.

Raw materials processing refers to the process of purifying extracted minerals to remove impurities and produce a more concentrated, pure and usable form of the extracted material. Refining further involves treating these processed materials to attain a level of purity that renders them suitable for incorporation into batteries. Batteries require high-purity minerals for safety and durability.[41] Subsequently, these purified materials are utilized to produce cathode and anode active battery materials.

2.4.1 Lithium Refining

Lithium deposits are present in hard rock mineral ores, as described above, which are subjected to mining and crushing processes. Hard rock lithium deposits can be transformed into lithium carbonate or lithium hydroxide, which serve as essential components in the fabrication of high energy-density cathodes. Lithium can also be found in saline water, from which it can be extracted through evaporation techniques. Brines can be processed directly into lithium carbonate, which is appropriate to produce cost-effective yet less energy-dense cathodes. The extraction of lithium involves pumping brine from underground aquifers to the surface, where it is subsequently directed into a series of evaporation ponds.[42] Figure 2.14 presents the flow diagram of Lithium.

Figure 2.14 Lithium flow diagram



Source: Supply Chain Insights 2024, 'The lithium flow diagram'

Lithium products are predominantly refined in China, with Australia, Chile and China being the principal producers of feedstock for lithium chemicals (lithium carbonate, lithium hydroxide and others). More than 50% of the production capacity for lithium carbonate is located in China, while for lithium hydroxide this number increases to 80%. The proximity and cost competitiveness to Asian end markets (Korea, Japan and mainly China) create a virtuous environment for refining capacity additions. Indonesia could leverage

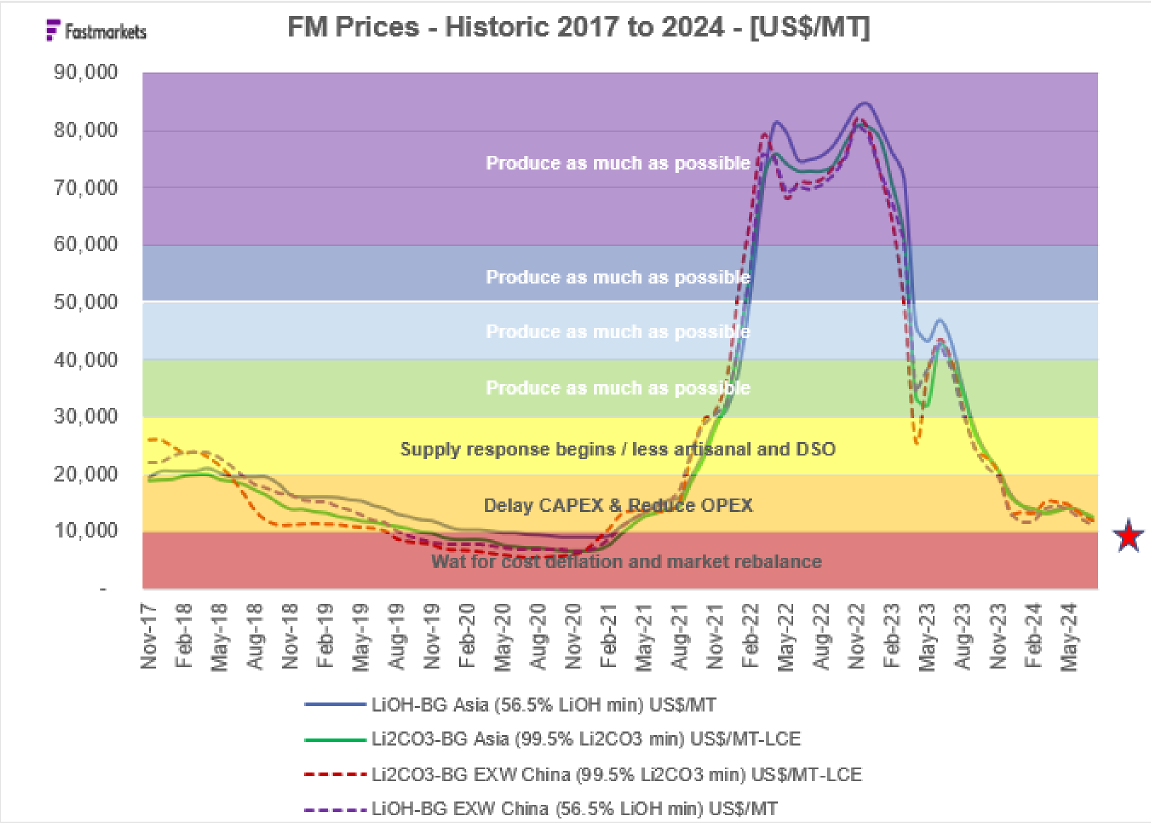
[41] *Although recent research questions this, see G Choe, H Kim, J Kwon, W Jung, K-Y Park and Y-T Kim, 'Re-evaluation of battery-grade lithium purity toward sustainable batteries' (1185) 15 Nature Communications (2024).*
[42] *K Brunelli, L Y Lee and T Moerenhout, 'Fact Sheet: Lithium Supply in the Energy Transition' December 20, 2023, Center on Global Energy Policy, Columbia SIPA.*

from its proximity as well and create attractive conditions for refining investors. Notwithstanding the above, Chile and Argentina have a combined capacity of 400,000 MT-LCE of lithium carbonate.

Due to escalating concerns about the price of battery constituents, China started improving and spread the use of sodium-ion batteries. The burgeoning focus on developing novel chemistries is a concern for a dominating country in the Lithium-ion battery supply chain, driven to control margins. This chemistry is an appealing alternative to more expensive conventional lithium-ion batteries; however, its energy density doesn't make it suitable for high-end EVs.

Figure 2.13 shows the evolution of lithium prices from November 2017 to June 2024. This figure is crucial because it depicts two effects: firstly, it shows how dramatic price volatility in the battery material markets can be. As opposed to price maximums during the 2014-2019 cycle hitting close to US$ 30,000/MT for spot prices, the latest price cycle (2020 to 2024) saw record spot prices of US$80,000/MT for lithium hydroxide. The latter is of significance to the miner of lithium, who increases its margins, however for the OEM it creates demand destruction. The second effect is directly related to geopolitics of battery materials and Chinese companies' strategies to keep prices low, which involve significant volumes of low-grade ores being sourced globally to put pressure on prices. The origin of these wave of new material ranged from African concentrates, through Brazilian tailing and finally Chinese lepidolite.

Figure 2.15 Lithium price references - historic prices since 2018



Source: Supply Chain Insights 2024, 'Where will prices settle in the long term?'

For lithium feedstock and chemicals, the codes for trade stats are the shown in Table 2.20:

Table 2.20 Lithium feedstock codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
AHECC	25309011	Lithium concentrates	Lithium feedstock	No	Australian code for spodumene concentrate
HS	25309093	Mineral substances not elsewhere specified or included	Lithium feedstock	No	Former Australian code for spodumene concentrate
HS	26179000	Spodumene concentrate grade	Lithium feedstock	No	SC7%
NCM-SIM	2827.39.60.000Z	Lithium chloride	Lithium feedstock	No	Argentinian customs
HS	2827 39 60	Lithium chloride	Lithium feedstock	No	
NCM-SIM	2836.91.00.000G	Lithium carbonate	Lithium feedstock	No	Argentinian customs
SACH	28369130	Lithium carbonate	Battery Grade and Technical Grade	Yes	Chilean customs
HS	28369100	Lithium carbonates	-	-	Carbonates: inorganic chemicals, organic or inorganic compounds
HS	28332980/ 28332990	Lithium sulphate	Lithium feedstock	No	Monohydrate
SACH	28252011	Lithium hydroxide	Battery Grade and Technical Grade	Yes	Monohydrate
HS	28252000	Lithium hydroxide	Battery Grade and Technical Grade	Yes	Oxide and Hydroxides (monohydrate)

2.4.2 Nickel Refining

Nickel can be found in two broad ore types: laterite (oxide) ores and sulphide ores. Laterite ores can be further separated into two subgroups: limonites and saprolites.[43] Variations in chemical compositions result in differing methods of extraction and processing for nickel, contingent upon the type of resource. There are two types of processed nickel products which are referred to as Class 1 and Class 2 nickel products. These products are used for different applications depending on purity requirements.[43]

Class 1 Nickel has a high purity level. It is primarily used in the production of batteries, particularly EVs, due to its superior quality and performance characteristics. Class 2 nickel has lower purity, and therefore it is mainly utilized in the stainless-steel industry.[43]

At present, limonite ores are primarily processed through leaching, a technique in which the ore is treated with sulfuric acid, facilitating the dissolution of nickel and cobalt. The resulting solutions yield nickel-cobalt intermediate products, which can be either refined into nickel metal or incorporated directly into the battery supply chain. This processing technique is referred to as hydrometallurgy.[43]

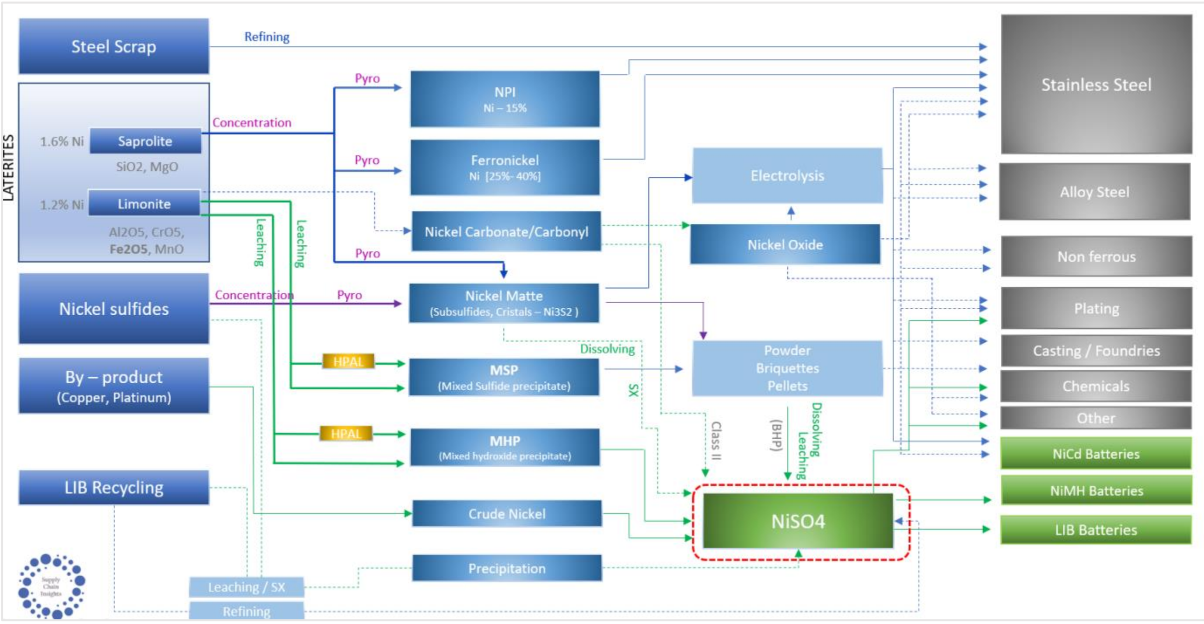
Conversely, saprolite ores are subjected to smelting, where the ore is dried and melted to recover nickel in the form of an iron-nickel alloy. Considering the rising demand for

[43] *Nickel Institute, 'Nickel industry – Part 1 – Processing nickel laterites and sulfides' May 03, 2024, available at https://nickelinstitute.org/en/blog/2024/may/nickel-industry-part-1-processing-nickel-laterites-and-sulfides/*

batteries, there has been a resurgence in the practice of converting this alloy into a higher-grade material known as nickel matte for subsequent refining. The processing method that involves melting materials at high temperatures is referred to as pyrometallurgy.[43]

Sulfide ores can be found at or near the surface, as well as deep underground. They often contain additional valuable resources, including copper, platinum, and palladium, which can collectively surpass the value of nickel. These ores can typically be upgraded on-site to produce a shippable nickel concentrate. This concentrate is then processed at centralised facilities, primarily nickel smelters. The nickel concentrate is melted using energy from sulfur and electricity to create nickel matte, which undergoes further refining.[43] Direct hydrometallurgical methods are also utilized in processing these ores. In addition to these traditional techniques, new processing technologies are emerging.[44] For example, high pressure acid leaching (HPAL) is an emerging technology that produces Class 1 nickel from lower grade laterite resources. Nickel processing is illustrated in Figure 2.16

Figure 2.16 Nickel processing



Source: SC-Insights 2024, 'Nickel processing flowsheet – Processing nickel laterites and sulphides' from the Nickel Value Chain Presentation.

Nickel's scenario is noteworthy, given Indonesia's downstreaming policies that have affected the global value chain. In 2020, Indonesia implemented a ban on the export of unprocessed nickel ore to encourage domestic processing and add value to its nickel resources[2]. Indonesia's nickel downstreaming policies focus on adding value to its nickel resources by processing them domestically rather than exporting raw nickel ore. Most notably, between the nickel ban introduced in 2019, and 2022, investment in mineral processing and manufacturing in Indonesia increased from USD $3.56 billion to USD $10.96 billion. This represents a 207.9% increase in investment. The majority of these investments are by Chinese companies that have moved their operations to Indonesia due to the export ban.[45]

For nickel feedstock and chemicals, the codes for trade stats are the following (Table 2.21):

[44] *ibid.*
[45] *D Guberman, S Schreiber and A Perry, Export Restrictions on Minerals and Metals: Indonesia's Export Ban of Nickel, March 2024 (U.S. International Trade Commission, Office of Industry and Competitiveness Analysis), p. 2.*

Table 2.21 Nickel feedstock codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	26040000	Nickel ores and concentrates	Feedstock	No	Saprolite and limonite should go under this category
HS	28332400	Nickel sulphate	PCAM/CAM feedstock	Both	Other sulphates of nickel
HS	75011000	Nickel mattes	Feedstock for NiSO4	No	Mattes, oxides and other intermediates products of nickel metallurgy
HS	75030010	Nickel waste	For further refining	No	Waste and scrap that is an alloy
HS	75040000	Nickel powders and flakes	Feedstock for NiSO4	No	-
HS	75089090	Nickel pellets	Feedstock for NiSO4	No	-
HS	7505	Nickel bars, rods, profiles and wire	Other	Yes	Includes nickel alloys and nickel that is not alloyed
HS	7201	Nickel pig iron	Other	No	General code
HS	72026000	Ferro-Nickel	Other	Yes	Chips, granules, coils, etc

2.4.3 Cobalt Refining

Cobalt is predominantly found in association with ores of copper, nickel, or copper-nickel. Similarly to nickel, cobalt refining involves several processes to extract and purify cobalt from its ores. The two primary methods used are hydrometallurgy and pyrometallurgy. The Hydrometallurgy process involves treating cobalt-containing ores with specific chemicals to dissolve the cobalt and separate it from other elements. The resulting solution is then processed to precipitate cobalt hydroxide, which can be further refined into pure cobalt metal. Pyrometallurgy refers to the process of melting the ore at high temperatures to separate cobalt from other metals. The ore is typically smelted in a furnace, where cobalt is recovered as part of an alloy or as nickel-cobalt matte, which can then undergo additional refining. These methods are essential for producing high-purity cobalt for batteries.[46]

Cobalt refining and chemical manufacturing currently occurs predominantly in China, accounting for over 65% of the global activity. The initial cobalt product from processing, typically impure cobalt hydroxide, undergoes refinement through hydrometallurgical and electrometallurgical methods to yield various pure cobalt chemicals, such as cobalt nitrate, sulphate or hydroxide, as well as cobalt metal. These refined metals serve as inputs for component manufacturing.[47]

For cobalt feedstock and chemicals, the codes for trade stats are the following (Table 2.22):

Table 2.22 Cobalt feedstock codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	26050000	Cobalt ores and concentrates	PCAM/CAM feedstock	No	-

[46] *Q Dehaine, L T Tijsseling, H J Glass, T Törmänen and A R Butcher, 'Geometallurgy of cobalt ores: A Review' 160 Minerals Engineering (2021), 106656.*
[47] *https://www.cobaltinstitute.org/divi_overlay/phase-3-refining-and-chemical-manufacture/*

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	28332990	Cobalt sulphate	PCAM/CAM feedstock	Both	Inorganic chemicals; organic or inorganic compounds
HS	282200	Cobalt oxides and hydroxides	Cobalt feedstock	No	Includes commercial oxides
HS	2844402000	Cobalt and its salts	Cobalt feedstock	No	Inorganic bases and oxides
HS	8105 2000 00	Cobalt mattes and other inter-mediate	Feedstock for CoSO4	No	Products of cobalt metallurgy and powders
HS	8105 3000 00	Cobalt waste and scrap	Feedstock	No	-
HS	8105 9000 10	Bars or wires made of cobalt	Related	Co cath-odes	Related

2.4.4 Graphite Refining

Batteries can use both natural and synthetic graphite. Natural graphite is formed naturally and can be found as amorphous, flake or crystalline vein graphite[48]. Synthetic graphite is produced through a high-temperature treatment of non-graphitic carbon materials[48]. The difference between these two, besides the manufacturing process, lies in its density, porosity, thermal conductivity and costs. The battery industry has had high demand for synthetic graphite due to its fast charge turnaround and longevity. However, the market has been changing toward natural graphite due to its environmental and cost advantages[48].

Graphite processing is primarily taking place in China, with significant natural graphite deposits in the country.

Graphite refining involves several key processes to purify and enhance the quality of graphite for carious applications. First, to enrich and improve the mineral content of the ores, unwanted components are removed. This so-called beneficiation process includes crushing and grinding to liberate the graphite flakes from the surrounding material. To separate graphite from further impurities, a variety of hydrometallurgical purification methods can be used, such as flotation, acid-base and hydrofluoric-acid methods. Pyrometallurgy purification technologies include chlorination roasting and high-temperature methods.[49]

For graphite feedstock, the codes for trade stats are the following (Table 2.23):

Table 2.23 Graphite feedstock codes

Source	Code	Description	LIB Supply chain	Finished prod-uct	Notes
HS	250410	Flake or Powder graphite	Feedstock for Anode	Both	Natural graphite
HS	25041010	Flake or Powder graphite	Feedstock for Anode	Yes	Crystaline
HS	25041020	Flake or Powder graphite	Feedstock for Anode	No	Amorphous

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[48] *Ceylon Graphite (2023) Natural Vs Synthetic Graphite. Available at: https://www.ceylongraphite.com/posts/natural-vs-synthetic-graphite/#:~:text=How%20to%20identify%20Natural%20from,standard%20price%20of%20natural%20graphite.*

[49] *A D Jara, A Betemariam, G Woldetinsae, J Y Kim, 'Purification, application and current market trend of natural graphite: A review' 29 (5) international journal of Mining Science and Technology (2019) pp. 671-689.*

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	25041090	Other natural graphite	Feedstock	No	Powder or flakes
HS	25041091	Spherical graphite	Feedstock for Anode	Both	Coated and uncoated
HS	25049000	Natural graphite	Related	Yes	Solid, lump, blocks
HS	25049010	Flake graphite	Feedstock for Anode	Yes	Micronized
HS	38011000	Artificial graphite	Related	No	Paste, block, plates, or other-semimanufactures
HS	38012000	Artificial graphite	Related	No	Colloidal or semi-colloidal
HS	38013000	Artificial graphite	Related	No	Carbonaceous paste
HS	38019000	Other graphite	Related	No	-

2.4.5 Manganese Refining

Manganese in its pure form is obtained through hydrometallurgical and electrolytic methods, whereas ferromanganese (a type of manganese ferroalloy that is produced directly from manganese ores through smelting processes) and silicomanganese (produced by the smelting of slag from high-carbon ferromanganese) are produced via the smelting of ores, typically conducted in a blast furnace or, more frequently, in an electric furnace. [50]

Manganese sulphate, in its high purity form, has traditionally been undervalued due to its widespread availability and low cost. However, the rising adoption of NMC battery chemistry, particularly in the US and EU, is expected to increase demand and potentially elevate prices.

For manganese feedstock and chemicals, the codes for trade stats are the following (Table 2.24):

Table 2.24 Manganese feedstock codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	260200	Manganese ores and concentrates	Feedstock for MnCO3, MnSO4	No	-
HS	28201000	Manganese powder	Feedstock for MnCO3, MnSO4	No	-
HS	28369990	Manganese carbonate	PCAM/CAM feedstock	Yes	99.9% metal base
HS	283322940	Manganese sulphate	PCAM/CAM feedstock	Yes	Hydrate, monohydrate, tetrahydrate

2.4.6 Refining of other commodities

Aluminium and sodium are two commodities that have a very specific roles to play in energy storage; basically, supplying battery grade chemicals for NCA and SIBs- respectively.

- **Iron Phosphate**

[50] J H Downing, 'Manganese processing' Britannica, available at https://www.britannica.com/technology/manganese-processing

The chemical process to refine raw materials and synthetize LFP-CAM is a sequence of precipitation, lithiation, sintering and finally spherical coating. The following table details what the main features of LFP are in terms of its constituents:

Table 2.25 LFP cathode and its features

CAM	Formula	Representative materi-als	Iron source
Phospho-olivine	$LiMPO_4$	M={Fe, Co, Mn, Ti}	Fe(NO3)3 FeSO4 FeCl3

The refining portion of LFP involves the constant agitation of the precursor at an auto-clave reactor, followed by filtration and washing under vacuum conditions to obtain a battery-grade LiFePO4. Then the material is ready to be coated.

In terms of business development, due to cost of production and availability of materials this chemistry has been matures and widely spread by the Chinese market. As of 2023 SC-Insights numbers, there are seventy-one (71) plants that are actively producing this chemistry, with 38 more plants entering the market before the end of the decade. Adding all those 71 plants a total capacity arises equal to 230 GWh, a considerable amount and share of total LIB production. Is also worth noticing that except for ten (10) plants, the remaining 61 are all based in China. Table 2.26shows the ten largest LFP plants in pro-duction, which happen to concentrate almost 50% of global production capacity:

Table 2.26 Ten largest LFP cell producing plants globally

Rank	Company	Plant	Country	Chemistry	Capacity 2023
1	CATL/SAIC	Liyang	China	LFP for EVs	GWh
2	CATL	Liyang	China	LFP for EVs	GWh
3	BYD	Chongqing	China	LFP for EVs	GWh
4	BYD	Shenzhen	China	LFP for EVs	GWh
5	BYD	Yancheng	China	LFP for EVs	GWh
6	CALB	Changzhou	China	LFP for EVs	GWh
7	BYD	Changzhou	China	LFP for EVs	GWh
8	Tianneng	Changxinig	China	LFP for EVs	GWh
9	EVE	Huizhou	China	LFP for EVs	GWh
10	BYD	Guiyang	China	LFP for EVs	GWh

It's important to notice that **the largest ten global LFP plants are located in China, and that their final customer are manufacturers of electric vehicles. It's also important to notice that BYD (integrated player) hold five of the ten major LFP manufacturing plants.**

- **Aluminium**

Aluminium plays a critical role in the performance of NCA cathode active materials. The use of this element improves the thermal stability, electrochemical performance and also stabilizes the structure of the cathode. The following table details what source of alumin-ium is used per type of cathode:

Table 2.27 NCA cathode and their sources of aluminium

CAM	Representative materials	Detail	Al Source

Layered Structure	$LiNi_xCo_yAl_zO_2$	NCA CAM is a particular case of "layered structure", but without	Al2(SO4)3

Despite having a production capacity of 66 GWh in 2023, this chemistry is in decline compared to other prominent cathodes such as LFP, LMFP, NMC622, NMC811 and even SIBs. Between today and 2028, there are no new projects for NCA, only expansions of capacity. The latter can be seen in the next table:

Table 2.28 Current NCA capacity and projection to 2028

Rank	Company	Plant	Chemistry	Capacity 2023	Capacity 2028
1	Tesla	Nevada, US	NCA for EVs	35GWh	35GWh
2	CATL	Cheiwan, China	NCA for EVs	8GWh	32GWh
3	Panasonic	Suminoe, Japan	NCA for EVs	7GWh	10GWh
4	Panasonic	Suminoe, Japan	NCA for 3Cs	5GWh	5GWh
5	BAK	Zhengzhou, China	NCA for EVs	5GWh	5GWh
6	Tesson New Energy	Lushui, China	NCA for EVs	3GWh	5GWh
7	Samsung SDI	Tianjin, China	NCA for EVs	2GWh	3GWh
8	Sunpower	Taixing, China	NCA for EVs	1.2GWh	2GWh
9	Tenpower	Zhangjiagang, China	NCA for 3Cs	1.1GWh	1.1GWh
10	SVOLT	Huzhou, China	NCA for EVs	1.0GWh	15GWh
11	Panasonic	Tokushima, Japan	NCA for 3Cs	0.6GWh	0.6GWh

Five years from now, NCA capacity will reach 112 GWh, a 70% increase for aluminon sulphate as well. Since the production of this comes from the process of leaching and heating bauxite or clays, due to the abundance it won't represent a bottleneck.

- **Sodium**

The raw materials for SIBs batteries can be obtained from abundant sources which are not limited to specific regions. Sodium is one of the most abundant elements both in the Earth's crust, and the oceans. Similarly, different compounds of sodium can be used for each cathode type. The following table details what source of sodium is used per type of cathode:

Table 2.YY Na-ion cathode and their sources of sodium

CAM	Representative materials	Other elements	Na Source
Layered metal oxide	$Na_{0.44}MnO_2$	Co, Cu, Ni, Ti	Na2CO3, NaCl
Polyanionic	$NaVPO_4F$	-	Na2O
Prussian blue analogues	$Na_2Fe_2(CN)_6$	-	NaCl

So, a variety of sodium salts can be used for the different forms of Na-ion cathodes. However, demand is still building up, with the majority of the capacity built in China, and some scattered attempts elsewhere. Unsurprisingly, the majority of the capacity is being built for ESS:

Table 2.29 Sodium ion battery plants globally

Rank	Company	Plant	Country	Chemistry	Capacity 2023
1	CATL	Ningde, Fujian	China	Na for EV	2 GWh
2	HiNa Battery	Zhongguancun	China	Na for ESS	1 GWh
3	ET Energy	Chengdu	China	Na for ESS	1 GWh
4	NGK Insulators	Nagoya	Japan	Na for ESS	0.3 GWh
5	Jiangsu Highstar	Qidong	China	Na for ESS	0.2 GWh
6	AMTE Power	Thurso	UK	Na for 3Cs	0.2 GWh
7	Beijing Xuexiong Technology	Beijing	China	Na	0.1 GWh
8	Zoolnasm	Zoolnasm	China	Na for ESS	0.1 GWh
9	Exliporc New Energy	Shenzhen	China	Na for 3Cs	0.1 GWh
10	Hakadi	Shenzhen	China	Na for 3Cs	0.1 GWh
11	Tiamat	Amiens	France	Na for 3Cs	0.1 GWh
12	Altris	Uppsala	Sweden	Na for ESS	0.1 GWh

In total, 5.3 GWh of sodium-ion cell capacity were in place for 2023. In five years from now, the expansions plans are quite impressive, reaching almost 143 GWh (almost 30-fold). Chinese policy makers and companies understood that Na-ion is a cheap alternative for the ESS marker, especially when prices of battery materials (Li, Ni, Co and Mn) start to gain momentum. And more importantly, with an abundant salt supply like (NaCl or N2CO3 or Na2O), supply constraints are not an issue, even under a demand scenario increased 30-fold.

2.5 Cathode Active Materials

Cathode Active Materials (CAM) represent the quintessential part of a lithium-ion battery cell. This constituent is not only what dictates the chemistry of the cell but also determines the cost and essential performance. Today the main dilemma for EV manufacturers is what chemistry to use. For Asian manufacturers the proportion has been relatively stable with NMC representing between 40% and 60% during the last 5 years.

2.5.1 Capacity and growth

As of 2023 figures, China represents almost 79% of the global cathode capacity, followed by South Korea and third Japan, the three of them accounting for 98% of the global cathode capacity. In a matter of 5 years China managed to increase its share from 66% to 79%, showing significant dynamism and competitivity at manufacturing cathode active materials (Table 2.30). Secondly comes South Korea and Japan, who together hold 20% of the global capacity, with very little growth outside Asia. It's quite revealing what has happened with companies like Johnson Matthey and Northvolt, who have left the cathode market for strategic reasons.

Table 2.30 Global cathode capacity development in the next 10 years

Rank	Country	Global capacity share	Capacity (Tonnes)			CAGR 10-yr (%)
			2023	2028	2033	
1	China	79%	2,871,800	6,390,100	7,634,100	10.3%
2	South Korea	14%	515,900	715,400	742,200	3.7%
3	Japan	5%	195,930	325,930	340,430	5.7%

Rank	Country	Global capacity share	Capacity (Tonnes)			CAGR 10-yr (%)
			2023	2028	2033	
4	Poland	0.6%	20,000	105,000	245,000	28.5%
5	Germany	0.4%	15,450	130,300	130,300	23.8%
	Others	0.6%	20,405	2,829,700	3,295,900	66.3%
	TOTAL	**100%**	**3,639,485**	**10,496,430**	**12,387,930**	**13.0%**

The Chinese cathode market is quite diverse and dynamic. Instead of being concentrated among a few players, it's comprised of close to 100 traceable players, who have mastered not only the production of LFP, but also NMC. Below, in Table 2.31, are the largest ten Chinese cathode manufacturers, where it is surprising how much capacity each one is deploying, but also how many plants are capable of producing both NCM precursor and CAM:

Table 2.31 Chinese cathode material producers and production capacities in 2023 and 2028

#	Company	Plant	Chemistry	Capacity 2023	Capacity 2028
1	Dynanonic	Shenzhen	LFP	265,000	265,000
2	GEM	Several	NCM-LFP	170,000	170,000
3	Yuneng New Energy	Several	LFP	117,000	132,000
4	Shanshan	Several	NCM	115,000	147,500
5	Gotion	Guoxuan	LFP	110,000	150,000
6	Xiamen Tungsten	Ningde	LFP	95,000	140,000
7	BTR	Several	NCM	90,000	102,000
8	Ronbay	Several	NCM	90,000	135,000
9	B&M	Several	NCM	78,000	155,000
10	Huayou Cobalt	Several	LFP-LCO-NCM	70,000	130,000

The Korean cathode market is concentrated in seven (7) big players (Table 2.32), with Umicore, LG Chem and Ecopro having more than 100,000 tons of capacity each during 2023. Posco is an interesting player who is integrated upstream, with mining and refining capacity in lithium. It is expected for them to cross the 100,000 ton mark before 2023. From this group there are two companies which are integrated in CAM and LIB cell production: LG Chem and Samsung SDI, while SK Innovation isn't.

Table 2.32 Korean cathode material producers and production capacities in 2023 and 2028

#	Company	Plant	Chemistry	Capacity 2023	Capacity 2028
1	Umicore	South Korea	NCM-LCO	144,500	170,000
2	LG Chem	South Korea	NCM	115,000	130,000
3	Ecopro	South Korea	NCA-NCM	105,000	155,000
4	Posco	South Korea	NCM	55,200	104,200
5	Samsung SDI	South Korea	NCA-NCM	43,000	43,000
6	L&F	South Korea	NCM	33,000	53,000
7	Cosmo AM&T	South Korea	NCM	20,000	60,000

The cathode production market in Japan is highly concentrated, where four main players dominate the space (Table 2.33). Nichia and Sumitomo Metal Mining (SMM) are historic players who buy from everywhere and everyone. BASF is another key player, a German chemical giant who in 2014 started a JV with TODA KOGYO Corp as a strategic alliance.

Table 2.33 Japanese cathode material producers and production capacities in 2023 and 2028

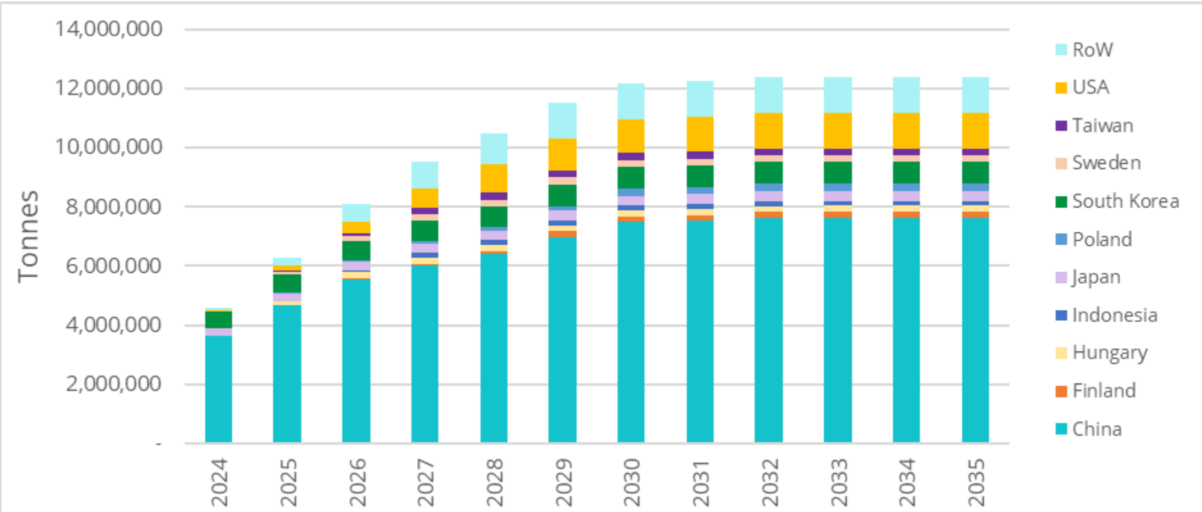
#	Company	Plant	Chemistry	Capacity 2023	Capacity 2028
1	Nichia Chemical	Japan	NCM	80,500	110,500
2	SMM	Japan	NCM-NCA	56,000	100,000
3	BASF-TODA	Japan	NCA-NCM	30,000	60,000
4	Tanaka	Japan	NCA	24,000	50,000

Despite being an incredibly complex industry in terms of technology, the margins have decreased during the last cycle of battery material prices. Large and integrated Chinese players such as OEMs make their margins from the sale of EVs, therefore there is little incentive to keep "upstream" margins healthy. Refining and CAM are two industries that have suffered significantly due to Chinese pressure over margins.

2.5.2 Geographies

The majority of cathode production comes from China, accounting for 79% of current global capacity, with South Korea and Japan following respectively (Figure 2.17). **During the subsequent five years China will continue dominating the cathode landscape, however there are some interesting trends outside Asia**. It's quite remarkable how the US adds close to 1.5 Mtonnes in 2028, among 15 new projects. It's also impressive how the EU started adding capacity among Sweden, Poland, Hungary and Finland. Altogether Europe will add close to a million ton capacity in 2028.

Figure 2.17 Estimated cathode production by selected countries (2024–2035) – Tonnes



Source: SC Insights

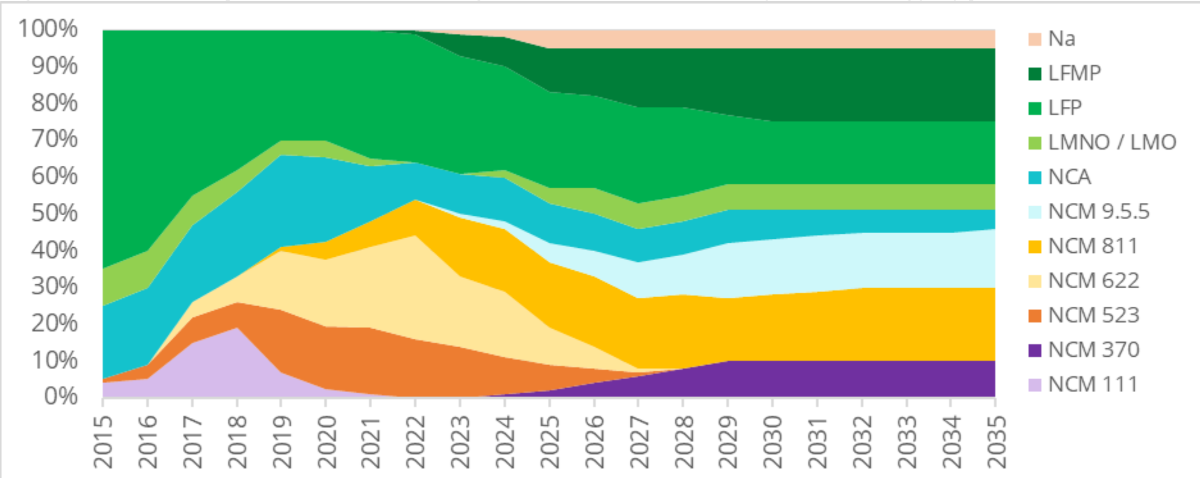
Indonesia will add two projects over the next decade that will account for 160,000 tons of capacity. Nevertheless, the strategic role of Indonesia in the nickel market and its competitiveness in terms of energy/reagent could attract even more projects.

2.5.3 Chemistries

As elaborated in Section 0 above, nickel-based (NMC and NCA) and iron-based (LFP) lithium-ion batteries are the most commonly used chemistries in the cathode space. Nevertheless, when taking a dive deep into each subsector, important takeaways can be noticed (Figure 2.18).

Firstly, in the Transportation sector an important growth in the NCM group happened during the last decade, driven by the sharp development of NCM 523 and NCM 622. Since 2020, the space has witnessed a sharp growth of NCM 811 and LFP, which offer solutions for two different car applications: the first one for premium EVs with high performance, while the second one offers a more affordable alternative but safer solution to EV ownership. Since 2022, the market has seen the introduction of two improved chemistries for each type of EV; on one hand the high nickel NCM 9.5.5, while on the other LFMP. The latter trends can be seen in the following figure:

Figure 2.18 Transportation cathode global market share by technology type

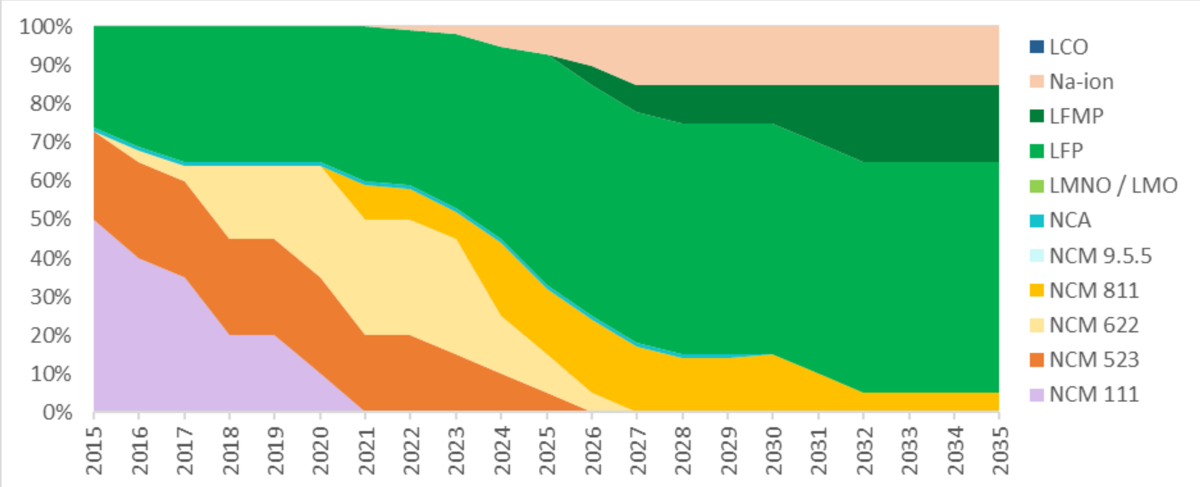


Source: SC Insights

These trends present an optimistic scenario for Indonesia as the market share of especially NCM9.5.5 and NCM811, both nickel intensive, are expected to increase during the next decade.

Secondly, the Energy Storage sector has seen significant changes during this decade. Before 2020, NCM chemistries dominated the market, with NCM523 being the preferred choice. While NCM 622 saw rapid growth between 2018 and 2021, it was LFP that ultimately emerged as the leading option for ESS. Today, there is considerable optimism surrounding LFP continued dominance, with expectations for LFMP to enter the market by 2025 (Figure 2.19). In the ESS space, energy density is less of a priority, as large warehouses offer ample space for these technologies. As a result, competitive technologies like LFP and LFMP are well suited for these applications.

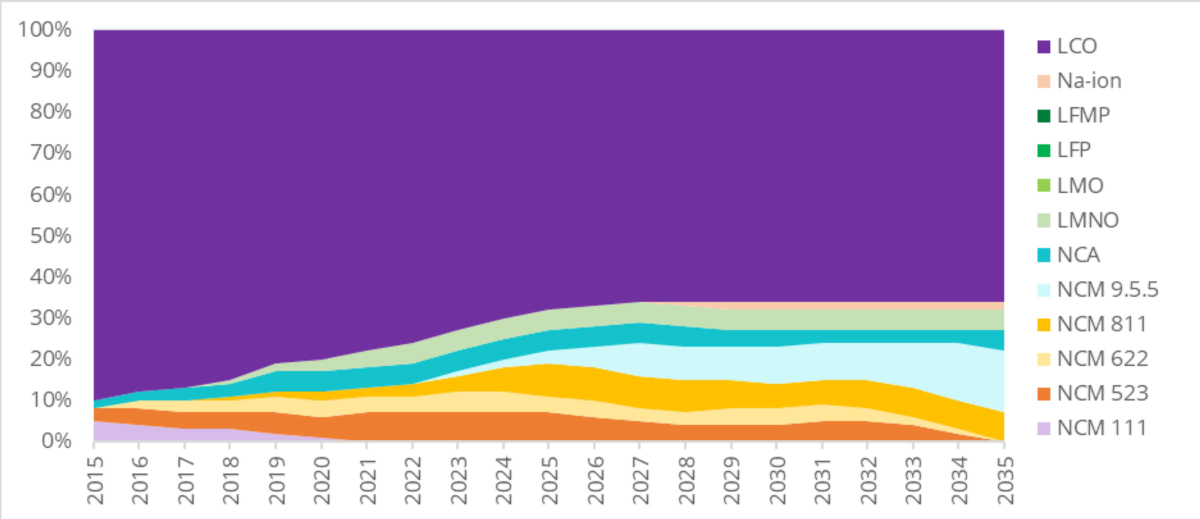
Figure 2.19 Energy Storage Systems (ESS) cathode global market share by technology type



Source: SC Insights

Finally, in the Portable sector there is a historic predominance of LCO, the preferred chemistry (Figure 2.20). However, the gradual growth of Power Tools using NCM is partially changing that trend. Today, over 20% of Portable devices carry an NCM cathode, with some devices even using LMNO. The latter is due to the increase in sales of Computing devices, which usually rely on nickel cobalt manganese oxide cathodes:

Figure 2.20 Portables cathode global market share by technology type



Source: SC Insights

2.5.4 HS Codes

For CAM, the codes for trade stats are the following (Table 2.34):

Table 2.34 Cathode Active Materials HS codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	74031100	Cathodes and sections of cathodes	CAM	Yes	Could include copper cathodes
HS	382499	Cathode active material PNC-P0 1	CAM	-	-
HS	8507.90.8000	Battery cathode material	CAM	-	-

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	28259090	Lithium cobalt oxide	PCAM	No	LCO compounds or Salts
HS	2825.90.9000	Nickel cobalt manganese hydroxide	PCAM/CAM	Both	NCM salts, bases, oxides, hydroxides, peroxides
HS	38249090	Lithium iron phosphate	PCAM/CAM	Both	LFP
HS	750110 / 750120	Nickel-cobalt intermediates	PCAM	No	

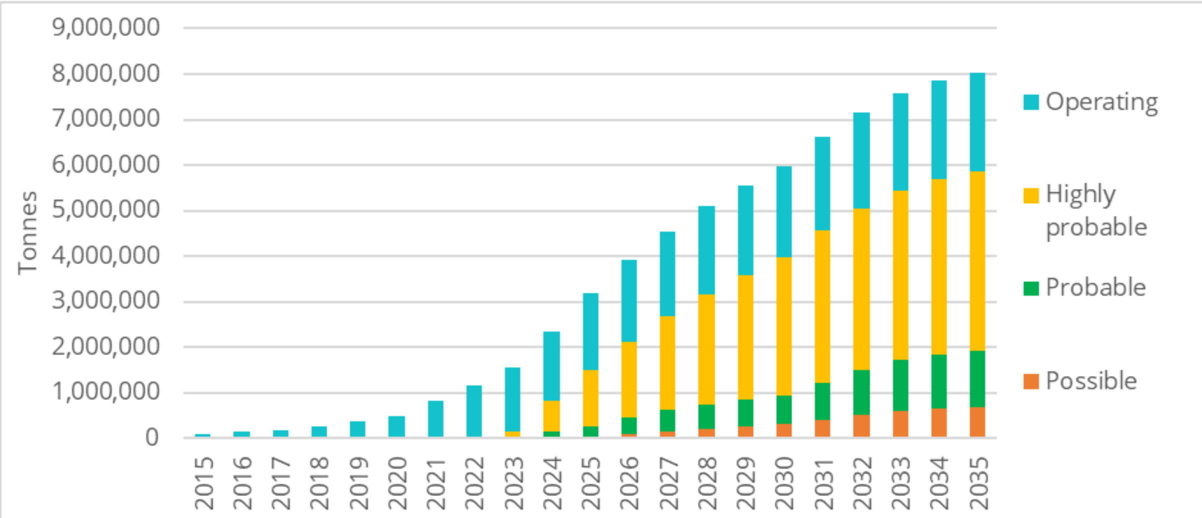
2.6 Anodes

Anode active materials are predominantly composed of graphite, with the majority of global production capacity for these materials being concentrated in China. The two main types of graphite used in LIB cells are natural graphite and synthetic graphite. This element is highly conductive, therefore suitable for high capacity and charging/discharging efficiency.

2.6.1 Capacity and growth

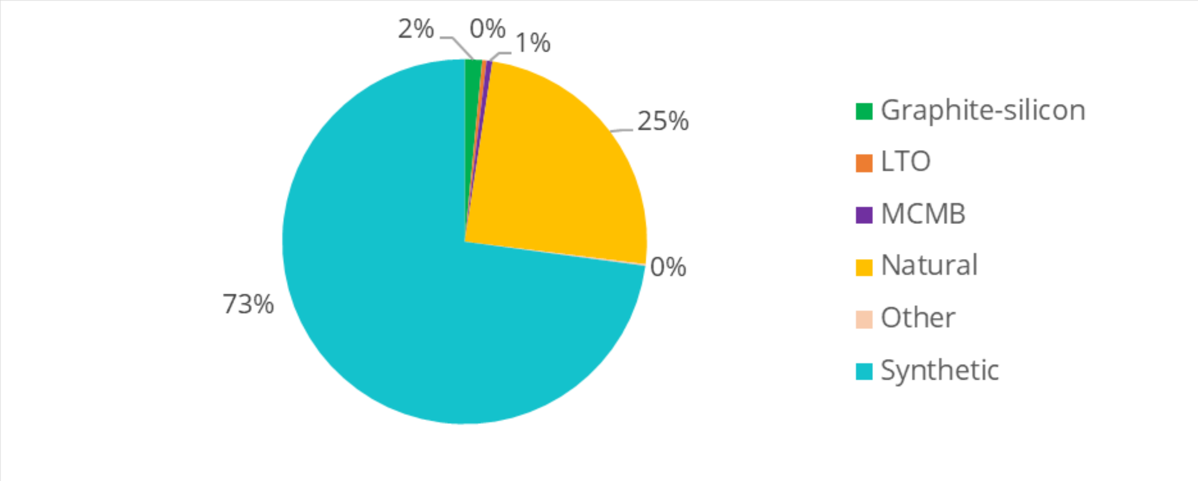
In 2023 numbers, total anode capacity reached 1,550,000 tons, with the possibility of doubling that capacity by 2028 (Figure 2.21). With regards to the deployment capacity, it is pretty much in line with cell demand, doubling every five years. Most of the installed capacity is to produce synthetic graphite, accounting for almost 75% of global output, despite being more expensive than natural flake graphite (Figure 2.22). In the next decade, operating and anode capacity facilities are expected to have a fivefold increase from the 2023 capacity.

Figure 2.21 Anode capacity per status



Source: SC Insights

Figure 2.22 Capacity share per anode group (2024)

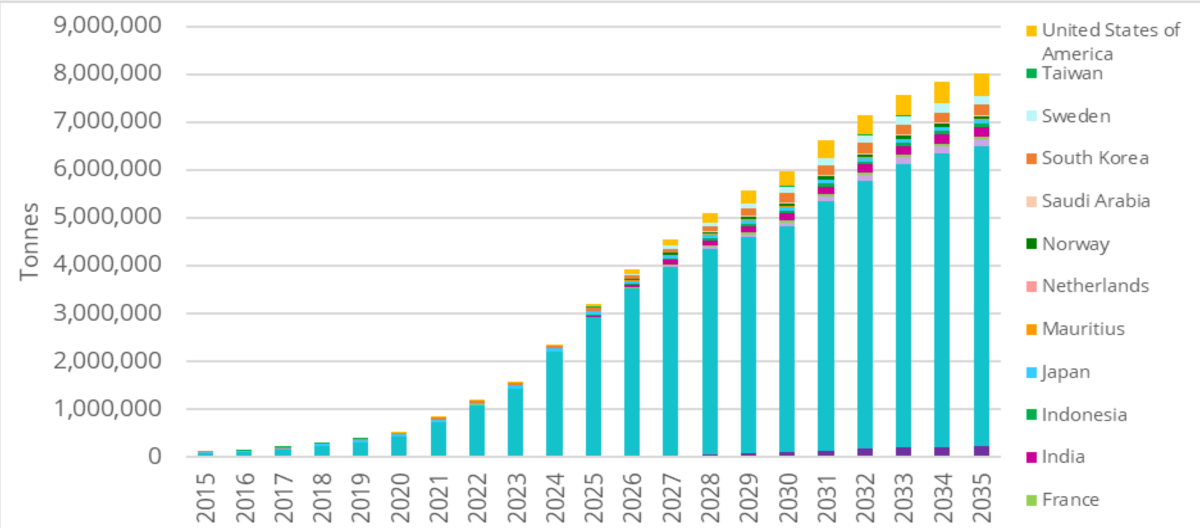


Source: SC Insights

2.6.2 Geographies

Figure 2.23 depicts the forecasted trends for anode capacity until 2035. In terms of anode capacity, the majority is found in China and will continue to be so. Later this decade there will be some attempts to add new capacity outside China, especially in the US, Europe, India and Indonesia. All in all, additional capacity from Rest-of-China will not exceed one million tons, representing almost 20% of the total anode capacity worldwide. In conclusion, at least in the next decade, the industry will continue to be dependent on China for the anode side.

Figure 2.23 Anode capacity per country

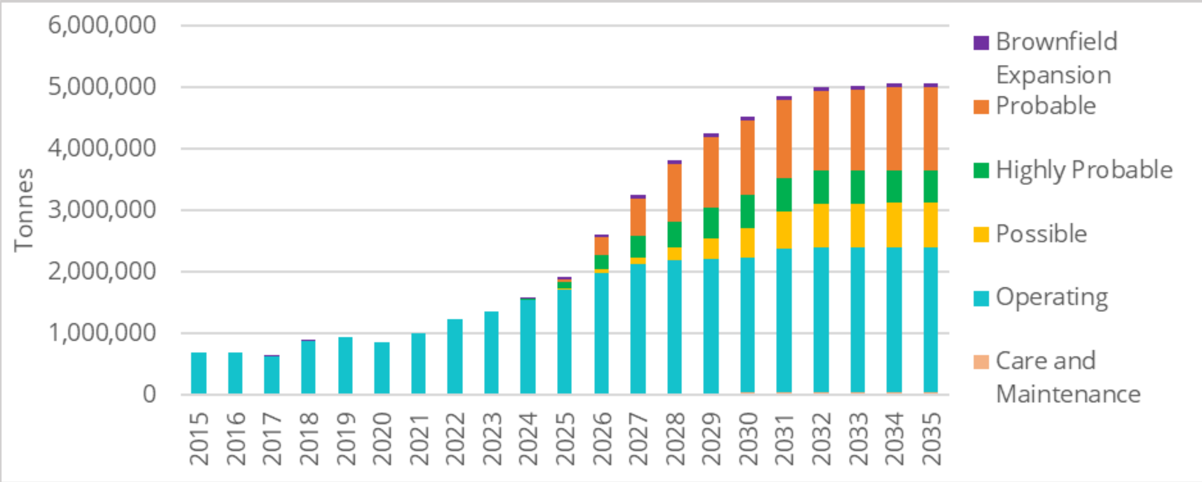


Source: SC Insights

2.6.3 Chemistries

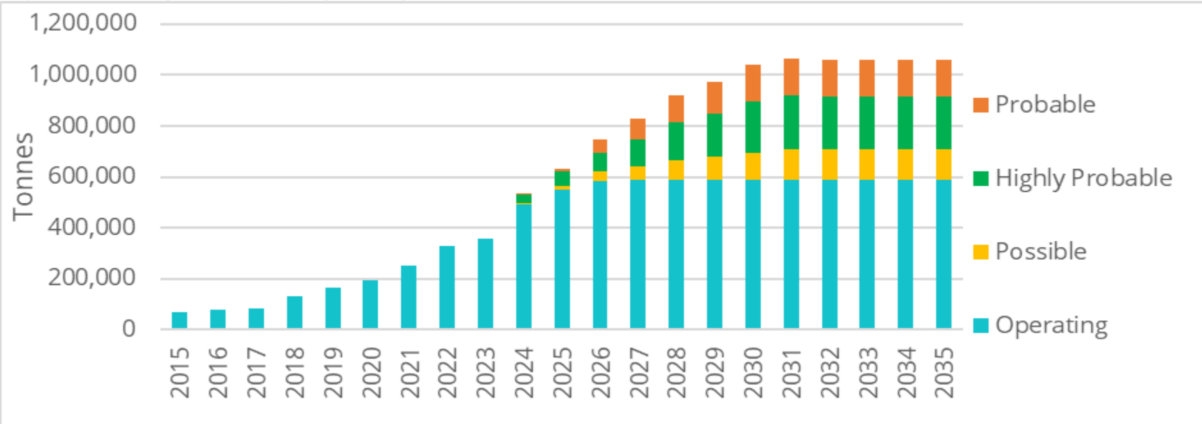
Spherical graphite is a key component in LIB cells, where it is used as an anode. This form of graphite is also known as battery-grade graphite. In addition, natural graphite is also key in the production of anodes, since it represents close to 25% of feedstock. Both elements are expected to triple between 2023 and 2035, as depicted in Figure 2.24 and Figure 2.25.

Figure 2.24 Natural graphite project status



Source: SC Insights

Figure 2.25 Spherical graphite project Status



Source: SC Insights

2.6.4 HS Codes

For Anodes, the codes for trade stats are the following (Table 2.35):

Table 2.35 Anode related HS codes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	250410	Natural Graphite	Anode feed-stock	Both	Powder or Flake
HS	25041010	Natural Graphite	Anode	Yes	Powder or Flakes, Crystalline
HS	25041020	Natural Graphite	Anode		Amorphous
HS	25041090	Natural Graphite	Anode	Both	Classified as other
HS	25041091	Natural Graphite	Anode	Yes	Spherical
HS	25049010	Natural Graphite (Ex Pow-der or Flakes)	Anode	Yes	Micronised
HS	25049090	Natural Graphite (Ex Pow-der or Flakes)	Anode	Both	Classified as other
HS	380110	Artificial Graphite	Anode	Yes	Plates, rods, pow-der and other forms
HS	38012000	Artificial Graphite	Related	No	Colloidal or semi-colloidal graphite
HS	38013000	Artificial Graphite	Related	No	Carbonaceous pastes

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	38019000	Artificial Graphite	Related	No	Other

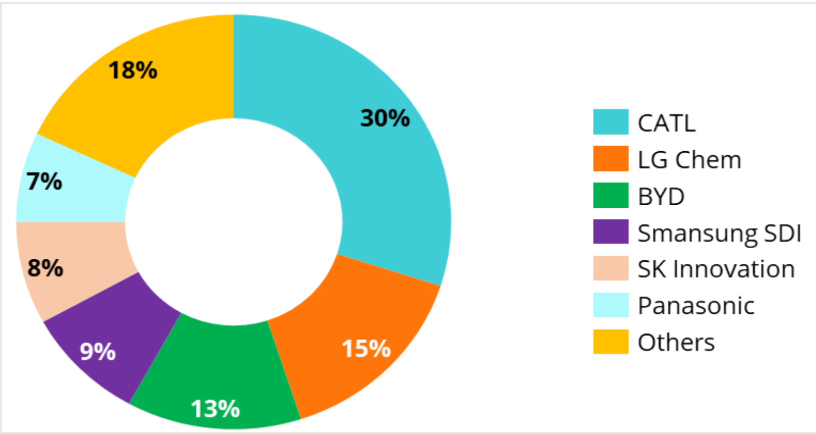
2.7 LIB Cell Manufacturing

Lithium-ion battery (LIB) cell manufacturing has become one of the most important units of analysis and trade throughout the LIB supply chain. And additionally, it has become a topic of debate among experts in the field, especially when talking about the security of supply and the development of new western supply chains.

2.7.1 Capacity

The LIB Cell space has become more concentrated in the last five years, with a remarkable capacity increase from Contemporary Amperex Technology Co. (also known as CATL). This company has managed to increase its capacity above Panasonic, SDI and LG Chem during the past decade. Today it holds 30% of the entire global LIB capacity (Figure 2.23 and Table 2.28), and not only producing for the domestic market but also supporting the sale of western EVs.

Figure 2.26 LIB cells manufacturing capacity per producer



Source: SC Insights

Table 2.36 LIB cell manufacturing capacity per company

Rank	Company	Origin	2023 Capacity (incl expansions)	Share (%)	Presence
1	CATL	China	552 GWh	30%	Global
2	LG Chem	South Korea	172 GWh	15%	Global
3	BYD	China	148 GWh	13%	Global
4	Samsung SDI	South Korea	109 GWh	9%	Global
5	SK Innovation	South Korea	92 GWh	8%	Global
6	Panasonic	Japan	80 GWh	7%	Global

Source: SC Insights

Diving into the CATL strategy, it's quite noticeable the number of operating plants and capacity the company deploys. All plants are dedicated to the production of EV batteries, using prismatic format. With regards to chemistry, it immediately stands out that the company is not only devoted to the production of LFP, on the contrary a large share of its production is devoted to NCM (Funding, their largest plant produces NCM 622). The company is developing the EV Battery Industrial Chain Project with and investment of nearly USD $6 billion that aims to lead the battery industry technology direction for high nickel NCM and ensure the cost competitiveness of NCMs in the competition with LFPs. CATL is also expanding abroad, with their Erfurt plant in Germany totally operational, plus the construction of the new project in Debrecen, Hungary. Below, Table 2.37, the 15 largest plants CATL operates directly:

Table 2.37 Largest plants around the world

Rank	Plant	Country	LIB	Chemistry	Production 2023
1	CATL, Fuding	China	Prismatic	NCM 622	30 GWh
2	CATL/SAIC, Liyang	China	Prismatic	LFP	25 GWh
3	CATL, Liyang	China	Prismatic	LFP	21 GWh
4	CATL, Hudong	China	Prismatic	NCM 622	15 Gwh
5	CATL/FAW Ningde	China	Prismatic	NCM 622	9 GWh
6	CATL, Yibin	China	Prismatic	NCM 811	8 GWh
7	CATL/Dongfeng	China	Prismatic	NCM 811	7.5 GWh
8	CATL, Germany	Germany	Prismatic	NCM 622	7.4 GWh
9	CATL, Cheliwan	China	Prismatic	NCA	6.8 GWh
10	CATL, Xining	China	Prismatic	LFP	5 GWh
11	CATL, Zhaoqing	China	Prismatic	NCM 622	5 GWh
12	CATL, Guiyang	China	Prismatic	LFP	4.5 GWh
13	CATL/GAC Guang-zhou	China	Prismatic	NCM 811	2.1 GWh
14	CATL/Geely, Yibin	China	Prismatic	NCM 811	2 GWh
15	CATL Na-ion	China	Prismatic	Na	2 GWh

Source: SC Insights

CATL's rival and second largest producer LG Chem is developing a strategy targeting geographies outside South Korea: as of today, their largest project (Wroclaw, Poland) is located outside South Korea, with the addition of two (2) strategic projects in the US (Table 2.38). LG Chem and its global strategy is particularly relevant, since the construction of CAM capacity in Indonesia is an ideal partner for any producer of battery materials in the country. Finally, it's worth to mention that all but three plants are dedicated to EVs: the plants producing NCM532 and LCO are exclusive to portable electronics.

Table 2.38 LG Chem LIB plants

Rank	Plant	Country	LIB	Chemistry	Production 2023
1	LG Chem Wroclaw Energy	Poland	Pouch	NCM 622	35 GWh
2	LG Chem Michigan	USA	Pouch	NCM 622	12 GWh
3	LG Chem Korea	South Korea	Pouch	NCM 622	10 GWh
4	LG Chem/Geely	China	Pouch	NCM 622	3.5 GWh
5	LG Chem Korea	South Korea	Cylindrical *	NCM 532	3.5 GWh
6	LG Chem/GM, Lord-stown	USA	Pouch	NCM 811	1.3 GWh
7	LG Chem Korea	South Korea	Pouch *	LCO	0.6 GWh
8	LG Chem Korea	South Korea	Prismatic *	LCO	0.3 GWh

Source: SC Insights

And finally, the third largest player globally; Build Your Dreams also known as BYD. The company has a different strategy compared to CATL and LG Chem, in the sense that the majority of their capacity is deployed in China with medium to low capacity. In terms of chemistry, the company has diversified with EVs, ESS and Portable, with a significant share on LFP. Below, Table 2.39, the 16 largest plants BYD operates directly:

Table 2.39 BYD largest production plants

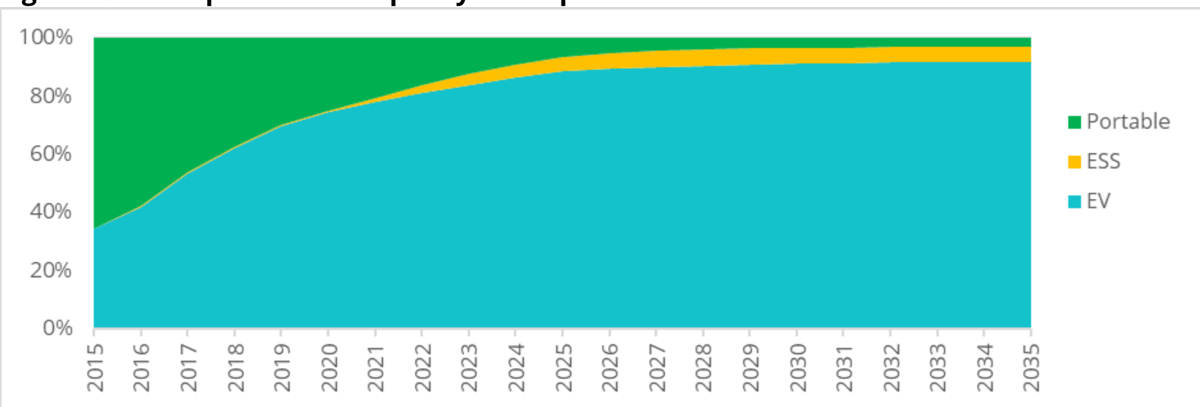
Rank	Plant	Country	LIB	Chemistry	Production 2023
1	BYD Changsha	China	Prismatic	NCM 532	15 GWh
2	BYD, Qinghai	China	Prismatic	NCM 622	12 GWh
3	BYD, Chongqing	China	Other	LFP	12 GWh
4	BYD Xi'an	China	Prismatic	NCM 622	12 GWh
5	BYD, Shenzhen (Kengzi)	China	Prismatic	LFP	10.5 GWh
6	BYD, Yancheng	China	Other	LFP	9 GWh
7	BYD/Changan JV	China	Prismatic	NCM 811	7 GWh
8	BYD Changchun	China	Other	LFP	7 GWh
9	BYD, Guiyang	China	Other	LFP	6 GWh
10	BYD, Zengcheng	China	Pouch	NCM 811	5 GWh
11	BYD, Shengzhou	China	Other	LFP	4 GWh
12	BYD, Huizhou	China	Pouch	LFP	3.5 GWh
13	BYD Xiangyang	China	Prismatic	NCM 811	1.9 GWh
14	BYD Chuzhou	China	Other	LFP	1.5 GWh
15	BYD, Shenzhen (Kengzi)	China	Pouch	LCO	1.4 GWh
16	BYD Bengbu	China	Other	LFP	1 GWh

Source: SC Insights

2.7.2 Geographies

During the last 10 years, the growth of the EVs space has been extraordinary; both in terms of rates and volumes. What started as 440,000 EVs sold in 2015, today has surpassed 10 million units sold. Sales of passenger BEV and PHEVs reached 14.1 million units, while for this year 2024 is expected to reach 18 million, equivalent to a 20% penetration globally. These numbers are exceptional; however, it puts a lot of pressure on the ESS customers when securing those cells, who have to compete with electric vehicles' OEMs in order to secure those cells. The development and share of EVs can be seen in Figure 2.27.

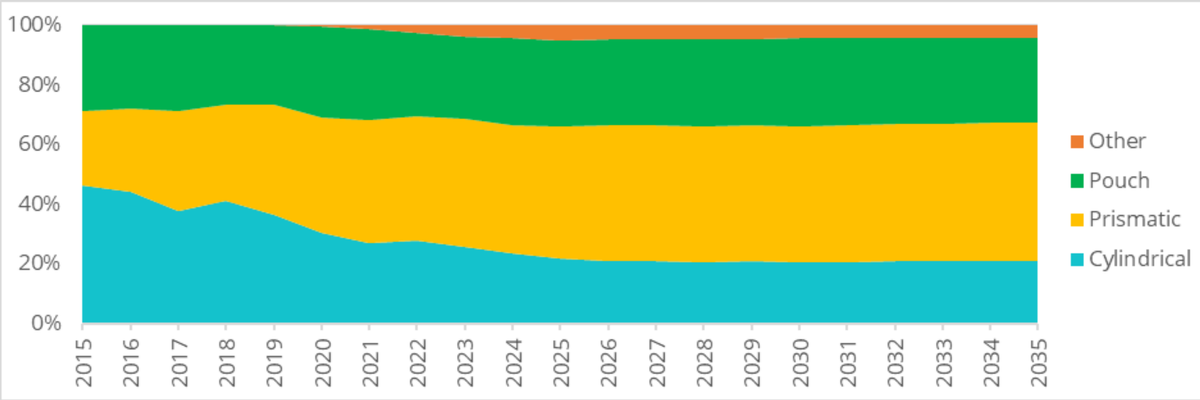
Figure 2.27 Cell production capacity share per end-use



Source: SC Insights

In addition, the discussion regarding what type of design to pick for an electric vehicle is becoming extremely relevant. The preferred cylindrical format, which was quite popular during the last decade, is giving way to pouch and prismatic (Figure 2.28). The latter format has several advantages such as space efficiency, thermal management, safety and an easy integration. Since the prismatic cells are larger than cylindrical, fewer cells are needed to achieve the same amount of energy. This means that fewer connections are needed, which reduces the probability of manufacturing defects.

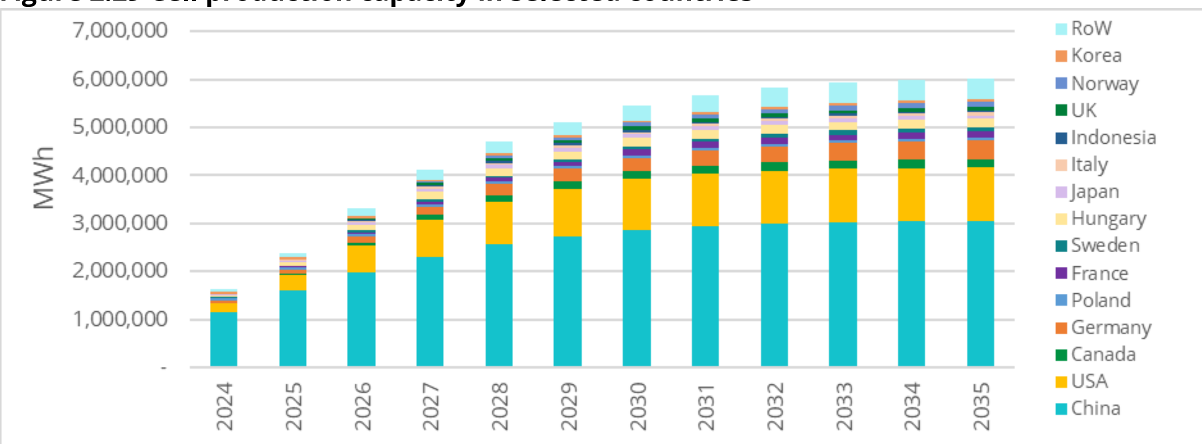
Figure 2.28 Cell production capacity share per cell type



Source: SC Insights

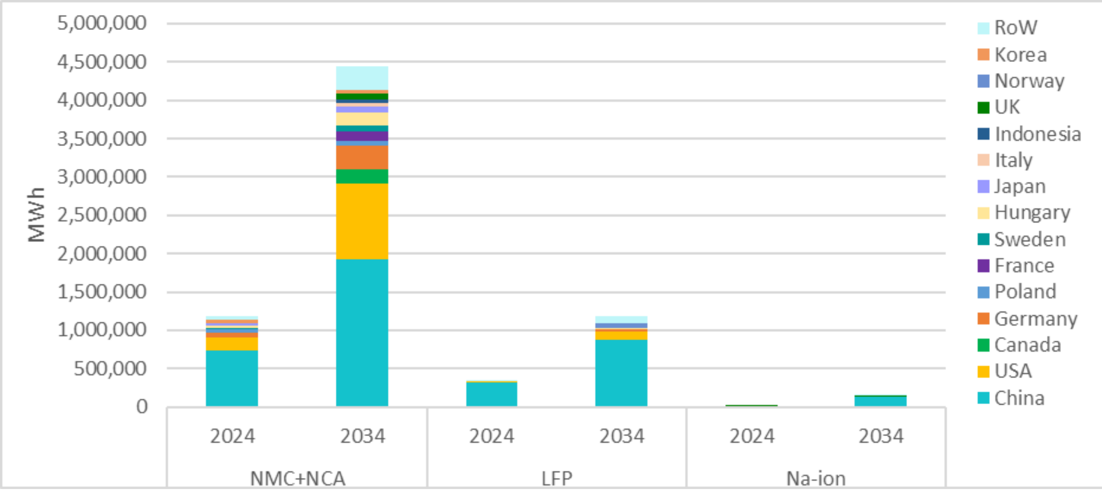
Notwithstanding the above, obviously the dominance of China today is turning this country into a pilar of global supply. (Figure 2.29). Today, China does not only fulfil its domestic supply of cells, but it also dispatches units to western markets. The footprint of Chinese cell manufacturers is also in other geographies, implementing their vast knowledge on the production of NCM cells worldwide (Figure 2.30). However, in ten years from now the cell landscape will see the development of projects outside of China, moderating its share by the mid 2030s. There is enormous potential to develop cell and cathode projects outside traditional Asian markets, such as Europe and the US. In fact, new markets with significant end markets like the EU and the US have even attracted key Asian companies (mainly Chinese, Korean and Japanese) to invest strategically. Figure 2.31 shows the origin of investments (Northamerican, European and Asian) for four (4 quadrants) different parts of the global LIB supply chain: i) Investments in the North American CAM sector, ii) Investments in the North American LIB cell sector, iii) Investments in the European CAM sector, and finally iv) Investments in the European LIB cell sector. All quantities measured in MWh invested.

Figure 2.29 Cell production capacity in selected countries



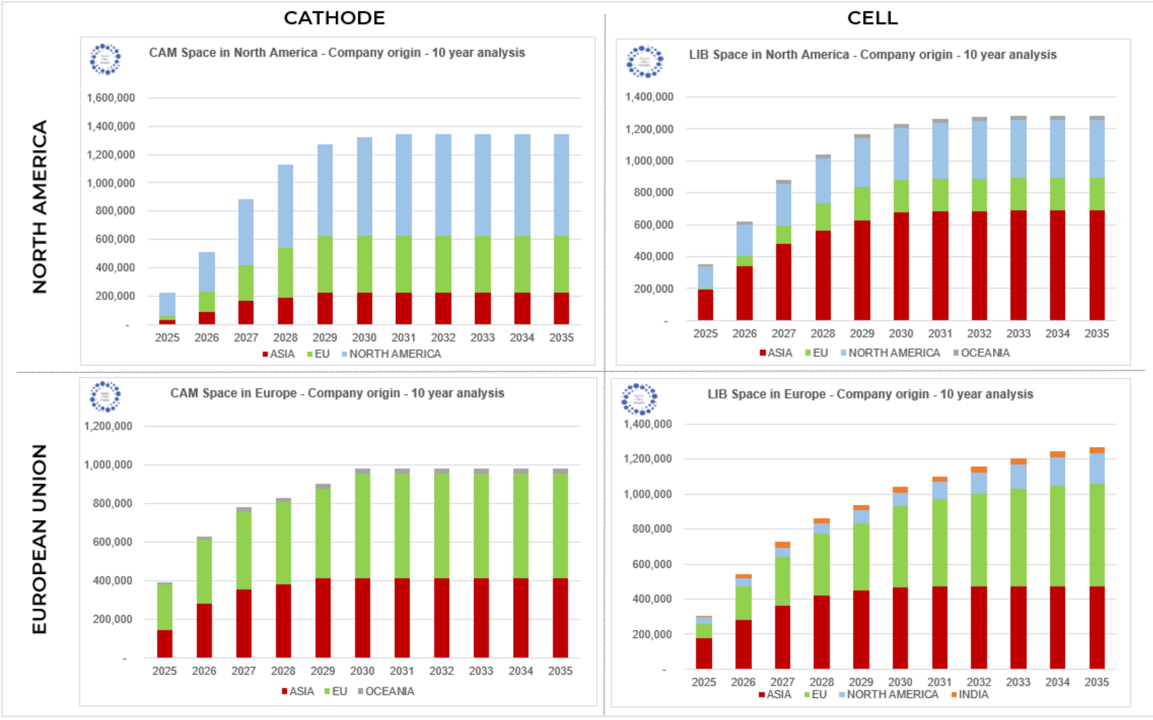
Source: SC Insights

Figure 2.30 Battery cell - Production capacity in 2035



Source: SC Insights

Figure 2.31 Origin of CAM/LIB cell investments for EU and US



Source: SC Insights

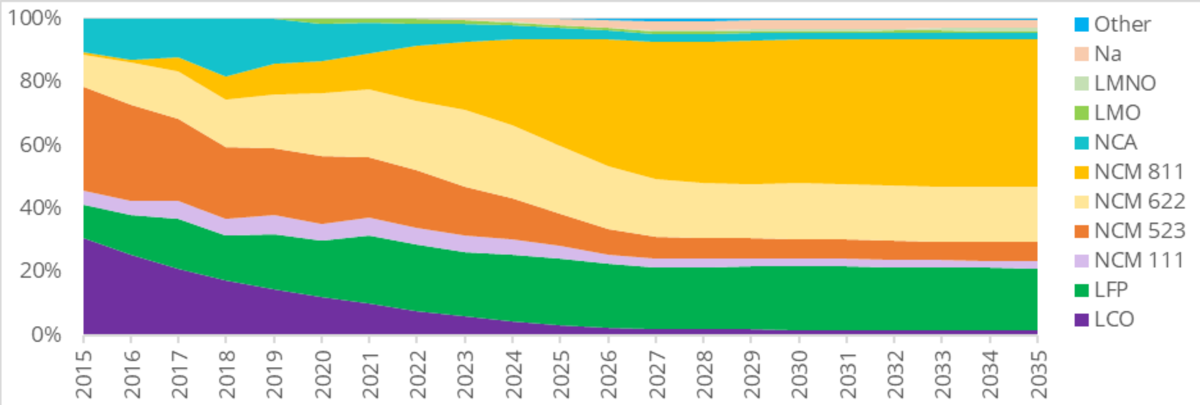
2.7.3 Chemistries

Cell capacity follows the indications of OEMs globally and has a direct relationship with the strategy/targets that these corporations set. Before the pandemic, there was consensus regarding how well balanced the market was among chemistries. It seemed rational to the sector that all chemistries would coexist. Today that theory needs to be revised, in the sense that the market is focusing more and more on producing primordially three chemistries: NCM811, NCM622 and LFP. NMC batteries hold 60% of the market share[51] in the EV market, specifically the NCM811 variant provides a balance between cost, safety and capacity, making it a popular choice in the EV segment. Lithium iron phosphate is not only a great alternative to control the costs on an electric vehicle, but also a feasible technological alternative for ESS. It is also quite remarkable how many Chinese players are

[51] *IEA (2023), Global EV Outlook 2023, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2023, Licence: CC BY 4.0*

mastering the production of NCM811, which explains why the global cell production capacity is biased towards high nickel chemistries. And also, why there is so much interest for Chinese players to keep lithium and nickel mining/refining margins under control. The latter trends are presented in the following figure:

Figure 2.32 Cell production capacity share per chemistry



Source: SC Insights

The predominance of Chinese battery production is not only limited to LFP, but also spreading to NCM. However, to offset that, several areas have noticed the importance of developing their own LIB supply chain, such is the case of the US. Through the implementation of the Inflation Reduction Act (IRA) and the strategy of several Korean players (LG Chem and SK Innovation included), the US response has been to speed up the construction of gigafactories, mainly to support EVs deployment. For 2028, the ten largest cell manufacturing plants in the US will be the following:

Table 2.40 Ten largest cell manufacturing plants projected in 2028

Rank	Plant	Country	LIB	Chemistry	Capacity 2028
1	Tesla Gigafactory 5	USA	Cylindrical	NCM 811	95 GWh
2	Tesla Gigafactory 1 - US expansion	USA	Cylindrical	NCM 811	85 GWh
3	Statevolt, imperial Valley	USA	Prismatic	NCM 811	46 GWh
4	Tesla Gigafactory 1	USA	Cylindrical	NCA	35 GWh
5	LG/Honda Fayette	USA	Pouch	NCM 811	34 GWh
6	Tesla Megapack factory	USA	Cylindrical	NCM 811	34 GWh
7	Gotion, Manteno	USA	Prismatic	NCM 811	34 GWh
8	LG Chem, Arizona	USA	Cylindrical	NCM 811	31 GWh
9	SK / HMG Bartow	USA	Pouch	NCM 811	30 GWh
10	LG Hyundai Savannah	USA	Pouch	NCM 811	30 GWh

2.7.4 HS Codes

For lithium-ion cells, the codes for trade stats are the following (Table 2.41):

Table 2.41. Harmonized system codes for lithium-ion cells

Source	Code	Description	LIB Supply chain	Finished product	Notes
HS	85076000	Secondary lithium batteries	LIB	Yes	-
HS	8507600010	Secondary lithium batteries	LIB	Yes	Lithium-ion batteries used as the primary power source for electrically powered vehicles
HS	8507600010	Secondary lithium batteries	LIB	Yes	Other lithium-ion batteries
HS	8506	Primary cells and primary batteries	Related	Yes	-
HS	85065000	Primary cells and primary batteries	Related	Yes	Lithium primary cells and batteries
HS	8506509090	Primary cells and primary batteries	Related	Yes	Other lithium primary cells and batteries
HS	8507	Electric accumulators, including separators	Related	Yes	-
HS	85078000	Electric accumulators, including separators	Related	Yes	Other accumulators

2.8 End of Life

As the demand for secondary batteries increases, managing their lifecycle sustainably becomes crucial. When a battery reaches its End of Life, proper management before final disposal can mitigate risks related to the leakage of flammable and hazardous electrolytes into the environment, while also recovering valuable materials contained within the battery. This approach helps address raw material supply insecurities and price fluctuations.

Once a battery has reached the End-of-its first life, several options can be considered: i) Repurposing the battery for a second life in less demanding applications, ii) Recycling of scrap; and iii) End-of Life Recycling systems. These systems involve collecting End-of-Life batteries, breaking them down into their core components and processing them to create new batteries and other products.

Recycling used batteries, along with the device containing them, will mitigate emerging challenges associated with the clean energy transition and avert issues stemming from improper battery disposal. Spent EV batteries contain valuable minerals essential to produce new batteries, and recycling can therefore contribute significantly to meeting the growing demand.

2.8.1 Repurpose

The reuse of batteries refers to the practice of taking used batteries, especially used EV batteries, and repurposing them for other applications. When the battery pack's capacity drops below 80% of its nominal level, it can no longer perform effectively in a mobile application, leading to a reduced range. Consequently, it becomes necessary to replace the battery with a newly installed unit to restore expected performance levels.[52] Despite spent EV batteries being no more able to meet EV performance standards, following manufacturing, these batteries retain sufficient performance capabilities to be utilized in less-

[52] *See e.g. M K Al-Alawi, J Cugley and H Hassanin, 'Techno-economic feasibility of retired electric-vehicle batteries repurpose/reuse in second-life applications: A systematic review' 3 Energy and Climate Change (2022), 100086.*

demanding applications, such as stationary energy storage applications.[53] The significant potential for the second life of EV batteries has prompted major automotive companies to explore second-life applications for these used batteries.[54]

2.8.2 Recycling of scrap

As gigafactories continue to refine their manufacturing processes, recovering valuable materials from battery manufacturing scraps may emerge as an alternative to reducing raw material extraction, especially since end-of-life batteries take about 10 years to become suitable for recycling.

Manufacturing scraps include byproducts and waste generated during production and assembly[55]., as well as batteries that are defective or rejected during quality control stages. Additionally, raw materials can be recovered during R&D and cell manufacturing, as the coating process is a major contributor to high rejection rates in current battery cell production. Recycling manufacturing scraps could become a primary source of materials for battery production in the coming decade.

2.8.3 End of Life (EOL) LIB Recycling

LIB Recycling, on the other hand, encompasses techniques employed to recover resources, such as metals and other chemical materials, from the electrodes of batteries.[56] For lithium-ion battery recycling there are currently two main methods: (1) pyrometallurgy; and (2) hydrometallurgy.[57]

- **Pyrometallurgy**: This method involves high temperatures. The batteries are heated up in a furnace, causing them to melt to recover the active cathode material. As they melt, the different metals inside, like lithium, cobalt, and nickel, separate out. This method can be effective, but it can also be energy-intensive and may produce emissions. The biggest players that utilise pyrometallurgy include Umicore, Nickelhütte AUe, Nippon Recycle Center Copr and Glencore.
- **Hydrometallurgy**: This method encompasses pretreatment to recover the cathode materials followed by leaching and subsequent purification and recovery techniques such as selective precipitation, ion exchange, and solvent extraction to extract the valuable metals (Figure 2.33). This method tends to be less energy-intensive and can be

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[53] *H Rallo, L Canals Casals, D De La Torre, R Reinhard, C Marchante and B Amante, 'Lithium-ion battery 2nd life used as a stationary energy storage system: Ageing and economic analysis in two real cases' 272 Journal of Cleaner Production (2020), 122584; H Engel, P Hertzke and G Siccardo, Second-life EV batteries: The newest value pool in energy storage (McKinsey and Company 2019), available at https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Second%20life%20EV%20batteries%20The%20newest%20value%20pool%20in%20energy%20storage/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage.ashx*

[54] *Fraunhofer ISI, Lithium-Ion Battery Roadmap -- Industrialization Perspectives Toward 2030 (December 2023, Fraunhofer ISI), available at "https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/Fraunhofer-ISI_LIB-Roadmap-2023.pdf, pp. 64-65.*

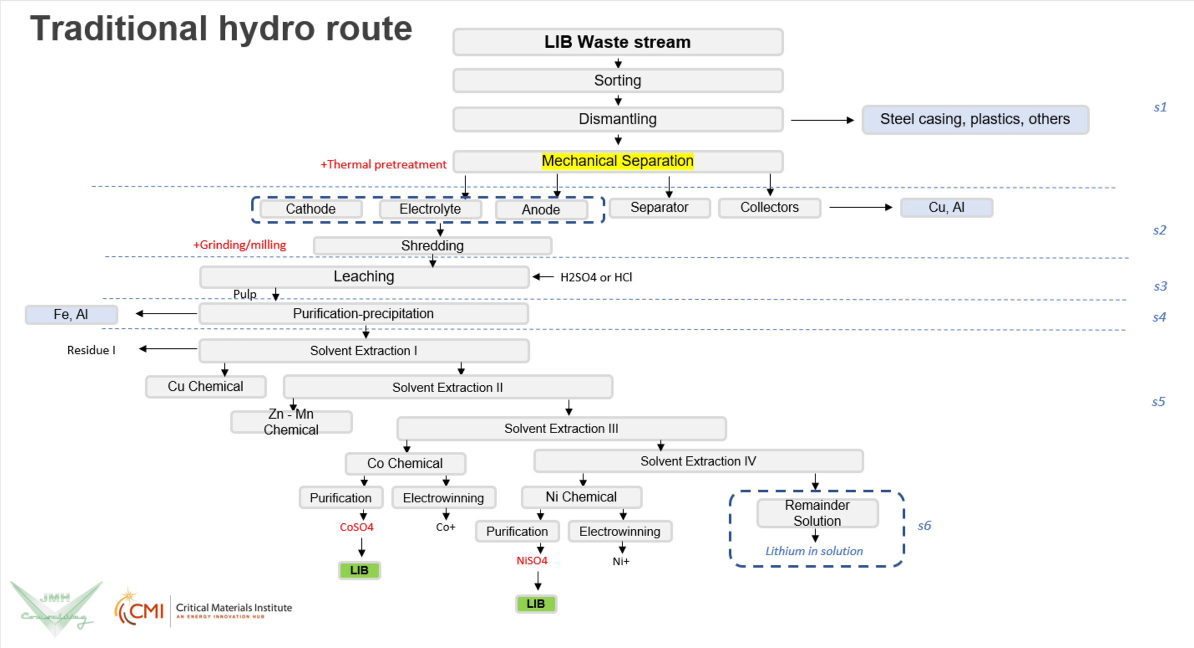
[55] *Lu Yu, Yaocai Bai, Bryant Polzin, Ilias Belharouak, Unlocking the value of recycling scrap from Li-ion battery manufacturing: Challenges and outlook, Journal of Power Sources, Volume 593, 2024, 233955, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2023.233955.*

[56] *H Engel, P Hertzke and G Siccardo, Second-life EV batteries: The newest value pool in energy storage (McKinsey and Company 2019), available at https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Second%20life%20EV%20batteries%20The%20newest%20value%20pool%20in%20energy%20storage/Second-life-EV-batteries-The-newest-value-pool-in-energy-storage.ashx*

[57] *Lithium-Ion Battery Recycling', United States Environmental Protection Agency, available at* https://www.epa.gov/hw/lithium-ion-battery-recycling

more environmentally friendly[58]. Hydrometallurgy is utilised in particular by BASF, SungEel HiTech, AVE Green Recycling, and Neometals [59]. A typical hydrometallurgical flowsheet looks like this:

Figure 2.33 Hydrometallurgical processing flowsheet



Source: JMH Consulting, Critical Material Institute (CMI)

Both processes involve batteries being disassembled into their components, with ultimately battery cells crushed to segregate the various minerals they contain. These materials are then repackaged and sold back to battery manufacturers to produce new batteries. Many of these components are infinitely recyclable, allowing for repeated use and reuse.[60]

In addition to these, direct recycling conserves energy by maintaining the highly engineered cathode structure, which is the most valuable component of the lithium-ion battery. This approach minimizes the manufacturing processes required to recycle these materials into a new battery.[61] However, direct recycling is still in its development phase.[62]

While most battery recycling companies operate as independent recyclers, original equipment manufacturers, battery producers, miners, and processors are beginning to enter the market.[63] This development is also driven by legislative obligations, which has led

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[58] *Brian Makuza, Qinghua Tian, Xueyi Guo, Kinnor Chattopadhyay, Dawei Yu, Pyrometallurgical options for recycling spent lithium-ion batteries: A comprehensive review, Journal of Power Sources, Volume 491, 2021, 229622, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2021.229622. (https://www.sciencedirect.com/science/article/pii/S0378775321001671*

[59] *Fraunhofer ISI, Lithium-Ion Battery Roadmap -- Industrialization Perspectives Toward 2030 (December 2023, Fraunhofer ISI), available at "https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/Fraunhofer-ISI_LIB-Roadmap-2023.pdf, p. 64.*

[60] *ibid.*

[61] *ibid.*

[62] *Fraunhofer ISI, Lithium-Ion Battery Roadmap -- Industrialization Perspectives Toward 2030 (December 2023, Fraunhofer ISI), available at "https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/Fraunhofer-ISI_LIB-Roadmap-2023.pdf, p. 64.*

[63] *IEA, Global Supply Chains of EV Batteries (IEA Publications 2022), p. 25.*

companies to establish joint ventures. For example, Extended Producer Liability obligations under the EU's Sustainable Batteries Regulation holds battery producers accountable for the environmental impacts of their batteries through the lifecycle of the battery.[64]

Although long-term resource scarcity is not anticipated, potential undersupply in the short to medium term is attributable to insufficient investment in upstream activities.[65] Bridging the gap between demand and supply could therefore benefit from policy and legislative frameworks that support the development of recycling technologies.

Given that EV batteries must first be utilized before they can be repurposed or recycled, it will take time until the secondary supply chain is established. In addition, it should be noted that the empirical data on battery lifetimes is still relatively scarce and future developments regarding Vehicle-to-Grid technologies becoming more common might alter the cycle life requirements of batteries.[66] Similarly, reuse in second-life applications will postpone recycling.[67]

The growing volume of returned batteries enhances the economic appeal of recycling, leading to the emergence of initial market activity in this sector: the conventional lithium-ion batteries contain numerous valuable key minerals, notably cobalt, nickel and lithium that make recycling economically attractive. In particular, cobalt and lithium are the most valuable of these minerals.[68] This is significant especially in the context of the NMC/NCA chemistry.

In turn, the proliferation of LFP batteries presents significant challenges for battery recycling, primarily due to the limited profitability in recovering iron and phosphorus.[69] In the absence of high-value metals such as nickel and cobalt, the economic return from recycling LFP batteries is substantially diminished when compared to traditional recycling methods, thereby raising concerns about their overall economic feasibility.[70]

The new opportunities provided by spent lithium-ion battery recycling has accelerated significantly the establishment of lithium battery recycling facilities in particular in the EU and North America. In 2023, approximately 40 companies in Canada and the US, along with 50 in Europe, either recycled lithium batteries or intended to start doing so. Partnerships formed between automotive manufacturers and battery recyclers aim to provide the automotive sector with reliable sources of battery materials.[71]

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[64] *Article 56 of the Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66&EC, OJ L 191, 28.7.2023, p. 1-117.*

[65] *IRENA, Geopolitics of the Energy Transition: Critical Materials (IRENA 2023), p. 28.*

[66] *Fraunhofer ISI, Lithium-Ion Battery Roadmap -- Industrialization Perspectives Toward 2030 (December 2023, Fraunhofer ISI), available at "https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/Fraunhofer-ISI_LIB-Roadmap-2023.pdf, p. 18.*

[67] *ibid., p. 76.*

[68] *Fraunhofer ISI, Lithium-Ion Battery Roadmap -- Industrialization Perspectives Toward 2030 (December 2023, Fraunhofer ISI), available at "https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2023/Fraunhofer-ISI_LIB-Roadmap-2023.pdf, p. 65.*

[69] *'NMC to LFP transition poses battery recycling challenge' November 29, 2023, Argus, available at https://www.argusmedia.com/en/news-and-insights/latest-market-news/2513976-nmc-to-lfp-transition-poses-battery-recycling-challenge*

[70] *IEA, Global Supply Chains for EV Batteries (IEA Publications 2022), p. 13.*

[71] *U.S. Geological Survey, 'Mineral Commodity Summaries 2024' (U.S. Geological Survey 2024), p. 110.*

Given the current state of technological development, the recycling processes for solid-state batteries have remained insufficiently explored[72], however recent publications indicate emerging opportunities in this field.[73]

[72] *L Azhari, S Bong, X Ma and Y Wang, 'Recycling for All Solid-State Lithium-Ion Batteries' 3 (6) Matter (2020), pp. 1845-1861.*
[73] *Y-C Lan, PH Lai, B D Vo and E D Gomez, 'interfacial Layers to Enable Recyclability of All-Solid-State Lithium Batteries', 9 (7) ACS Energy Letters (2024).*

3 Resource availability and production capacity in Indonesia

Indonesia's mineral resources, particularly nickel, cobalt, and manganese, are vital in battery industries. However, the rapid extraction of these materials raises concerns about long-term sustainability. This section will explain the availability of these key resources.

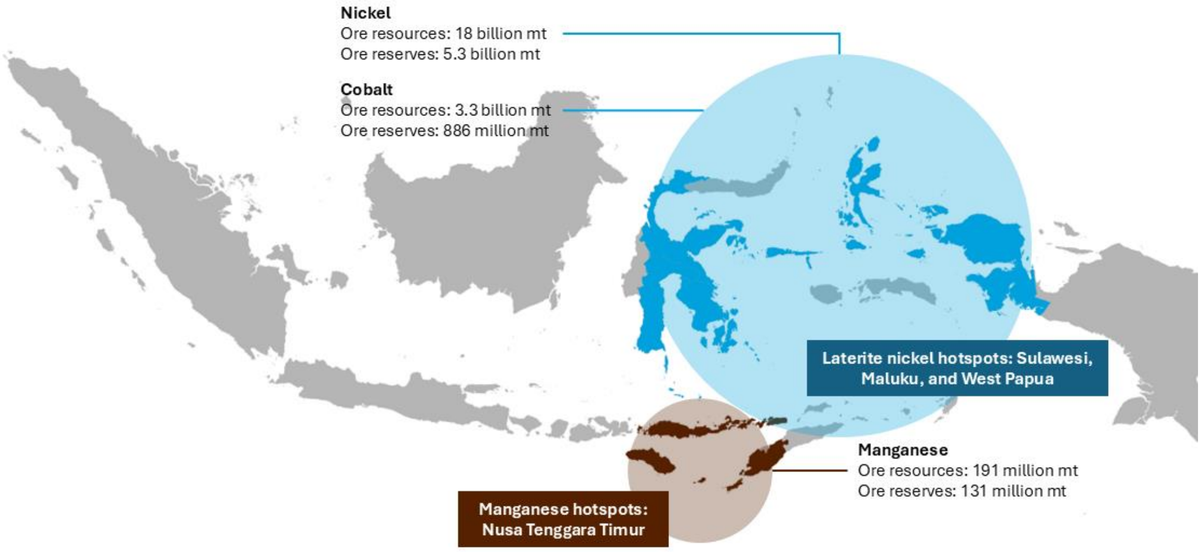
3.1 Resource availability

Indonesia is home to one of the largest laterite nickel deposits in the world[74]. It holds about 20% of global nickel reserves[75]. Per MEMR[76] data, Indonesia has 18 bn mt and 5.3 bn mt of nickel resources and reserves, respectively. Nickel hotspots are reported in Sulawesi, North Maluku, and Papua. Through laterite limonite nickel, Indonesia can extract cobalt. The country has 3.3 bn mt and 886 million mt of cobalt resources and reserves[76], accounting for 7.2% of global cobalt reserves[77].

As for manganese, Indonesia holds 3.8% of global reserves[78]. Recent MEMR[76] data shows that there are 191 million mt of resources and 131 million mt of reserves. Manganese is reportedly most abundant in Nusa Tenggara Timur (NTT)[78].

Figure 3.1 shows an overview of the distribution of these minerals in Indonesia.

Figure 3.1 Laterite nickel and manganese hotspots in Indonesia



Source: MEMR, 2024[83]

[74] *Marsh, Erin & Anderson, Eric & Gray, Floyd. (2013). Nickel-Cobalt Laterites—A Deposit Model.*
[75] *Purwanto, N. P. (2024). Government Policy to Maximize Nickel Potential in Indonesia. Info Singkat A Brief Study of Actual and Strategic Issues Vol. XVI No. 20/II/Pusaka/October/2024*
[76] *MEMR Decree No. 132.K/GL.01/MEM.G/2024 on National Minerals and Coal Resources and Reserves Balance in 2023*
[77] *Government of Canada. (2023). Cobalt facts.*
[78] *MEMR. (2021). Peluang Investasi Mangan di Indonesia*

3.1.1 Laterite nickel

Indonesia's nickel ore consists of two types: saprolite (iron-rich, contains 1.5 - 3.0% Ni) and limonite (contains 0.8 - 1.5% Ni and 0.1 - 0.2% Co)[79]. The iron-rich saprolite ore is used to produce ferronickel (FeNi), nickel pig iron (NPI), and nickel matte, which supplies the steel industry and makes up 70% of Indonesia's nickel demand[80]. The cobalt-containing limonite ore is used to supply the battery industry through products such as mixed hydro precipitate (MHP), nickel sulphate (HS 28332400), and cobalt sulphate (HS 28332990). Nickel matte (HS 75011000) has also recently been used to feed into the battery sector[81].

Per data from the Indonesia Nickel Miners Association (APNI), Indonesia has an annual nickel ore demand of 240.1 million mt for saprolite ore and 48.2 million mt for limonite ore (Table 3.1). The number of currently operating smelters is 49 pyrometallurgy and 5 hydrometallurgy smelters[82]. These numbers are projected to grow to 120 pyrometallurgy and 27 hydrometallurgy smelters by 2026, with an expected ore demand of 584.9 million mt and 150.3 million mt, respectively[83].

Table 3.1 Current status of nickel production in Indonesia

Type of Nickel Ore	Nickel content (%)	Reserves (million mt)*	Processing	Products	Demand (million mt/year)*		
					Operating (Current)	Construc-tion	Plan
Saprolite	1.5-3.0	3,688.6	Pyrometal-lurgy	FeNi, NPI, nickel matte	240.1	150.3	194.5
Limonite	0.8-1.5	1,554.9	Hydromet-allurgy	MHP	48.2	33.6	68.5

*2022 data

Source: Indonesia Nickel Miners Association, 2024[83]

Based on this data, the Indonesia Nickel Miners Association projected that saprolite and limonite ore reserves would deplete in 6 and 10 years, respectively[84]. MEMR and MOI have discussed moratorium plans to manage this issue[85], yet no such policy has come to fruition. There is a risk that Indonesia may not be able to secure its resources beyond the processing stage. Accelerated ore processing that is not met with developed battery manufacturing can drive processed metals to be exported overseas.

Indonesia has the target to produce 600,000 EV units by 2030, which would require 37,600 tons of nickel, assuming all EVs use NMC811 batteries. According to MEMR, the country has 184,606,736 thousand tons of metal nickel including inferred, indicated and measured resources (Table 3.2), which means they have enough nickel resources to cover their national production target and still have a large amount of resources to produce EVs for the international market.

[79] *Nikel 101: Perbedaan Produk Akhir NCKL, MBMA, INCO, dan ANTM (stockbit.com 2023)*

[80] *Dua Teknologi Smelter Nikel di Indonesia, Mana yang Ramah Lingkungan? (Tempo 2024)*

[81] *Tsingshan starts producing EV battery raw material nickel matte in Indonesia (Mining.com 2021)*

[82] *Dua Teknologi Smelter Nikel di Indonesia, Mana yang Ramah Lingkungan? (Tempo 2024)*

[83] *Indonesia Nickel Miners Association. (2024). Unveiling Indonesia's Nickel Potency in Orchestrating Global Battery Manufacturing Excellence. International Battery Summit 2024.*

[84] *Per PE2 (December 12th 2024), the Director of Mineral Business Development MEMR addressed that this projection is based on current exploration data which amounts to 30-40% of permitted concessions, revealing more than 50% left untapped. More exploration studies are required to update this projection.*

[85] *Pemerintah Sepakat! Moratorium Smelter Nikel RKEF (CNBC Indonesia 2024)*

Table 3.2 Nickel resources and reserves in Indonesia (in thousand mt)

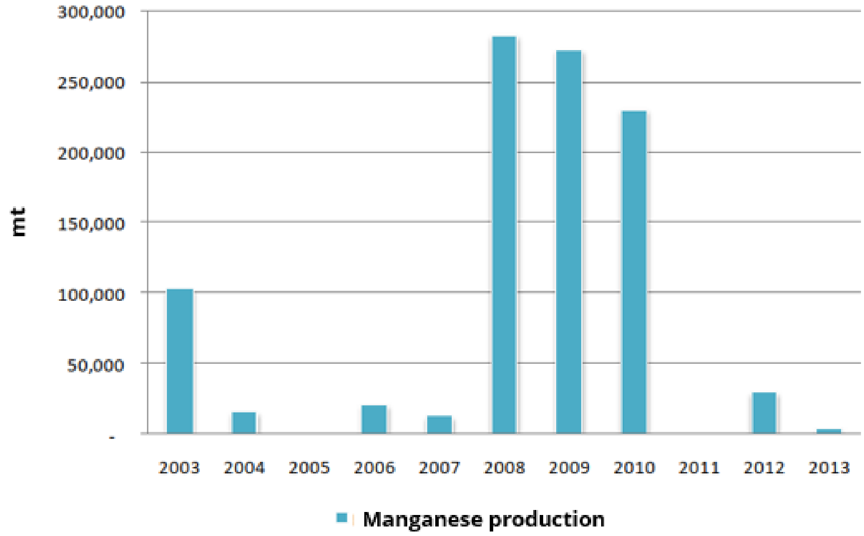
Resources						Reserves			
Inferred		Indicated		Measured		Probable		Proved	
Ore	Metal	Ore	Metal	Ore	Metal	Ore	Metal	Ore	Metal
8,677,763,011	92,232,207	6,108,117,892	55,585,949	3,764,477,225	36,785,580	3,423,289,094	35,910,615	1,902,501,747	20,206,573
TOTAL						TOTAL			
Ore: 18,550,358,128						Ore: 5,325,790,841			
Metal: 184,606,736						Metal: 56,117,187			

Source: MEMR, 2024[86]

3.1.2 Manganese

There is very limited public information on Indonesia's manganese sector. The most recent recorded production capacity was 4,912.5 mt in 2020[78]. A 2017 MEMR report shows that manganese production between 2003 and 2013 had seen fluctuations (as presented in Figure 3.2), particularly in relation to the introduction of the raw ore export ban[87]. No production was recorded in 2023[88].

Figure 3.2 Manganese production between 2003 and 2013 in Indonesia



Source: MEMR, 2017[87]

Manganese refining is reported to be present domestically, but only for ferromanganese and silico-manganese products[87]. Battery-related products, such as manganese oxide and manganese dioxide, are reportedly due for smelter development by PT Gulf Mangan Grup[94] in NTT. Located closer to manganese hotspots, the smelter's development is expected to stimulate manganese extraction, yet the development has been difficult since 2015[89, 90].

Per Presentation Event 2 (PE2) on December 12th 2024[90], the Directorate of Mineral Business Development MEMR addressed that no manganese production has been reported

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[86] *Per PE2 (December 12th 2024), as presented by the Director of Mineral Business Development MEMR.*

[87] *MEMR. (2017). Kajian Dampak Hilirisasi Mineral Mangan Terhadap Perekonomian Regional. Pusat Data dan Teknologi Informasi Energy dan Sumber Daya Mineral.*

[88] *Gulf Manganese Corporation Limited. (2015). Gulf Manganese – Timor Smelter Update – Licensing.*

[89] *Ayodhia Klarifikasi Lagi Investasi Smelter Mangan di Pulau Timor (KatongNTT.com 2023)*

[90] *Presentation Event 2 - Battery Value Chain for Energy Transition in Indonesia – Engagement session carried out the past December 12th 2024, in Jakarta Indonesia.*

per annual reports collected from concession holders. There is limited information on the current demand for manganese products, particularly for the battery industry.

3.2 Battery production capacity

In general, Indonesia's battery supply chain is aimed at EV production. As addressed in PE2, the main focus of Indonesia's battery supply chain is nickel-based lithium-ion batteries, particularly NMC[91]. NMC batteries promote domestic resource absorption, particularly nickel, cobalt, and manganese. LFP batteries are also assembled in Indonesia using imported materials to compensate for the country's lack of lithium resources[92,93] (see 3.2.2 Refining for more on lithium-processing facilities and Figure 3.3 for the overall supply chain flow).

Indonesia has a robust mining and refining sector, particularly for nickel. According to the Ministry of Investment, the country has the potential to become one of the top five global battery manufacturers by 2040, with a total production capacity of 650 GWh per year, accounting for 10% of the global battery demand. However, the rate of nickel production in the last two years[94] was not well absorbed by domestic battery manufacturing. That said, new battery manufacturing facilities (i.e., cathode, anode, battery cell, and assembly) opened in 2024, leading to the promise that domestic resources could be better utilized. This year's rapid growth of battery production represents the industry gaining immense support from multi-stakeholders.

3.2.1 Mining

Indonesia has an established nickel mining industry with an annual production of 175,617,183 mt. Some of the largest nickel mining concessions are located in Sulawesi, North Maluku, and West Papua[83].

However, the same cannot be said about manganese. Apart from seeing no production in 2023, manganese extraction has not been stable since the introduction of the raw ore export ban (see subchapter 3.1.2 Manganese). The last recorded production was 4,912 mt in 2020. There seemed to be efforts to stimulate foreign investment into the manganese sector, particularly in relation to the battery sector, as shown in a document released by MEMR in 2021 on Manganese Investment Opportunities[78] yet no development has been reported since.

To promote further battery development, focus on manganese should at least reach the same level as nickel to secure the required capital and resources.

3.2.2 Refining

Indonesia's nickel refining industry is already quite established, particularly in pyrometallurgy. With the addition of the battery industry, Indonesia has started to process other nickel products through hydrometallurgy process. Cobalt products, such as cobalt sulfate

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[91] Per PE2 (December 12th 2024), material presentation by the Directorate of Mineral and Coal Downstreaming MoInv.
[92] Per PE2 (December 12th 2024), based on consultation with representative from MoI.
[93] Based on consultation with a MoI rep in PE2, sodium-based batteries are not seen as an option for Indonesia.
[94] Ekspor Nikel Indonesia Kian Tinggi pada 2023, Tembus Rekor Baru (databox Katadata 2024)

($CoSO_4$) are also produced through nickel refining. To date, refined products that are reportedly used to supply the battery supply chain are mixed hydroprecipitate (MHP), nickel sulfate ($NiSO_4$), and cobalt sulfate ($CoSO_4$). Nickel matte, processed via pyrometallurgy, is used as feed to produce $NiSO_4$.

Per this report, Indonesia has 49 pyrometallurgy and five hydrometallurgy smelters in operation (see **Table 3.1**). Annual production of processed products are as follow: 670,857 mt of mixed hydro precipitate (MHP), 71,400 mt of nickel matte[95], 719,114 mt of $NiSO_4$, and 31,800 mt of $CoSO_4$ (see **Table 3.3**). The table below lists operational HPAL smelters in Indonesia as per the report.

Table 3.3 Consolidated production capacity and investment value of operational HPAL smelters

Company	Product	Production Capacity (mt/year)	Major Shareholder and Country of Origin	Investment Value (US$)
PT Halmahera Persada Lygend	MHP	365,000	Trimegah Bangun Persada (45.1%) – Indonesia[96]	1.26 billion
	$NiSO_4$	246,750		
	$CoSO_4$	31,800		
PT Huayue Nickel Cobalt	MHP	163,000	Zhejiang Huayou Cobalt Co., Ltd. (57%) - China[97]	1.28 billion
PT QMB New Energy Materials	MHP	142,857	GEM Co., Ltd. (63%) - China[98]	998.57 million
	$NiSO_4$	136,364		
	$CoSO_4$	19,512		
PT Fajar Metal Industry	$NiSO_4$	168,000	Excelsior International Investment Pte. Ltd. (99.9%) - Singapore[99]	1.26 billion
PT Teluk Metal Industry	$NiSO_4$	168,000	Tsingshan Holding Group Co.,Ltd. (99.9%) - China	1.26 billion

Source: Rosa-Luxemburg-Stiftung, 2023[100] and multiple sources (shown as footnotes)

Some refining products are exported. In 2023, nickel matte exports hit an all-time high (about 7-fold from 2021 exports) at 1.26 million tonnes in 2023[101]. ICT[102] also reported exports in $NiSO_4$ (66,400 mt in 2023) where China dominates the export destination (100% of total exports). However, some products may not have yet met production targets, such as MHP and $CoSO_4$. ICT reported higher imports than exports in 2023 (2,414 mt for MHP and 82 mt for $CoSO_4$, both mainly from China). Despite nickel being the more mature industry in the country, there is an imbalance in the availability of key components, which hinders the overall supply chain and drives further exports if it persists.

95 MEMR. (2024). Kinerja Subsektor Minerba Tahun 2023: PNBP dan Produksi Batubara Meroket, Atur Tegas Reklamasi dan Smelter. Press Release.
96 HPL Corporate Website. https://hpalnickel.com/
97 Zhejiang Huayou Cobalt Co., Ltd.. (2023). 2023 Semi-Annual Report of Zhejiang Huayou Cobalt Co., Ltd.
98 PT. QMB NEW ENERGY MATERIALS. (2023). Due Diligence Management System ANNUAL REPORT
99 Nickel Industries. (2023). Notice of Extraordinary General Meeting.
100 Rosa-Luxemburg-Stiftung. (2023). Fast and Furious for Future: The dark side of electric battery vehicle components and their impacts in Indonesia. Publication. Southeast Asia - Socio-ecological Transformation - COP26 - Green New Deal.
101 Ekspor Nikel Indonesia Kian Tinggi pada 2023, Tembus Rekor Baru (databox Katadata 2024)
102 International Trade Centre. Trade Map. https://www.trademap.org/

The refining of manganese has not reached the same maturity as nickel. A MEMR representative in PE2 addressed that little is known regarding its demand[103] which may be a factor as to why manganese projects are not further developed. A manganese smelter by PT Gulf Mangan Grup based in NTT has been under development since 2015[88], yet it seems to have faced difficulties[89].

In the LFP pathway, there is an effort to bring lithium resources closer to its assembly manufacturers. Lithium processing facilities are reportedly under development in Sulawesi. Products include lithium hydroxide (LiOH) and lithium carbonate (Li_2CO_3). The targeted production capacity is 50,000 mt of LiOH and 10,000 mt of Li_2CO_3[104]. As lithium deposits are absent in Indonesia, raw materials are reportedly imported from Australia[105].

3.2.3 CAM manufacturing

Indonesia's first cathode production facility was recently inaugurated in October 2024--PT LBM Energi Baru Indonesia. This company producers LFP cathodes, which is key to the LFP supply chain. It is a partnership between INA and Changzhou Liyuan New Energy Technology Co., Ltd. The first phase, which is already operational, has a capacity of 30,000 mt[106]. The second phase is targeted at 90,000 mt by 2025[107].

In contrast, the NMC supply chain has not yet been linked to CAM production. LG Energy Solutions plans a combined production capacity of 160,000 mt NMC cathodes for the following decade (see Figure 2.4) yet it will not be until 2025 that it sees its first production. If Indonesia does not meet the commissioning target for this project, the country will be further behind in securing its NMC supply chain.

3.2.4 Anode manufacturing

Anode producer PT Indonesia BTR New Energy, located in Central Java, was inaugurated in August 2024. The production facility has a capacity of 50,000 mt of natural graphite anode and 30,000 mt of artificial graphite anode[108,109]. Anodes are reportedly made from imported graphite from Africa[110,111]. Products not absorbed by the domestic market are targeted for export[112]. As the facility is still recent, trade records have not captured this information.

3.2.5 LIB cell manufacturing

As mentioned above, two types of batteries are produced in Indonesia: NMC and LFP.

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[103] *Per PE2 (December 12th 2024.*
[104] *RI Lagi Bangun Pabrik Lithium, Ini Dia Pemiliknya (CNBC Indonesia 2023)*
[105] *Demi Jadi 'Raja', RI Impor 60 Ribu Ton Lithium dari Australia (CNBC Indonesia 2023)*
[106] *Production capacity number. Limited information on actual production numbers.*
[107] *PT LBM Energi Baru Indonesia Resmi Beroperasi di KEK Kendal (Pajak.com 2024)*
[108] *Pabrik Anoda PT Indonesia BTR New Energy Beroperasi, Nilai Investasi Rp 7,8 T (kumparanBISNIS 2024)*
[109] *Production capacity number. Limited information on actual production numbers.*
[110] *Jokowi: Ada Bahan Baku di Pabrik Anoda Baterai Lithium Kendal yang Diimpor (Bisnis.com 2024)*
[111] *This data is not yet reflected in the latest ICT data (dated 2023) as the production plant is still very recent.*
[112] *MoF. (2024). Hadiri Undangan PT Indonesia BTR New Energy Material, Pabrik Bahan Anoda Baterai Litium Kapasitas 80.000 Ton per Tahun. News. Direktorat Jenderal Bea dan Cukai. Kementerian Keuangan.*

The only NMC battery producer operating at this point is PT HLI Green Power, a joint venture between Hyundai Motor Company, LG Energy Solution, and IBC, which has a capacity of 10 GWh NMC (nickel-manganese-cobalt) battery cells[113,114]. The first phase began commercial production in April 2024, and the second phase is currently under development, with a production target of 20 GWh by 2025[113,115].

In the LFP pathway, current battery producers are PT Gotion Green Energy Solutions Indonesia and PT International Chemical Industry (Intercallin)[116,117]. The reported production capacity is at least 100 MWh[118]. The battery parts are reportedly imported from China[119]. However, PT LBM Energi Baru Indonesia's recent inauguration may minimize imports by bringing the supply chain closer to home.

3.2.6 Battery pack assembly

Battery cells are typically packed in the same company where battery cells are produced.

To date, Indonesia has a production capacity of 138,000 units of LFP battery packs (90,000 units from Intercallin[117] and 48,000 units from Gotion[120]) and 50,000[121] units of NMC battery packs[122]. The current NMC battery packing capacity is roughly less than 50% of the LFP battery packing capacity. If Indonesia wants to encourage the utilization of domestic resources, NMC battery cell manufacturing and packing need to outcompete LFP's.

3.2.7 End use

Indonesia's battery production is largely aimed for EV production (**Table 3.4**). Per this study, Indonesia has not explored far on other pathways of the battery supply chain. No policy framework is available for other battery end-use, e.g., ESS.

According to the production numbers between January and November 2024 from Gaikindo[123], Indonesia has produced 24,655 4W BEV units and 65,026 4W HEV units. Top three companies who contributed most to BEV production are Wuling (55%), Chery (21%), and Hyundai (15%), whereas Toyota (66%) and Suzuki (32%) dominated HEV production. In addition, Indonesia also produces electric buses (4W EV >10 persons). The production capacity is small compared to other EV types at 1,980 units[124]. Reported producers are Mobil Anak Bangsa, INKA, VKTR, and SAG[125].

MoI has addressed in PE2 that Indonesia's annual production target is 600,000 by 2030[126]. With the current rate, Indonesia is capable of fulfilling 4.1% (without HEVs) or 14.9% (with HEVs) of this target.

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113 *Jokowi Resmikan PT HLI Green Power Karawang, Pabrik Baterai EV Terbesar di Asia Tenggara (Tempo 2024)*
114 *Race to produce high-nickel batteries accelerates (The Korea Economic Daily 2021)*
115 *Production capacity number. Limited information on actual production numbers.*
116 *NETA Resmi Jalin Kerjasama dengan PT Gotion Green Energy Solutions Indonesia (Beritaplus.id 2024)*
117 *ABC Tegaskan Jadi Produsen Cell Baterai Kendaraan Listrik Pertama (Kompas.com 2022)*
118 *Miliki Kapasitas Produksi Baterai 90.000 Pack, ABC Perluas Pasar ke Energi Terbarukan (Tribunbisnis 2024)*
119 *Pabrik Perakitan Baterai Gotion di Bogor, Fokus LFP (Kompas.com 2024)*
120 *Kapasitas Produksi Pabrik Baterai Gotion Tembus 48.000 Unit Per Tahun (Kompas.com 2024)*
121 *Fakta-fakta Pabrik Sel Baterai Mobil Listrik yang Baru Diresmikan di Indonesia (kumparanOTO 2024)*
122 *Production capacity number. Limited information on actual production numbers.*
123 *Produksi Domestik Kendaraan BEV, PHEV, dan Hybrid, Januari – November 2024 (Gaikindo 2024)*
124 *Investasi Perakitan Kendaraan Listrik RI Tembus Rp 4,49 T, Ini Rinciannya (detikFinance 2024)*
125 *Empat Produsen Bus Listrik Ini Bakal Dapat Insentif dari Pemerintah, Salah Satunya Milik Moeldoko (Tribunnews 2023)*
126 *Per PE2 (December 12th 2024), as mentioned by the Director of the Planning of Natural Resources MoInv.*

Table 3.4 EV production and targets in Indonesia

EV type	Total Production	Annual Production Target by 2030	2030 Target Realization
2W EV	100,000 units[a]	13,000,000 units	<1%
4W EV (<10 persons)	24,655[b] units (without HEVs) 89,681[b] units (with HEVs)	600,000[c] units	4.4% (without HEVs) 15.3% (with HEVs)
4W EV (>10 persons)	1,980 units		

[a]Production in 2023
[b]Production between January and November 2024
[c]Electric bus production adds to the 4W EV 2030 target of 600,000 units[127]

Apart from 4W EVs, Indonesia has 2W EV production targets. Former president Joko Widodo has addressed that actual 2W EV production was at 100,000 units in 2023, despite an annual production capacity of 1,600,000 units[128]. This is less than 1% of the targeted annual production by 2030 (13,000,000 units[119]). This may be attributed to low market demand; domestic sales in 2023 were 11,532[129] units, whereas exports were reported at 101,790 units[102]. 2W EV producers include Alva, Gesits, Electrum, and Swap[130].

As of 2023, Indonesia is a net exporter of 2W and 4W EVs. ICT[102] reports that 2023 exports quantify 2.9% and 0.6% of global exports for 2W and 4W EVs, respectively. Most of these exports go to the Philippines (31% of exports for both 2W and 4W EVs). By contrast, Indonesia is a net importer of electric buses from China (95.6% of imports). Although Indonesia's current annual production is less than 10% of the 2030 target, Indonesia has demonstrated its capacity as a regional EV player.

3.2.8 End-of-life

Per this study, the only battery recycling company in Indonesia is PT Indonesia Puqing Recycling Technology. This company is located in Morowali. It can process up to 18,144 mt/year of used lithium batteries[131].

The facility has a production capacity of 24,000 mt of crude Ni-$CoSO_4$, 510 mt of crude Li_2CO_3, and 1,840 mt of crude MnOH yet no actual production was reported in 2022[132]. Indonesia's nascent battery industry is not yet able to provide sufficient materials for battery recycling. Black mass imported from China is reported to be the current feedstock for the recycling plant[133].

Table 3.5 Current state of the national battery supply chain including HS codes

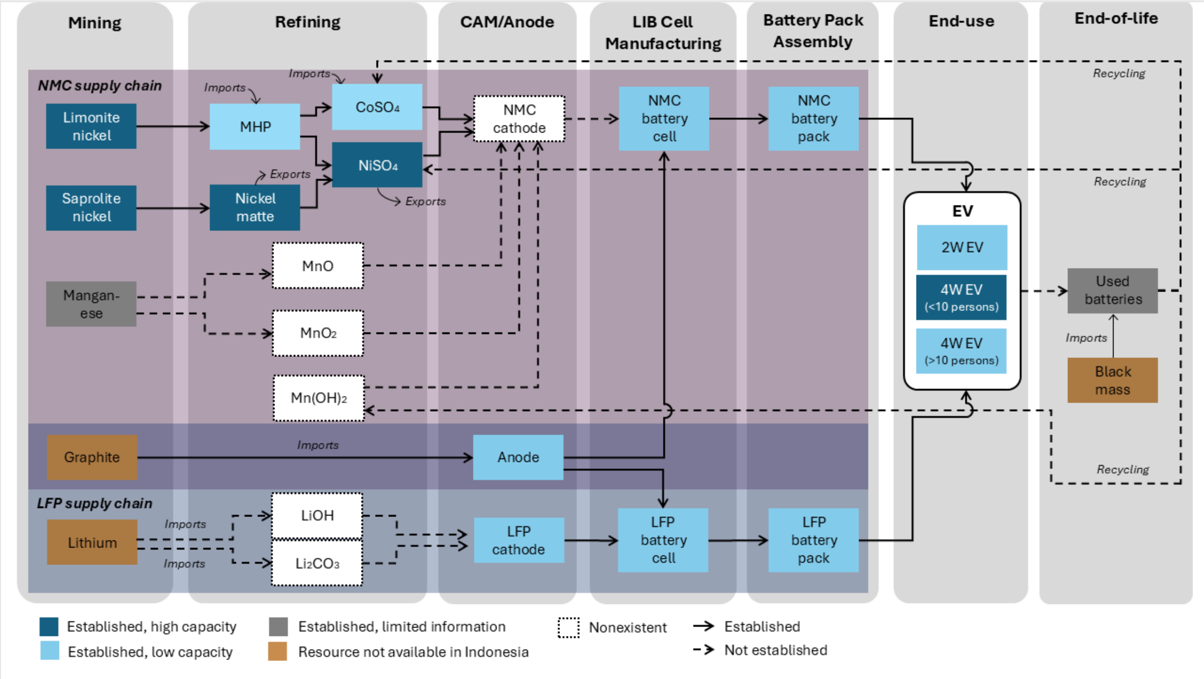
Supply chain phase	Current state	Product/ HS Code	Annual Production
Overall	• Indonesia produces two types of battery: NMC and LFP. • NMC batteries promote domestic resource absorption, whereas LFP utilize imported resources.	-	-
Mining	• Indonesia has an established nickel mining industry.	Nickel ore/ 260400	175,617,183 mt

[127] *Ini Target Produksi Mobil dan Bus Listrik di 2030 (Media Indonesia 2024)*
[128] *Jokowi Sebut Kapasitas Produksi Motor Listrik di RI 1,6 Juta Unit, Baru Tercapai 100 Ribu Unit (Tempo 2024)*
[129] *Subsidi Gagal? AISI Sebut Penjualan Motor Listrik di Indonesia Masih Jauh dari Harapan (SindoNEWS 2024)*
[130] *AEML. (2023). Indonesia's Electric Vehicle Outlook. July 2023.*
[131] *Wajah Industri Nikel Kini (Betahita 2022)*
[132] *PT Indonesia Puqing Recycling Technology. (2022). Profil Badan Usaha.*
[133] *Per PE2 (December 12th 2024), as informed by a representative from PT CBL Indonesia Investment.*

Supply chain phase	Current state	Product/ HS Code	Annual Production
	• No manganese extraction since 2020.	Manganese ore/ 260200	-
Refining	• Nickel processing industry is seeing rapid growth. Many nickel products are exported overseas, e.g. nickel matte, $NiSO_4$. • Despite nickel being the more mature industry in the country, there is an imbalance in the availability of key components, which hinders the overall supply chain and will drive further exports if it persists. • The refining of other minerals has not reached the same maturity as nickel.	MHP/ 294200	670,857[a] mt
		Nickel matte/ 750110	71,400 mt
		$NiSO_4$/ 283324	719,114[a] mt
		$CoSO_4$/ 810520	31,800[a] mt
		MnO/ 282090	-
		MnO_2/ 282010	-
		LiOH/ 282520	-
		Li_2CO_3/ 283691	-
CAM	• LFP CAM production plant has recently opened in 2024. However, NMC CAM production is not yet present domestically. • If Indonesia does not start NMC CAM production soon, the country will be further behind in securing its NMC supply chain.	LFP cathode/ 850790	30,000[b] mt
		NMC cathode/ 850790	-
Anodes	• Anode production has only started in the last quarter of 2024 using imported graphite.	Natural graphite anode/ 854519	50,000[a] mt
		Artificial graphite anode/ 380110	30,000[a] mt
LIB cell manufacturing	• NMC production has only started this year through PT HLI Green Power. • LFP batteries are produced through PT International Chemical Industry (Intercallin) and PT Gotion Green Energy Solutions Indonesia.	LFP battery cells/ 850610	100[a] MWh
		NMC battery cells/ 850610	10[a] GWh
Battery Pack Assembly	• The current NMC battery packing capacity is roughly less than 50% of the LFP battery packing capacity. • If Indonesia wants to encourage the utilization of domestic resources, NMC battery cell manufacturing and packing need to outcompete LFP's.	LFP battery packs/ 850760	138,000[a] units
		NMC battery packs/ 850760	50,000[a] units
End-use	• Battery production in Indonesia is intended primarily for the EV industry. • Indonesia's current 4W EV can fulfill 4.1% (without HEVs) or 14.9% (with HEVs) of this target. • Current 2W EV production is less than 1% of the targeted annual production by 2030. This may be attributed to low market demand, yet there is promise from exports.	2W EV/ 8711	100,000 units
		4W EV (<10 persons)/ 8703	89,681 units
		4W EV (>10 persons)/ 870240	1,980 units
End-of-life	• Indonesia's nascent battery industry is not yet able to provide sufficient materials for battery recycling.	Crude Ni-$CoSO_4$	-
		Crude Li_2CO_3	-
		Crude $Mn(OH)_2$	-

[a]*Production capacity; not actual production*

Figure 3.3 General flow of the battery supply chain in Indonesia



Source: Internal expertise elaboration based on the supply chain flow in Indonesia

3.3 Current challenges and opportunities

Indonesia's mining industries face significant challenges and promising opportunities, particularly in the transition to sustainable aspects. The following section will explain several issues related to responsible sourcing, geopolitics, and developing artificial minerals.

3.3.1 Exploration opportunities

Indonesia possesses significant mineral potential. As pointed out by the Geological Body in MEMR[134], Indonesia has 15 mineralization belts that stretch across a total length of 15,000 km. Of these, 7,000 km have already been extensively explored and exploited. However, there remains an unexplored and underdeveloped 8,000 km of mineralized areas, presenting a tremendous opportunity for Indonesia to drive exploration further and maximize its mineral resource potential. This untapped expanse highlights the immense opportunities for future mineral discovery and exploitation, offering the potential for substantial economic growth and development in the country's mining sector.

The government has also implemented a policy for transferring concessions or IUP (*Izin Usaha Pertambangan*), opening opportunities for Junior Mining Companies to actively discover new mineral resources. These resources can then be developed by other entities with sufficient capital. Through this mechanism of IUP transfer, the government's auction process for IUP can become more efficient, as it provides a chance for larger capitalized companies to take over and manage mines that have already been explored. This, in turn, increases the likelihood of project success in the mining sector.

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[134] *Geologi ESDM, 2021. Geomap. Kementerian Energi dan Sumber Daya Mineral Republik Indonesia.*
Link: https://geologi.esdm.go.id/geomap

3.3.2 Responsible nickel sourcing

On principle, Indonesia already has a standard for good mining practices as regulated in MEMR Decree No. 1827.K/30/MEM/2018 on Guidelines for the Implementation of Good Mining Principles[135]. In addition, strict environmental licensing procedures pertaining to the Omnibus Law (Law No. 22/2020) are enforced in high-risk industries, particularly mining. Exercising good practices gives companies more market access as well as confidence for investors. Good practices include but are not limited to replacing fossil fuels with renewable energy, resource efficiency, and waste minimization[136].

That said, problems associated with nickel mining and refining are reported, making the business difficult to attract foreign investors. In 2021, Tesla withdrew from investing due to environmental concerns[137]. EU-based BASF and Eramet have also withdrawn from the "Sonic Bay" project in Weda Bay over impacts on cultural lands[138].

Despite existing problems, a couple of companies in Indonesia have demonstrated good practices that others should follow. Vale Indonesia has successfully reduced nickel production costs by 30% using hydropower as its primary power source[120]. Ceria Group has obtained global certifications such as the Renewable Energy Certificate (REC) and Initiative for Responsible Mining Assurance (IRMA)[139].

3.3.3 Access to international markets

Indonesia's substantial natural resource potential positions the country as a strong contender in the global battery supply chain industry. However, strategic interventions are essential to compete effectively in the international market. Partnerships between Indonesian companies and Chinese firms are notably prominent[140], creating both opportunities and challenges. These include international-level issues such as sustainability concerns and the uncertainties of global geopolitics[141].

One pressing issue is the disparity between domestic environmental standards and established international benchmarks (see 3.3.2 Responsible nickel sourcing). Efforts toward sustainability often fall short of meeting these standards, raising significant concerns for Indonesia. Moreover, the strong alignment with Chinese firms presents strategic complications, particularly given the heightened tensions between the United States and China. The U.S. government, through measures like the Inflation Reduction Act (IRA), has sought to reduce China's dominance in strategic industries[142]. The IRA provides subsidies perceived by China as excessive protectionism, excluding minerals sourced from countries without a free trade agreement (FTA) with the U.S. from tax incentives such as credits[143].

Indonesia's lack of an FTA with the U.S. significantly limits its ability to diversify and grow its battery supply chain industry. The IRA framework further restricts opportunities by excluding minerals produced by companies with more than 25% Chinese ownership.

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[135] *As addressed by the Director of Mineral Business Development MEMR in PE2.*
[136] *Vale Lirik Bisnis Nikel Hijau, Biaya Produksi Bisa Lebih Hemat (Bloomberg Technoz 2024)*
[137] *Indonesia has a long way to go to produce nickel sustainably (Dialogue Earth 2021)*
[138] *EU faces green dilemma in Indonesian nickel (DW 2024)*
[139] *Produsen Green Nickel Product, Ceria Terus Dukung Hilirisasi Mineral di Indonesia (Nikel.co.id 2024)*
[140] *Per stakeholder consultation during PE2 (December 12th 2024). Exact numbers were not given.*
[141] *US may block Indonesia nickel on forced labor issues (Asia Times 2024)*
[142] *US-China trade talks break down over Inflation Reduction Act energy tax credits (S&P Global, 2024)*
[143] *The Inflation Reduction Act: Here's what's in it (Mckinsey & Company, 2024)*

These provisions pose substantial barriers to Indonesia's efforts to access and compete in international markets, given its dependence on Chinese partnerships[144].

Indonesia must prioritize diversifying its trade and investment partners and reduce reliance on a single actor. Expanding collaboration with a broader range of international stakeholders would not only enhance Indonesia's competitiveness but also increase economic resilience amid global uncertainties.

One promising avenue is participation in the Mineral Security Partnership (MSP)[145], a multinational initiative involving 14 countries and the European Union. The MSP aims to establish a sustainable mineral supply chain, aligning closely with Indonesia's vision of optimizing its mineral resource potential. Membership in the MSP would enable Indonesia to strengthen its network of strategic partners, enhance the value of its mineral products, and secure a stronger position in the global supply chain.

3.3.4 Coal-to-artificial graphite

Graphite is commonly used to serve as the anode material in lithium-ion batteries. Conscious of the limited graphite resource in Indonesia, there have been talks about tapping the coal-to-graphite potential[146]. Indonesia has significant potential to develop synthetic graphite from coal due to its abundant coal reserves. As one of the largest coal producers in the world, this option can help domestic coal companies soft-land before a complete coal phase-out.

Such an opportunity has been explored by PT Bukit Asam Tbk (PTBA), a subsidiary of MIND ID. PTBA, in collaboration with the National Research and Innovation Agency (BRIN), has launched a pilot project to convert coal into artificial graphite and anode sheets[147]. Unlike natural graphite, which varies in purity and crystal size and is not always suitable for battery anode production, synthetic graphite offers consistent quality in these aspects[148].

That said, this option should be carried out cautiously, as it could prolong Indonesia's dependency on coal. Depending on fossil fuels to create alternative energy could be counterproductive in the long run considering the goal is net zero.

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[144] *Can Indonesia's Nickel Industry Break Free From China's Grip? (Foreign Policy, 2024)*

[145] *US approaches Indonesia for multinational critical mineral partnership (Reuters, 2024)*

[146] *Per Presentation Event 1 (August 30th 2024), a MoI representative opened a discussion on the opportunity to develop synthetic graphite from coal to be supplied to the battery industry.*

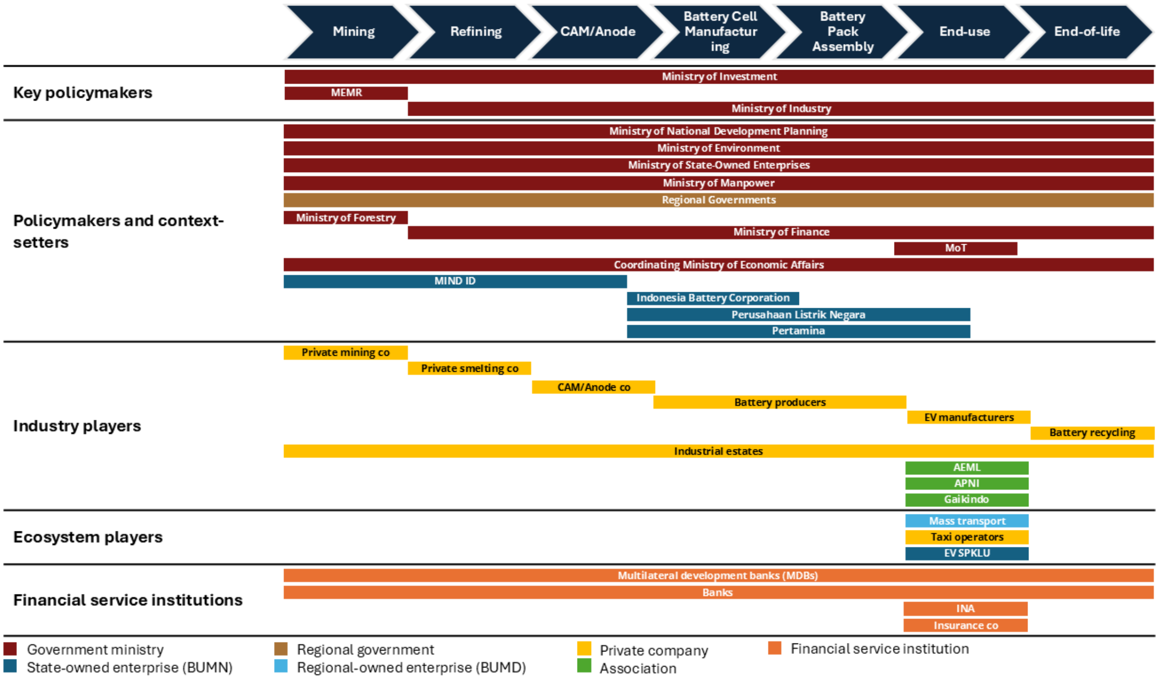
[147] *Bukit Asam. (2024). Pertama di Dunia, Bukit Asam dan BRIN Mulai Kembangkan Batu Bara untuk Bahan Baku Baterai Li-ion. News.*

[148] *PTBA to Establish EV Battery Anode Factory (katadata Insights 2023)*

4 Operating industries and organizations relevant to the Indonesia battery supply chain

Identifying industries and key players in the battery supply chain is vital to understanding it. This visualization gives an overview of the entities involved and their roles within it. The graph below provides an overview of the entities involved, categorized by their roles, influence, and significance within the ecosystem (Figure 4.1). Notably, as shown in the figure, end-of-life stage operators within Indonesia's battery supply chain have yet to be established.

Figure 4.1 Key players in Indonesia's battery supply chain



Source: Internal expertise elaboration based on the supply chain flow in Indonesia

4.1 National key players

4.1.1 Key policymakers

Many government institutions are vital in setting the stage for Indonesia's battery supply chain. The key policymakers identified are the Ministry of Energy and Mineral Resources (MEMR), the Ministry of Industry (MoI), and the Ministry of Investment (MoInv). These ministries regulate upstream and downstream industries in the battery supply chain, set industry targets for the EV industry, and attract foreign investment to drive further industrialization (Table 4.1).

Table 4.1 List of key policymakers in Indonesia's battery supply chain

Stakeholder	Supply chain phase[149]	Function in the supply chain
Ministry of Energy and Minerals Resources (MEMR)	Mining	MEMR is the ministry accountable for accelerating Indonesia's energy transitions. In the context of the battery supply chain, MEMR governs the mining industry, regulating the overall industry practice (e.g. production capacity, safety procedures, etc). The battery supply chain also falls within the boundary of MEMR's governance of the energy sector, where energy transition can benefit from battery technologies.
Ministry of Industry (MoI)	Refining CAM/anode Battery cell manufacturing Battery pack assembly End use End-of-life	The MoI strengthens national industrial growth, supports and regulates key industry members in the battery supply chain. It is accountable for issuing permits for industrial compounds and manufacturers, among other things. In response to Indonesia's interest in developing the supply chain further, the MoI has issued a developmental road map, specifically for BEV production.
Ministry of Investment (MoInv)	All	The Ministry is essential in attracting international and national investors to develop the batteries' supply chain and promote the country as an attractive investment destination, stimulating economic growth.

4.1.2 Policymakers and context-setters

While key policymakers set the context of the battery supply chain in Indonesia, other government institutions and state-owned enterprises (SOEs) complement or act under their direct mandate, further setting the stage. This group is comprised of central government institutions, regional government institutions, and SOEs. A full overview of how these parties impact the battery supply chain is shown in Table 4.2.

Table 4.2 List of policymakers and context-setters in Indonesia's battery supply chain

Stakeholder	Supply chain phase[149]	Function in the supply chain
Central Government		
Ministry of National Development Planning (BAPPENAS)	All	BAPPENAS is the Ministry that oversees national development in all sectors, including energy. Although not directly influencing the battery supply chain, its development could impact the national development plan, which is within BAPPENAS' jurisdiction.
Ministry of Environment (MoE)	All	MoE plays a crucial role in overseeing environmental protection laws, guidelines and promoting the sustainable management of Indonesia's natural resources, which may be affected by battery-related activities. MoE is fully accountable for issuing environmental-related permits and enforcing environmental sanctions. In relation to Indonesia achieving net-zero targets, it is in MoE's highest interest that the battery supply chain complies with relevant laws and regulations.
Ministry of Forestry (MoF)	Mining	MoF holds the authority over all forest areas in the country. MoF delineates and categorizes forest areas based on their status and usage and, in doing so, is able to issue forestry permits for industrial use. MoF is also able to enforce forest moratoriums. The extraction industry often goes over to forest boundaries, requiring them to engage with the MoF for their business.
Ministry of Transportation (MoT)	End use	MoT is the ministry accountable for transportation in the country. As the battery supply chain will impact transportation in the near future, MoT may have to adjust policies, especially regarding EVs or electric public transportation.
Ministry of Finance (MoF)	Refining CAM/anode Battery cell manufacturing Battery pack assembly End use	MoF plays an important role in building financing mechanisms to accelerate the development of the battery industry. Financing mechanisms issued by the MoF include incentives and tax exemptions. A mature national battery industry that can be capitalized may also be in the MoF's best interest.

[149] *Referring to the phases in battery supply chain as outlined in Figure 3-2 in the Inception Report*

Stakeholder	Supply chain phase[149]	Function in the supply chain
Ministry of State-Owned Enterprises (MoSOE)	All	MoSOE oversees all SOEs whose business activities are aligned with the country's objectives and goals. Almost all companies that play a significant role in the battery supply chain are SOEs. The MoSOE can influence the battery supply chain's SOEs and accelerate the development of the national battery ecosystem.
Ministry of Manpower (MoM)	All	The MoM oversees policies and regulations regarding manpower, such as occupational health,safety and the acquisition of local workers. National manpower standards apply to high-risk industries in the battery supply chain. Good human resource practices are key to companies seeking investment. The MoM could enforce sanctions on companies that do not comply with standards, e.g., reported accidents.
Coordinating Ministry of Economic Affairs (CMEA)	All	The CMEA is important in determining and accelerating nationally strategic projects (PSN), which can benefit the battery supply chain. The presence of a domestic battery supply chain can influence the national economic roadmap.
Regional Governments		
Governors	All	Governors, as representatives of regional governments, are essential in the battery supply chain. Governors receive the immediate impact from businesses, such as an increase in regional economic revenue. Likewise, they are among the first to face public grievances when negative business impact emerges. In some instances, governors can issue business-related permits and enforce sanctions.
Regional Agency for Energy and Mineral Resources/*Dinas Energi dan Sumber Daya Mineral*	All	The Regional Agency for Energy and Mineral Resources is an agency under the direct mandate of the governor, whose main role is to regulate energy and mineral resources affairs, including energy transition, within the governor's jurisdiction.
Regional Agency for Environment/*Dinas Lingkungan Hidup*	All	The Regional Agency for Environment is an agency under the direct mandate of the governor whose main role is to regulate environmental affairs, including the implementation of sustainable practices in businesses, within the governor's jurisdiction.
Regional Agency for Manpower/*Dinas Tenaga Kerja*	All	The Regional Agency for Manpower is an agency under the direct mandate of the governor whose main role is to regulate labor affairs within the governor's jurisdiction. These concerns include occupational health and safety, labor welfare, and certifications.
State-owned Enterprises		
Mining Industry Indonesia (MIND ID)	Mining Refining	Indonesia's mining industry holding company, which is comprised of PT ANTAM Tbk, PT Bukit Asam, PT Freeport Indonesia, PT Indonesia Asahan Aluminium (Persero), and PT Timah Tbk., plays a significant role in the battery supply chain. Its subsidiaries, particularly PT ANTAM Tbk, are large players in the mineral industry.
Indonesia Battery Corporation (IBC)	CAM/anode Battery cell manufacturing Battery pack assembly	IBC is a SOE focusing on battery development in Indonesia. It is a consortium of four SOEs: PT Antam Tbk, PT Indonesia Asahan Aluminium (Persero), Pertamina, and PLN[150]. IBC's position as a SOE is strategic in the battery sector as it works under the government's direct mandate and contributes to initiating other operating industries[151].
Indonesia Battery Corporation (IBC)	CAM/anode Battery cell manufacturing Battery pack assembly	IBC is a SOE developed mainly for battery development in Indonesia. As the initiator of the downstream business, IBC could strongly influence the battery ecosystem in Indonesia. In addition, its position as an SOE means it is strongly supported by the government.
Perusahaan Listrik Negara (PLN)	CAM/anode Battery cell manufacturing Battery pack assembly End use	PLN is the single electricity company in Indonesia. The company has absolute authority over the transmission, distribution, and supply of energy. PLN's RUPTL (Electricity Supply Business Plan) is a direct mandate of MEMR's RUKN (National Electricity Plan). As a power company, PLN is also part of the IBC and the consortium owns many BEV charging stations in the country (see **Table 4.4**).

[150] *Indonesia Battery Corporation corporate website*

[151] *Indonesia Battery Corporation. (2021). Pabrik Baterai IBC-Konsorsium LG Rp140 Triliun Segera Groundbreaking. News.*

Stakeholder	Supply chain phase[149]	Function in the supply chain
Pertamina	CAM/anode Battery cell manufacturing Battery pack assembly End use	As a state-owned oil and gas company, Pertamina has expanded its core business to include energy transition. Pertamina is also part of IBC's consortium[152]. Its subsidiaries have also reportedly contributed to strengthening the battery ecosystem, e.g., developing battery swapping facilities[153] and providing graphite for anode manufacturing[154].

Role of Regional Government in Indonesia's Battery Supply Chain

Regional governments play an essential role in Indonesia's battery supply chain, particularly in licensing and regulatory processes. While the sector is largely overseen by the central government due to its strategic importance and high foreign investment, regional authorities hold specific influence under the Omnibus Law. As the industry expands, regional governments are positioned to benefit from economic gains, including increased GDP and local development. At the same time, they will be on the front line in addressing community concerns, including land disputes, employment issues, environmental impact and pollution, making them key players in balancing development with local needs.

4.1.3 Industry players

Industry players in the battery industry are categorized based on the source of their investment: domestic and foreign investment. It is commonplace for domestic and foreign companies to form partnerships or joint venture companies (JvCo) to run one or more business activities in the supply chain. Detailed explanations of how these entities impact the battery supply chain is described in Table 4.3. Industry associations, which are comprised of these industry players, are also addressed.

Table 4.3 List of industry players in Indonesia's battery supply chain

Stakeholder	Supply chain phase[149]	Function in the supply chain
Private companies		
Private mining companies	Mining	Private companies largely drive the mining industry in Indonesia. Private sector players include PT Vale Indonesia Tbk (subsidiary of Vale Base Metal), PT Ceria Indotama Nugraha, and PT Merdeka Battery Materials Tbk[155].
Private smelting companies	Refining	The leading players in Indonesia's smelting industry are generally the same in the mining industry, as the raw ore export ban is enforced, and mining companies can only export processed ore. Smelting companies generally operate under a different entity (as a subsidiary or JVCo)[156]. Potentially large players in the processing phase include PT Huayue Nickel Cobalt (subsidiary of Zhejiang Huayou Cobalt) and PT Halmahera Persada Lygend (subsidiary of Lygend Resources & Technology Co., Ltd).
CAM/anode producing companies	CAM/anode	A couple of CAM/anode producers have entered Indonesia in 2024, promoting interconnectivity to the supply chain. Known companies are LFP cathode producer PT LBM Energi Baru Indonesia and anode producer PT Indonesia BTR New Energy (see **3.2 Battery production capacity**).
Battery manufacturing and assembly companies	Battery cell manufacturing Battery pack assembly	As Indonesia's battery manufacturing industry is still nascent, potential players reportedly come from existing players in the energy, battery, and automotive sectors in the form of joint ventures or subsidiaries such as PT HLI Green Power (JVCo of IBC, Hyundai, and LG Chem) .

[152] *Four SOEs unite to form EV battery producer – The Jakarta Post, 2021*
[153] *Elnusa Gandeng IBC Kembangkan Ekosistem EV – Pertamina, 2024*
[154] *Pabrik Anoda yang Diresmikan Jokowi di Kendal Pakai Limbah Pertamina – detik Finance, 2024*
[155] *Inilah 10 Perusahaan Tambang Nikel Terbesar di Indonesia, Apa Saja? – Media Nikel Indonesia, 2023*
[156] *Perluas Target Pasar Hilir Nikel, Akuisisi Saham MBMA Sudah Capai 60 Persen – Media Nikel Indonesia, 2023*

Stakeholder	Supply chain phase[149]	Function in the supply chain
EV manufacturing companies	End use	Automotive companies are growing in response to the increase in the EV market. Several automotive brands have capitalized on this trend, with Wuling, BYD, and Hyundai emerging as the leading 4W EV manufacturers[157]. 2W EV manufacturers, such as Gesits and Smoot Elektrik, as well as hauling truck manufacturers, such as VKTR, are also present.
Battery recycling companies	End-of-life	Battery recycling in Indonesia is still nascent, yet the presence of battery recycling companies promotes the retention of critical minerals. PT Indonesia Puqing Recycling Technology is the country's first EV battery recycling plant[122].
Industrial estates	All	Some supply chain activities may be conducted within industrial estates[158]. Companies within industrial estates are enforced with a different set of rules, regulations and permits and are given access to privileges, e.g., the ability to use industrial facilities for their business activities, such as ports and logistics, waste management, clean water provision, etc. Notable industrial estates associated with the battery supply chain are Indonesia Morowali Industrial Park (IMIP) and Indonesia Weda Bay Industrial Park (IWIP).
Industry/professional associations		
Indonesian Nickel Miners' Association (APNI)	Mining	APNI represents Indonesian nickel companies. Nickel companies play a crucial role in the development of the battery supply chain, as Indonesia already has an established upstream nickel industry. Companies within APNI are potential players in the supply chain.
Electric Mobility Ecosystem Association (AEML)	End use	AEML is an association of EV industry pioneers dedicated to catalyzing the development of a world-class electric mobility ecosystem in Indonesia.
Gaikindo (Association of Indonesian Automotive Industries	End use	Gaikindo plays an active role in encouraging the development of the automotive industry towards the production of environmentally friendly cars, including electric vehicles that require efficient and sustainable battery supplies. Gaikindo can also organize exhibitions by promoting green vehicle technology and facilitating dialogue between the government, industry players, and internationally.

4.1.4 Ecosystem players

Ecosystem players are essential in stimulating public EV adoption. Per the BEV development roadmap (MoI Regulation 28/2023), public transport operators and EV-exclusive zones initiate the development of EV ecosystems. The emergence of EV fleets in public transport, recharging stations, and battery swapping/recycling facilities are important EV ecosystem components. A full explanation of their roles is addressed in Table 4.4.

Table 4.4 List of ecosystem players in Indonesia's battery supply chain

Stakeholder	Supply chain phase[149]	Function in the supply chain
Mass transport operators (e.g., Transjakarta)	End use	Several public transport operators have included EVs in their fleet. This is part of the MOI EV development roadmap, which aims to create domestic market demand, push EV industrialization, and develop a battery ecosystem.
Taxi operators (e.g., Blue Bird, Grab, Gojek)	End use	Several taxi operators have included EVs (4W and 2W) in their fleet. This is part of the MOI EV development roadmap--to create domestic market demand, push EV industrialization, and develop a battery ecosystem.
EV recharging station providers (SPKLU)	End use	EV recharging stations, or SPKLU (*Stasiun Pengisian Kendaraan Listrik Umum*), are generally provided by PLN in strategic business partnerships with external parties such as Electrum and Volta[159160]. SPKLU units are reportedly increasing in response to the growing EV market.

[157] *10 Mobil Listrik dengan Volume Penjualan Wholesale Tertinggi di Indonesia (Semester I 2024) – Katadata, 2024*
[158] *IWIP Kebut Pengembangan Kawasan Industri untuk Komponen Baterai Kendaraan Listrik – Kontan.co.id, 2022*
[159] *Penyediaan SPKLU Hasil Kerja Sama PLN dan Mitra Swasta Terus Meningkat – Kontan.co.id, 2024*
[160] *Indonesia's Electric Vehicle Outlook (AC Ventures, 2023)*

4.1.5 Financial institutions

The role of financial institutions in the battery supply chain is to provide financing mechanisms to stimulate EV adoption. This group is comprised of sovereign wealth funds (e.g., Indonesia Investment Authority), lenders (e.g., multilateral development banks), and insurance companies. Sovereign wealth funds and lenders provide investments or loans to industry and ecosystem players, whereas banks and insurance companies provide EV financing mechanisms for retail consumers to promote EV purchases. A detailed description of how these institutions impact the battery supply chain is addressed in Table 4.5.

Table 4.5 List of financial institutions in Indonesia's battery supply chain

Name	Supply chain phase[149]	Function in the supply chain
Indonesia Investment Authority (INA)	End use	INA is a sovereign wealth fund body that invests Indonesia's sovereign wealth funds into infrastructure and assets that benefit people. INA's investment portfolio includes energy transition infrastructure. INA has stated that it intends to invest in the EV ecosystem, among other things.
Multilateral development banks (MDBs)	All	MDBs provide financing mechanisms to the battery supply chain to promote sustainable development and energy transition. Relevant MDBs include the World Bank (WB), Asian Development Bank (ADB), and European Investment Bank. MDBs not only provide loans for EV-related projects but also guide national policies and actions related to EV deployment. Examples include the ADB-funded "Electric Transportation and Charging Infrastructure Project" in Indonesia[161] and WB's "Climate-Smart Mining for Energy Transition"[162].
Banks	All	Banks are reported to be open to investing or lending funds to any stage of the battery supply chain. Many are interested in providing loans for the EV industry[163], but some are also reportedly interested in the mining industry[164]. For retail consumers, banks also offer financing for EV purchases[160].
Insurance companies	End use	Insurance companies, particularly related to automotive insurance, offer EV financing mechanisms for retail purchases to stimulate EV adoption[160].

4.2 International parties

Several parties in the international community have the potential to drive Indonesia's battery supply chain. International business partnerships and alliances where Indonesia is a signatory or has an interest can determine the investment climate in the supply chain. A list of identified international parties as well as how they impact Indonesia's battery supply chain is described in Table 4.6.

Table 4.6 List of international players in Indonesia's battery supply chain

Stakeholder	Supply chain phase[1]	Function in the supply chain
Foreign investment		
Foreign investors	All	Foreign investment is important for Indonesia as significant capital is needed to accelerate the battery supply chain. Although foreign investment is rapid in Indonesia, a number of them have also withdrawn. Issues such as environmental and social risks have been addressed (see3.3.1**)**
Bilateral governments		

[161] *Asian Development Bank. (2023). Indonesia: Electric Transportation and Charging. ADB Completion Report.*
[162] *World Bank. (2019). New World Bank Fund to Support Climate-Smart Mining for Energy Transition. Press Release.*
[163] *Perbankan Semakin Gencar Salurkan Kredit Kendaraan Listrik – Kontan.co.id, 2023*
[164] *Pertumbuhan Kredit Investasi Pertambangan Cetak Rekor – Bisnis.com, 2022*

Stakeholder	Supply chain phase[1]	Function in the supply chain
ASEAN Minerals Cooperation	Mining	The general aim of this bilateral government cooperation is to strengthen the extractive sector of ASEAN Member States. This government cooperation has built capacity for ASEAN Member States in the extractive industry, such as geological surveys, resource assessment and mapping, mine rehabilitation, and mining business and investment opportunities.
Multigovernment business agreements and partnerships		
Indonesia-Korea Comprehensive Economic Partnership Agreement (IK-CEPA)	End use	Promotes the implementation and expansion of cooperation in strategic sectors such as developing EV and EV battery ecosystems in Indonesia and energy transition. So far, there have been Memorandums of Understanding (MoUs) and implementations related to battery development, battery storage technology, and packaging for electric vehicles (EVs)[165].
Indonesia–Australia Comprehensive Economic Partnership Agreement (IA-CEPA)	All	This includes provisions for partnerships in the development of the EV manufacturing industry. This encompasses commercial partnerships in the supply and processing of minerals, battery manufacturing, vehicle production, technology platforms, and charging infrastructure[166].
Belt Road Initiative (BRI)	All	China's global development program aims to enhance cooperation in infrastructure, investment, and the economy within Indonesia's battery industry. A notable project resulting from the BRI collaboration between Indonesia and China is the IMIP industrial estate and investments from battery manufacturers[167][168].
Regional Comprehensive Economic Partnership	All	This partnership helps significantly boost Indonesia's battery industry by improving market access, strengthening supply chains, and promoting investment and technological collaboration[169].
European Battery Alliance	All	Provides knowledge and technology transfers, gaining access to advanced battery manufacturing techniques, sustainability practices, and resource management innovation, helping modernize its mining and processing industries.
Global Battery Alliance	All	Through multi-stakeholder collaboration, the GBA can support Indonesia in scaling up its battery material production while addressing environmental, social, and governance (ESG) risks. By working with Indonesian industry actors, the GBA helps to promote circularity in resource use, ensure the protection of ecosystems, and create fair labor practices throughout the battery value chain.

[165] *Ministry of Foreign Affairs. (2021). Penandatanganan MoU Kerja Sama Investasi Industri Sel Baterai antara Konsorsium Korsel dengan Pemerintah Indonesia dan PT. Industri Baterai Indonesia (IBI). News.*
[166] *Kemitraan Baterai Listrik Indonesia-Australia (Kompas 2023)*
[167] *China Belt and Road Initiative (BRI) Investment Report 2023. (Green Finance & Development Center 2024)*
[168] *CELIOS. (2023). Polemik Investasi China di Indonesia: Bagaimana Menghindari Kualitas Investasi yang Rendah dan Jebakan Utang?. Jakarta.*
[169] *Hadapi tantangan investasi dan akses pasar kendaraan listrik, Indonesia bisa manfaatkan perjanjian bebas RCEP (The Conservation 2023)*

5 Geopolitics of key transition minerals

5.1 Indonesia in the critical mineral geopolitics

Indonesia plays a significant role in the geopolitics of key minerals, particularly due to its abundant reserves of nickel and cobalt.
The country's foreign policy relies on sovereignty, non-alignment, economic diplomacy and expansion of Indonesia's role as a 'global middle power'.[170] Indonesia possesses several advantages that facilitate its global balancing position. First, Indonesia is located at a relatively stable region at the heart of Indo-Pacific, which is an area of growing strategic importance. Second, Indonesia is a member of the political and economic union of Association of Southeast Asian Nationals (ASEAN).[171] Third, Indonesia's constitution prohibits the country from joining any military alliances[172]. This principle is rooted in Indonesia's commitment to maintaining a neutral stance in foreign policy. This policy allows Indonesia to engage with various countries and international organizations.[173] Finally, Indonesia's economic growth is among the fastest among the emerging economies. By leveraging its strategic location, the trust fostered within ASEAN, its constitutional commitment to non-alignment and significant economic growth, Indonesia can effectively contribute to stability and cooperation.

In recent years, Indonesia has implemented strategic policies to strengthen its position in the global key minerals market. For instance, Indonesia banned the export of nickel ore in January 2020 to boost its domestic processing industry and add value to its supply chain. Additionally, Indonesia has sought to establish trade agreements, such as a proposed limited free trade agreement with the United States, to support its ambitions in key mineral markets as well as in the EV industry. The US, along with its 'allies', are actively seeking to reduce the dependency on China.

Considering that the US together with its 'alliance members' lack domestic nickel, they have a strong interest to establish a strong bilateral relationship with Indonesia – the world's largest nickel producer. The US, EU and other countries seek to build a more resilient battery supply chain to support the twin transition. They have vested interests in promoting imports of key minerals from countries other than China, driven in particular by security concerns regarding the long-term sustainability of raw material supplies for EV battery production. Given Indonesia's abundant mineral resources and its intent to diversify investment sources, it emerges as a natural partner in this context. Indonesia seeks to attract foreign investments in this sector and diversify exports but also to diversify foreign investment to avoid becoming overly dependent by a single country, namely China.

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[170] Cabinet Secretariat of the Republic of Indonesia, 'Indonesia's Foreign Policy Priorities in 5 Years Ahead' () January 2015); I Ardhani, R W Nandyatama & R Alif Alvian, 'Middle power legitimation strategies: the case of Indonesia and the ASEAN Outlook on the Indo-Pacific' 77 (4) Australian Journal of International Affairs (2023); A Rizky Mardhatillah Umar, 'The rise of the Asian middle powers: Indonesia's conceptions of international order' 99 (4) International Affairs (2023), pp. 1459-1476.

[171] <https://asean.org/member-states/>

[172]

[173] C Khoe, 'How will the Prabowo Administration Shape Indonesia's Foreign Policy As a Middle Power?' (20 August 2024, Asia Pasific Bulletin).

The nickel ore export ban, the aim of which was to enhance domestic value creation by ensuring that nickel is processed within the country rather than being exported in its raw form, was adopted in its most recent form in 2020. This policy was designed to (1) strengthen the domestic processing industry; (2) increase economic value by exporting higher-value processed nickel products instead of raw ore; (3) generate employment opportunities and stimulate economic growth; and (4) as a long-term goal to position Indonesia as a key player in the global EV market.[174]

The nickel ore export ban has resulted in significant investments within the country. Since the implementation of the ban, Indonesia has seen a substantial influx of capital directed towards the development of nickel smelters and industrial parks. The majority of these investments are by Chinese companies, including major companies such as Tsingshan Holding Group and Jiangsu Delong Nickel Industry.

These efforts are part of a broader trend where countries rich in key minerals are leveraging their resources to gain economic and strategic advantages in the global energy transition. Due to its mineral resources as well as foreign policy of non-alignment combined with democratic institutions and shared values such as respect for laws, Indonesia is an attractive strategic partner for all major global powers alike.

5.2 Geographic concentration and supply chain vulnerabilities

The uneven global distribution of minerals essential for the energy transition necessitates international trade. Countries rich in these resources need to export to those that lack them, fostering the need for increased global cooperation and interdependence.[175] The value of global trade in key minerals has been growing rapidly, outpacing overall merchandise trade.[176] This highlights the crucial role that international trade and supply chains play in processing and delivering these materials to users.

Geopolitical concentration also exposes supply chains to vulnerabilities, such as political instability and environmental, social and governance challenges. Due to the massive increase of demand for these minerals as required by the green energy transition, several jurisdictions are actively seeking to adopt tools to secure supply chains for such key minerals. Emerging geopolitical aspects in relation to key minerals encompass new, emerging trade patterns and the potential for new players – distinct from fossil fuels[177] – to establish dominance in key minerals markets.

In particular, the rise of China has disrupted traditional industrial power like the US and the EU, leading to new geopolitical alliances.[178] As discussed above in Section 2, geological concentration of resources is not limited only to their extraction; Chinese dominance is prevailing also in other stages of the supply chain. In the early 2000s China adopted a so-

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[174] *IEA, 'Prohibition of the export of nickel ore' (last updated 19 March 2024), <https://www.iea.org/policies/16084-prohibition-of-the-export-of-nickel-ore>*

[175] *N Srivastava, 'Trade in critical minerals: Revisiting the legal regime in times of energy transition' 82 Resources Policy (2023), 103491;*

[176] *P Kowalski and C Legendre, Raw Materials for the Green Transition: Production, International Trade and Export Restrictions, OECD Trade Policy Papers, No 269 (Paris: OECD Publishing), p. 5, 19.*

[177] *See IRENA, Geopolitics of the energy transition: Critical Materials (International Renewable Energy Agency, Abu Dhabi 2023), p. 13 summarising the main differences between fossil fuels and critical materials.*

[178] *S Kalantzakos, 'The Race for Critical Minerals in an Era of Geopolitical Realignments' 55 The International Spectator (2020), p. 2; V Vivoda, R Matthews and N McGregor, 'A critical minerals perspective on the emergence of geopolitical trade blocs' 89 Resources Policy (2024), 104587.*

called 'going-out' policy to acquire overseas assets, which provided access to those minerals that are not available in China. For example, in 2008 China signed an agreement with the Democratic Republic of Congo known as the Sicomines pact, which was a significant 'minerals-for-infrastructure' deal. Under this agreement, China secured rights to cobalt and copper mining in the Democratic Republic of Congo. In return, China committed to investing approximately $6 billion in various Congolese infrastructure projects. This pact was part of China's broader strategy to secure essential mineral resources for its rapidly growing economy. Similarly, China has formed strategic partnerships with numerous countries involved in the Belt and Road Initiative to secure access to key minerals. These partnerships often involve investments in mining projects and infrastructure development in exchange for mineral rights.[179]

For example, Chinese enterprises have established a dominant presence in Indonesia's nickel sector through substantial investments. In 2023, Indonesia emerged as the largest beneficiary of China's Belt and Road Initiative. Furthermore, Chinese firms have been responsible for constructing over 90 percent of Indonesia's nickel smelters.[180] In terms of downstream industry, Chinese EV firms have established a competitive edge over their US and EU counterparts thanks to decades of successful prioritization of the industry as established in the governments five-year plan as well as incentive policies introduced to further these policy goals by the government. Such incentives include a variety of subsidies to scale up EV production, increase market access as well as related policies such as incentives to build EV charging stations. Examples of such key factors that have contributed to the Chinese dominance are summarized in Figure 5.1.

Figure 5.1 Examples of key factors that have contributed to the Chinese EV dominance.[181]

Raw materials and refining	• China has significant control over the supply chain of raw materials needed for EV batteries, such as lithium, cobalt and nickel. • This control is bolstered by investments in mining operations both doemstically and internationally, as well as refining.
Battery production	• China is a global leader in battery manufacturing, particularly lithium-ion batteries
Research and development	• China has invested significantly in research and development that has led to advancements in EV technology.
Charging insfrastructure	• The development of extensive charging networks is crucial for the adoption of EVs; China has been rapidly expanding its charging infrastructure, also ensuring the growth of domestic market and demand.
Strategic government policies	• Early government policy decision to go 'all-in' regarding EVs and staying consistent with this policy choice. • China has adopted a range of successful government policies to support both supply and demand of EVs. These include, but are not limited to, government subsidies, tax breaks and procurement contracts.

Source: Own elaboration

[179] *T Chen and W Chen, 'Understanding the Belt & Road Initiative and its impact in China' (11 May 2024, Commercial Dispute Resolution Essential Intelligence), <https://www.cdr-news.com/cdr-essential-intelligence/belt-and-road-initiative/china/>*

[180] *See e.g., G Baskaran, 'Diversifying Investment in Indonesia's Mining Sector' (11 July 2024, Center for Strategic & International Studies), <https://www.csis.org/analysis/diversifying-investment-indonesias-mining-sector>*

[181] *See Z Yang, 'How did China come to dominate the world of electric cars?' (21 February 2023), MIT Technology Review.*

This dominance carries significant geopolitical implications – control over resources of key minerals provides substantial economic power and strategic advantage.[182] This development is naturally not limited only to encompassing battery minerals supply chains, but the same key minerals are the essential buildings blocks of many other modern technologies too. This results from the fact that key minerals and other raw materials are essential inputs for manufacturing various goods and services, placing them at the critical node of both domestic and international supply chains. Therefore, any disruptions affecting their supply can have widespread and significant impact throughout the entire system.[183] Table 5.1 illustrates various factors disrupting the stability and reliability of global supply chains for key minerals

Table 5.1. Disruptive factors related to stability and reliability of global supply chains

Factor categories	Examples of disruptive factors
External shocks	Natural disasters, pandemics, wars, mine accidents
Export restrictions	Export quotas, export taxes, obligatory minimum export prices
Resource nationalism	Tax disputes, expropriation, foreign investment screening
Mineral cartels	Coordination of production, pricing, market allocation
Political instability and social unrest	Labor strikes, violence, corruption
Market manipulation	Short squeezing, market cornering, spoofing, insider trading

Source: IRENA, Geopolitics of the energy transition: Critical Materials (International Renewable Energy Agency, Abu Dhabi 2023), p. 52.

5.3 Strategic competition

5.3.1 The rise of resource nationalism

Key minerals – encompassing their extraction and supply, processing, and manufacturing – as well as EVs as a final end use product have become a new element in the widening strategic and economic competition. This strategic competition manifests in many forms.

First, as illustrated in Section 2 on analyzing the current state of global supply chains, Chinese dominance is significant in every stage of the supply chain. To address Chinese dominance and in an effort to build more resilient supply chains, jurisdictions with significant demand for key minerals and EVs, in particular the US and the EU have adopted policies that prioritize securing different nodes of the supply chain through a variety of measures, such as key minerals stockpiling, on shoring and/or friendshoring, promoting research and development of alternative materials or supply sources and so on.[184] The policy prioritizes strategic competition over key minerals, batteries and EVs have thus materialized into specific legislative action.

Second, given the massive increase of key minerals required for the green energy transition and the concentration of supply, international trade will be crucial in meeting the

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[182] *V Vivoda, R Matthews and N McGregor, 'A critical minerals perspective on the emergence of geopolitical trade blocs' 89 Resources Policy (2024), 104587.*

[183] *OECD, Raw Materials Critical for the Green Transition: Production, International Trade and Export Restrictions (April 2023, OECD Trade Policy Paper No 269), p. 35.*

[184] *S L Penttinen and E Burlinghaus, 'The battery rush and global supply chains: Regulatory pathways towards resilient supply chains of critical minerals in the Us and the EU', McGill Journal of Sustainable Development Law (forthcoming 2025).*

rapidly increasing demand. The divergent interests of resource-rich countries and resource-dependent countries have resulted in conflicting trade policies, driving global trends. Resource-rich countries have adopted trade-restrictive measures to drive (national) industrialization forward, whereas resource-dependent countries leverage free trade agreements or other bilateral mechanisms to ensure market access and prevent the implementation of trade restrictions with like-minded allies. These often take the form of “strategic partnerships” and “strategic partnership agreements”.[185] Such arrangements operate outside the framework of multilateral trade law, are not legally binding, and show several trends, such as allowing resource-dependent countries to identify and subsidize projects in third countries.[186] For example, the European Union has signed several free trade agreements, for instance with Argentina, Paraguay, Uruguay and Brazil – one of the key sources of key transition minerals – that aims to eliminate export tariffs and taxes on minerals.[187]

Geopolitics have been leading economic policies in many countries. The clean energy transition that has led to the increasing demand of key minerals has resulted in the adoption of protectionist measures and resource nationalism.[188] This is illustrated also by the wide adoption of various trade restrictions, most notably in the form of restrictions on exports of selected key minerals. As key minerals serve as inputs to produce other goods, disruptions or policies affecting their supply can have significant systemic implications, leading to supply chain disruptions. This has often served as a justification for national policies adopted to support downstream domestic sectors.[189] In addition to supporting national industrial policy objectives, trade restrictions in the form of licensing requirements or export taxes can be adopted to support other national objectives, such as addressing environmental and social externalizations or adding government revenue.[190]

Between 2009 and 2022, export restrictions have increased five-fold.[176] Further, export restrictions tend to result in a cascading effect – restrictions often create incentives for other producing countries to adopt similar restrictions. This in turn puts pressure on international commodity prices, leading to further introduction of export restrictions. Table 5.1 provides an overview of the types of trade restrictions implemented and reported purpose of the measure by selected countries in 2022.

Table 5.1 Examples of types of trade restrictions in force in 2022 concerning minerals within the scope of this study

Country	Commodity	Trade restriction (2022)	Purpose of measure
Indonesia	Nickel ores & concentrates, HS 260400; Nickel oxides & hydroxides, HS282540	Licensing requirement; export ban	Monitoring/control of export activity; Protect local downstream industry

[185] S Sasmal,’A Stacked Deck That Keeps Getting Higher: The Relationship Between Critical Raw Materials, the WTO and ‘Strategic Parteneships’ (Briefing paper 79, April 2024, UK Trade Policy Observatory).
[186] ibid.
[187] European Commission Press Release, ’EU and Mercosur reach agreement on trade’ (28 June 2019, Brussels) IP/19//3396.
[188] See e.g., D Xu, S Dou, Y Zhu and J Cheng, ’Resource nationalism: the intersection of politics and economics’ 11 Humanit Soc Sci Commun (2024); A Hurrel, ’Geopolitics and global economic governance’ 40 (2) Oxford Review of Economic Policy (2024). pp. 220-233.
[189] P Kowalski and C Legendre, Raw Materials for the Green Transition: Production, International Trade and Export Restrictions, OECD Trade Policy Papers, No 269 (Paris: OECD Publishing), p. 35.
[190] ibid.

Zimbabwe	Lithium oxide & hydroxide, HS282520; Natural graphite, in powder/flakes, HS250410	Export ban; licensing requirement	Promote further processing/value added; Control of illegal mining activity; Generate revenue; monitoring/control of export activity
Argentina	Lithium oxide & hydroxide, HS282520	Export tax (4,5%)	Promote further processing/value added; Protect local downstream industry
China	Cobalt oxides & hydroxides, commercial cobalt oxides, HS282200;	Licensing requirement,	No purpose reported
Democratic Republic of Congo (DRC)	Cobalt oxides & hydroxides, commercial cobalt oxides, HS282200	Export surtax (1%), export tax (0,5%), fiscal tax (USD 100)	Generate revenue, monitoring/control of export activity
Russia	Nickel ores & concentrates, HS260400	Licensing requirement	No purpose reported

Source: OECD, Inventory of export restrictions on industrial raw materials, available at https://www.oecd.org/content/dam/oecd/en/topics/policy-sub-issues/export-restrictions-on-critical-raw-materials/oecd-industrial-raw-materials-complete-data_2023.xlsx

Resource nationalism and disruption in supply chains create substantial risks for global markets and signal a shift in "traditional" geopolitics. To underline the high strategic importance of supply chain resilience of key transition minerals' supply chains, the forerunner jurisdictions are advancing trade and industrial policies such as the EU's '(open) strategic autonomy'[18], 'Made in China 2025'[191] and 'Made in America Supply Chain for Critical Minerals'[192]. Embedding national security concerns to measures seeking to secure supply chain further highlights the importance of securing the key minerals' supply and the geopolitical implications of the supply chain. Recent measures adopted under these policy frameworks to build more diverse and resilient supply chains for key transition minerals have led to a modest diversification in the sourcing of such minerals, including initiatives in recycling and reuse, and in global processing and manufacturing capacity, as illustrated above in Section 3.

5.3.2 Tariff trade war

The US and its allies have long expressed concerns regarding China's ambitious industrial policies, which are heavily supported by substantial subsidies particularly in strategic sectors. These policies and subsidies have been instrumental in the success of China's EV industry over the past decade. Years 2023 and 2024 witnessed a wave of unilateral trade restrictions imposed on Chinese EVs by major export markets. First, the US announced tariffs to a group of Chinese commodities, including electric vehicle, battery and key mineral imports under Section 301 of the US Trade Act of 1974.[193] In 2024, the tariff rate for electric vehicles imported from China increased from 25% to 100%. The adoption of this policy seeks to ensure 'the future of the auto industry will be made in America by American workers – – [t]he increase in the tariff rate on electric vehicles will protect [American]

[191] Notice of the State Council on the Publication of "Made in China 2025" (PRC State 8 May 2015); English translation available at https://cset.georgetown.edu/wp-content/uploads/t0432_made_in_china_2025_EN.pdf

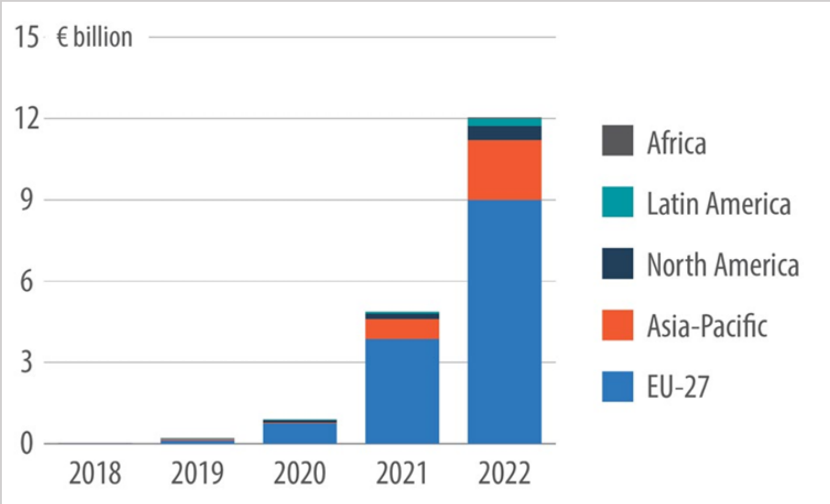
[192] Fact Sheet: Securing a Made in America Supply Chain for Critical Minerals (22 February 2022, the White House), available at https://www.whitehouse.gov/briefing-room/statements-releases/2022/02/22/fact-sheet-securing-a-made-in-america-supply-chain-for-critical-minerals/

[193] The White House, 'Fact Sheet: President Biden Takes Action to Protect American Workers and Businesses from China's Unfair Trade Practices' (14 May 2024), <https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/14/fact-sheet-president-biden-takes-action-to-protect-american-workers-and-businesses-from-chinas-unfair-trade-practices/>

investments and jobs from unfairly priced Chinese imports.'[194] The tariff rate for both lithium-ion EV batteries and battery parts increased from 7,5% to 25% in 2024. The tariff rate on natural graphite, permanent magnets and other critical minerals increased from zero to 25% in 2024.

Second, in 2023 EV imports from China to the European Union exceeded 10 billion US dollars.[195] Given the flow of Chinese solar panels, EVs and lithium-ion batteries to the EU-market area with significantly lower prices compared to their EU counterparts, the EU Commission initiated anti-subsidy probes to gather evidence whether these products benefit from subsidies that cause or threaten to cause injury to EU industries manufacturing similar products without benefiting from such subsidies that would be caught by the EU State aid rules.[196]

Figure 5.2 Battery electric vehicle exports from China by region, 2018-2022 in € billion



Source: European Parliament, available at <https://www.europarl.europa.eu/RegData/etudes/ATAG/2023/754553/EPRS_ATA(2023)754553_EN.pp>. Data from UN Comtrade. Battery electric vehicles for HS code 870380. Data does not include values for Luxembourg owing to a lack of data.

As a result of the probe, the EU Commission concluded that the EV value chain in China is supported by inequitable subsidization, which poses a significant risk of economic harm to EV manufacturers within the European Union.[197] Therefore, the EU Commission imposed countervailing duties up to 45,3 % on imports of battery electric vehicles from China for a period of five years. The new tariffs are being applied on top of the EU's already existing EU vehicle import duty of 10 per cent. The tariff rate is determined based on each EV manufacturer's involvement in the investigation and the extent of the support they are perceived to have received. Among the three sampled Chinese exporters, BYD faces a tariff of 17%, Geely 18.8%, and SAIC 35,3%. Other cooperating companies are subject to a 20.7% duty, with the option to request an expedited review to determine an individual rate. Non-cooperating companies are subject to a tariff of 35.3%. These tariffs will remain in force for five years, unless the EU decides to terminate them earlier.[198] As

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[194] *ibid.*

[195] *Data from UN Comtrade. BEVs for HS code 870380.*

[196] *Anti-subsidy measures aim to mitigate distortions in international trade and represent one of the three categories of EU trade defense instruments, alongside anti-dumping and safeguard measures. The legislative framework governing EU trade defense instruments is based on, and aligns with, the three corresponding multilateral agreements established by the WTO. See EU Parliament, 'EU anti-subsidy probe into electric vehicle imports from China',*

[197] *European Commission Press Release, 'EU imposes duties on unfairly subsidized electric vehicle from China while discussion on price undertakings continue' (29 October 2024), IP/24/5589.*

[198] *ibid.*

the imposed EV tariffs do not apply to hybrid cars, it is envisaged that this segment of vehicles imported to the EU market area will continue to increase significantly.[199]

Third, an additional import tax on Chinese imports was also adopted in Turkey. The main objective of imposing the tax was to protect the domestic EV industry and address trade imbalances. Finally, in October 2024 a 100 per cent surtax on all Chinese-made EVs entered into force in Canada, the rate increasing significantly from the previous 6.1 per cent. The tax imposed by the Government of Canada applies on all Chinese-made EVs, including electric and certain hybrid passenger automobiles, trucks, buses, and delivery vans.[200] Further tariffs imposed by Canada are also being planned.[201]

These tariffs imposed by the EU, US, Canada and Turkey exemplify the strategic measures adopted in response to competitive pressures by China. All jurisdictions discussed above have the same motivation behind the adopted measures: to protect and promote national, nascent EV sectors. Naturally, China does not overlook these measures. It has filed complaints with the WTO against the tariffs introduced by the EU and Canada, arguing that they violate international trade rules. The imposition of these tariffs takes place against a backdrop of rising concerns regarding the proliferation of protectionist trade barriers and the diminishing influence of the WTO.

Existing trade rules, namely under the World Trade Organization (WTO), have traditionally hindered resource-rich countries from implementing specific trade policies. Quantitative import and export restrictions are generally prohibited under Article XI of the WTO's General Agreement on Tariffs and Trade. The General Agreement on Tariffs and Trade (GATT) provides for the exception to the main rule. These derogation grounds, frequently evoked by WTO members in minerals and metals, relate to non-economic public policy grounds such as the protection of human, animal and plant life and health, the conservation of exhaustible natural resources, and the assurance of adequate domestic supply in particular conditions.[202]

Most recent in this regard is the Indonesia-EU dispute over the Indonesian nickel-ban. Indonesia imposed a ban on the export of nickel ore requiring that it be processed domestically before exportation.[203] This policy was adopted with a view to promoting the domestic processing industry. The EU raised a complaint before the WTO panel, arguing that the restriction unfairly limits access to raw materials needed in particular for stainless steel production. The WTO panel ruled in favor of the EU, stating that Indonesia's measures were inconsistent with the obligations under the GATT and were not justified by any exceptions.[204] Indonesia has now appealed the ruling to the WTO's Appellate Body,

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[199] Reuters, 'China automakers pivot to hybrids for Europe to counter EV tariffs' (5 December 2024), <https://www.reuters.com/business/autos-transportation/china-automakers-pivot-hybrids-europe-counter-ev-tariffs-2024-12-05/>

[200] Department of Finance Canada, 'Surtax on Chinese-made Electric Vehicles' (Government of Canada), <https://www.canada.ca/en/department-finance/news/2024/08/surtax-on-chinese-made-electric-vehicles.html>

[201] 'Canada to impose more tariffs on Chinese imports in new year' (17 December 2024, Mining.com) <https://www.mining.com/web/canada-to-impose-more-tariffs-on-chinese-imports-in-new-year/>

[202] See I Espa, 'GATT general exceptions relevant and applicable to WTO-inconsistent export restrictions' in Export Restrictions on Critical Minerals and Metals: Testing the Adequacy of WTO Disciplines (Cambridge International Trade and Economic Law, Cambridge University Press 2015), pp.193-228.

[203] Regulation of the Minister of Energy and Mineral Resources 11/2019.

[204] World Trade Organization, "Indonesia – Measures Relating to Raw Materials" WT/DS592R (2022).

which is currently non-functional[205], thus effectively blocking the final resolution of the dispute. The EU is considering using its Enforcement Regulation[206] to impose counter-measures if the dispute remains unsolved.[207] Furthermore, it should be noted that in 2020, a group of 20 WTO members, including the European Union, signed the Multi-Party Interim Appeal Arbitration Arrangement (MPIA) under Section 25 of the WTO Dispute Settlement Understanding. This arrangement allows these members to use arbitration as an alternative to the traditional WTO dispute settlement process.

While the US justified its EV tariffs by referring to China's unfair trade practices, accusing it of flooding global markets with artificially low-priced exports that could potentially serve as a basis for a WTO complaint, the US did not file one but instead decided to proceed with adoption of the tariffs. Interestingly, China did not lodge a complaint against the US tariffs. This is likely due to the current dysfunction of the WTO dispute resolution process. The US is not a party to the MPIA and given the current state of play of the WTO system, China probably considered lodging a complaint against the US ineffective.[208]

The EU's imposition of tariffs was articulated using 'WTO compliant language', highlighting that the Chinese EV value chain benefits from unfair subsidization, posing a threat of economic injury. The EU Commission emphasized its efforts to seek WTO-compatible solutions. According to the WTO Agreement on Subsidies and Countervailing (SCM) measures, members may impose countervailing duties on subsidized imports that harm domestic industries, provided these duties do not exceed the subsidy amount. As outlined above, the EU's investigation resulted in varying tariffs for different Chinese manufacturers. In response, China filed a WTO complaint against these tariffs and announced an investigation into certain EU dairy products, suspecting them of being subsidized. The EU, again in turn, filed a WTO complaint, claiming China's investigation was retaliatory and unfounded.[209] In addition, China has also been introducing retaliatory tariffs for example on European liquors, hitting French brandy particularly hard[210] in addition to which anti-dumping measures targeting pork imports from the EU have been opened, putting stress on Spain.[211]

Unlike the EU, Canada did not base its tariff level on a subsidy investigation aligned with WTO and SCM agreements. In retaliation, China filed a WTO complaint against Canada's tariffs in 2024 and initiated an anti-dumping investigation into Canadian canola and chemical products, in addition to which a separate anti-discrimination investigation was

[205] For an overview of the WTO Appellate Body Crisis, see e.g., P Van den Bossche, Can the WTO Dispute Settlement System Be Revived? Options for Addressing a Major Governance Failure of the World Trade Organization (WTI Working paper no. 03/2023), available at https://www.wti.org/media/filer_public/dc/68/dc6816ae-6d34-4f95-8d8d-837597ce54f3/wti_wp_03_2023.pdf

[206] Regulation (EU) 2021/167 of the European Parliament and of the Council of 10 February 2021 amending Regulation (EU) No 654/2014 concerning the exercise of the Union's rights for the application and enforcement of international trade rules, OJ L 49, 12.2.2021, p. 1—5.

[207] European Commission, 'EU launches consultation on use of Enforcement Regulation on Indonesian nickel export restrictions' Brussels (7 July 2023).

[208] G Lan, 'Electric Vehicle Tariffs by the US, EU, and Canada: Different Approaches and Implications for the WTO' 28 (12) American Society of International Law (13 December 2024).

[209] ibid.

[210] T Espiner, 'China hits back at EU with brandy tax' (8 October 2024, BBC), <https://www.bbc.com/news/articles/cn8jz39xl19o>

[211] A Ford, S Lau and A Zimmermann, 'Political pork: China probes, Spain Scrambles' (17 June 2024, Politico), <https://www.politico.eu/article/china-spain-anti-subsidy-probe-eu-pork-imports-trade-war/>

opened.[212] Unlike the EU, Canada has not filed a complaint against China's anti-dumping investigation.[213]

Concurrently with the trade war unfolding within the framework of the WTO, the EU and China are also exploring diplomatic channels to achieve mutual understanding. This diplomatic engagement may prove more advantageous, considering the protracted and potentially indefinite nature of the WTO dispute resolution process – in particular in the current state of the WTO framework. Diplomatic negotiations could facilitate more flexible and timely solutions, addressing underlying issues more effectively than the formal WTO mechanisms, which are often slow and cumbersome.[214]

It is likely that as a result of these recent tariff policies adopted by the major export destinations of Chinese EVs, Chinese companies will be forced to diversify their exports in new markets. As Chinese domestically based companies will encounter increased trade barriers in international markets, they are compelled to consider relocating production.[215] This is prone to lead to a situation where Chinese manufacturers are seeking to invest in third countries such as Indonesia and Thailand. Currently, China's BYD and GAC Aion are already building gigafactories in Indonesia, also benefiting from tax incentives offered by The Indonesian Government.[216] In addition to the Chinese companies, French Citroën is benefiting from the same fiscal policies. The beneficial investment environment supported by 'local' upstream segments of the supply chain makes Indonesia a logic alternative for relocation to circumvent tariffs introduced against Chinese EVs. To fully harness the potential benefits of the spillover effects triggered by the tariff trade war, it is of great importance that Indonesian fiscal policies attracting foreign investments are formulated in a manner that fully benefit the industry as a whole, for example by embedding local content requirements into the policy and regulatory framework.

However, relocation of production can lead to claims on circumvention of existing anti-dumping and anti-subsidy tariffs.[217] In a worst-case scenario from the viewpoint of Indonesia, such measures could be extended to target downstream production facilities abroad. Consequently, trade protection duties imposed on parent companies are extended to their foreign subsidies. This may impede the development of countries such as Indonesia that require foreign investment to increase economic growth and further industrialization.[218] Therefore, while the tariff trade war may provide an opportunity to attract more investments in downstream segments of the supply chain, a certain level of caution should nevertheless be exercised.

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[212] *'Major economies are taking aim at China's EV industry. Here's what to know.' (16 September 2024, World Economic Forum), <https://www.weforum.org/stories/2024/09/major-economies-are-taking-aim-at-china-s-ev-industry-here-s-what-to-know/>*

[213] *G Lan, 'Electric Vehicle Tariffs by the US, EU, and Canada: Different Approaches and Implications for the WTO' 28 (12) American Society of International Law (13 December 2024).*

[214] *See e.g., 'EU, China agree to more talks on potential alternatives to EV tariffs' (25 October 2024, Reuters), <https://www.reuters.com/business/autos-transportation/eu-china-agree-further-technical-negotiations-evs-2024-10-25/>*

[215] *S Brinley, 'A Breakdown on Europe's Chinese EV Tariffs' (11 July 2024, UtilityDive), <https://www.spglobal.com/mobility/en/research-analysis/a-breakdown-on-europe-chinese-ev-tariffs.html>*

[216] *The companies are benefitting from an exemption on import taxes, a release from the luxury goods tax and a 1 % value-added tax rate.*

[217] *'Major economies are taking aim at China's EV industry. Here's what to know.' (16 September 2024, World Economic Forum), <https://www.weforum.org/stories/2024/09/major-economies-are-taking-aim-at-china-s-ev-industry-here-s-what-to-know/>*

[218] *V Crochet and W Zhou, 'Preventing the Anti-Circumvention Instrument from Undermining Development through Investment' 72 (3) International & Comparative Law Quarterly (2023), pp. 601.*

Finally, it should be noted the dynamic nature of the EV sector. For example, the EU's tariffs are currently standing for five years. It will remain to be seen what the overall impact of the tariffs is also on the EU itself; considering the bloc's ambitious decarbonization targets, domestic production as well as production flowing from third countries might not be enough to fill in the gap left by Chinese companies. Fine-tuning of policies might thus be required.

5.4 Technological development, innovation and diversified supply sources

The International Renewable Energy Agency (IRENA) categorized three shifting and partially overlapping dynamic stages in terms of the technical evolution of key transition minerals.[219] The first stage is marked with physical constraints such as manufacturing bottlenecks and difficulties matching supply with the rising demand for certain key minerals. The first stage requires measures that both boost mining and processing of the key minerals but also measures that improve material recovery from tailings and recycling technologies.[220]

The government's role in this regard is to invest in infrastructure, design enabling frameworks and support research and innovation in recycling technologies. Increasing demand for key transition minerals has already brought about various geopolitical tensions that resulted in particular from the current state of the global supply chain. In addition, new deposits are being actively studied to meet the growing demand for key minerals, including deposits in deep-sea beds, The Arctic and outer space. New significant discoveries have been found, for example in Sweden (rare earths)[221] and Arkansas, the US (lithium)[222].

Considering the ongoing geopolitical tensions involving the Arctic Circle or conflicts over maritime space, the potential for these areas to contribute to the global mineral supply as new supply sources is potentially significant but fraught with geopolitical rivalries. New discoveries in these areas hold promise for future commercial deployment and diversification of raw material supplies. However, to fully capitalize on these new sources, it is essential to address processing and manufacturing bottlenecks by developing downstream and manufacturing capabilities.

Particularly important for Indonesia is participation in the current turbulent debate over drafting the rules for deep-sea mineral mining. The International Seabed Authority, acting under the United Nations Convention on Law of the Sea (UNCLOS), serves as the authoritative body responsible for protecting the seabed in areas beyond national jurisdiction. It oversees the exploration and exploitation of resources in these regions, ensuring that activities are conducted in accordance with international law and environmental standards. This includes setting environmental standards and ensuring that mining practices

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[219] *IRENA, Geopolitics of the energy transition: Critical Materials (International Renewable Energy Agency, Abu Dhabi 2023), p.27.*

[220] *Ibid.*

[221] *Phelan Chatterjee, 'Huge rare earth metals discovery in Arctic Sweden' (12 January 2023, BBC), available at https://www.bbc.com/news/world-europe-64253708*

[222] *The U.S. Geological Survey (USGS), 'Unlocking Arkansas' Hidden Treasure: USGS Uses Machine Learning to Show Large Lithium Potential in the Smackover Formation' (21 October 2024, National News Release), available at https://www.usgs.gov/news/national-news-release/unlocking-arkansas-hidden-treasure-usgs-uses-machine-learning-show-large*

do not harm delicate marine ecosystems.[223] The Indonesian government has been developing a regulatory framework to manage and oversee deep sea mining activities.[224] While deep sea mining might in the future be a potential driver for further economic growth in Indonesia, there are significant environmental concerns associated with deep sea mining that must be addressed first.

The second stage, which is already underway at scale, will drive disruptive innovation through novel ideas and experiments designed to reduce materials consumption, which will eventually lead to the third stage, where circular economy plays a prominent role.[225] As illustrated above in Section 1 Battery technologies, the conventional lithium-ion batteries have been dominating the market, with NMC/NCA and LFÅ as the most prevalent chemistries. While NMC and LFP batteries are considered to dominate the market in the future too – which technology will ultimately take the lead remains nevertheless unknown today.[226] It should also be noted that the chemistry mix has changed rapidly, and the current dynamics and trends should be followed closely in order to adjust national policies accordingly, which in turn might have geopolitical implications. Changes in battery chemistries can alter the geopolitical landscape by shifting the demand for certain minerals. Countries that are major producers of these minerals may gain or lose strategic importance based on these shifts.

In this regard, it is important to note that the nickel-based chemistries are currently envisaged to be the mainstreaming battery chemistry in the US and the EU in particular, whereas the LFP is projected to continue dominating Asian markets. LFP batteries, which do not rely on nickel and cobalt, have transitioned from a niche product to supplying a significant share of the EV market.[227] The Chinese dominance in Indonesian markets currently hint towards the further development of LFP industry with products mainly directed to Asian markets. However, to fully benefit from the Indonesian nickel and cobalt resources, strengthening the value chain for nickel-based chemistries should be embraced, too.

This requires careful balancing in the current geopolitical tension, with growing anti-China policies as signalled by the US, the measures adopted by the EU and the US with protectionist tendencies and new blocks forming around key minerals. It should also be noted that if Indonesia wishes to strengthen the sustainability credentials of its battery value chain, with a view also to develop a secondary supply route in the future from recycled materials, batteries relying on NMC chemistries contain more valuable raw materials compared to their iron-based counterpart. Thus, balancing between global geopolitical tensions requires balancing also between technological choices. Policies and regulations imposing protectionist requirements and environmental and sustainability standards are being discussed in the following.

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[223] For an overview of the state-of-play, see e.g., C Pickens, H Lily, E Harrould-Kolieb, C Blanchard and A Chakraborty, 'From what-if to what-now: Status of the deep-sea mining regulations and underlying drivers for outstanding issues' 169 Marine Policy (2023), 105967.

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[225] IRENA, Geopolitics of the energy transition: Critical Materials (International Renewable Energy Agency, Abu Dhabi 2023), pp. 27-32.

[226] ibid., p. 30.

[227] J Rachman, 'Indonesia Bets Big on Electric Vehicles' May 8, 2024, Foreign Policy.

5.5 Policies and regulations: protectionist tendencies and environmental and social sustainability standards

Recent years have witnessed the adoption of a range of protectionist industrial policies such as the US Inflation Reduction Act and the CHIPS and Science Act, the EU's Critical Raw Materials and Net Zero Industry Acts as well as Canada's Critical Minerals Strategy and the Investment Canada Act. These protectionist policies reflect a broader trend towards resource nationalism, where countries seek to exert greater control over their natural resources to safeguard their economic and strategic interests.[228] Key factors contributing to the adoption of such regulatory and policy measures include:

1. **National security**: Both the US and the EU view key minerals as essential for national security. The application of these minerals is not naturally limited only to clean tech as discussed here; instead, they are critical for the production of a variety of advanced technology, including military equipment, high-tech electronics and of course, clean tech. Ensuring a stable, uninterrupted and secure supply of these minerals is therefore considered a strategic priority.
2. **Supply chain resilience**: While assessing supply chain risks and risk management is part of the everyday operations of companies, the COVID-19 pandemic, together with other (global) upheavals have highlighted vulnerabilities in global supply chains. By implementing measures considered as protectionist, the US and the EU aim to reduce dependence on foreign sources, particularly from China.
3. **Economic competitiveness**: Enhancing domestic production capabilities and securing access to key minerals are seen as ways to boost economic competitiveness; in the US this policy falls under the heading "Buy American" or "America first". Measures adopted are designed to support local industries and reduce reliance on imports of key minerals and products that require them, such as EVs.
4. **Environmental and social sustainability standards**: Both regions are motivated by the desire to ensure that the extraction and processing of critical minerals meet high environmental and social sustainability standards. By controlling more of the supply chain domestically or through trusted partners, 'allies', stricter regulations can be enforced and sustainable practices promoted.

Uncertainty in future critical material needs is influenced by policies aimed at achieving the 1.5 degrees Celsius pathway of the Paris Agreement. Political developments can significantly impact demand projections and investment certainty. An example of the recent developments that has major potential to shake up global EV markets is the re-election of Trump in the 2024 US presidential election as president-elect Trump has indicated his wish to abolish the EV tax credit of the IRA.[229] If this plan is carried out, it will have significant impact not only on EV demand but also for example on investment certainty, potentially directing investments into more lucrative regions. On the other hand, certain US states have state-level vehicle emissions standards in place, which include requirements for sales of all-electric vehicles which in turn might reduce the impact of the potential IRA

[228] See C Jamasmie, 'Global scramble for critical minerals fuelling protectionism' (12 December 2024, Mining.com) <https://www.mining.com/global-scramble-for-critical-minerals-fuelling-protectionism/> analysing recent study by a global risk intelligence company Verisk Maplecroft. Their study reveals a spiking 'Resource Nationalism Index' in protectionist policies adopted in the EU and North America.

[229] See, e.g., M Wayland, 'What Trump's election to the White House could mean for EVs' (6 November 2024, CNBC).

abolishment.[230] Furthermore, the ability to use alternative materials and select from various technologies with continually emerging innovations can influence demand projections, together with new potential extraction sites. However, this often involves trade-offs, such as economic or performance-related costs.

On another front, the recent legislative framework adopted under the EU Green Deal[231] has had an impact on the investments of the EU companies. The EU Corporate Sustainability Due Diligence Directive[232] requires that EU companies take action to ensure environmental and social sustainability attributes, including human rights, which are protected throughout their supply chains. As a result of the requirements imposed by the EU legislation, the German company BASF as well as the French company Eramet withdrew from the Sonic Bay nickel and cobalt refinery project located in the Weda Bay Industrial Park. While the companies referred to changes in the global nickel market as the reason for their withdrawal[233], growing criticism over the impact of the proposed project has on environmental and social issues, particularly in the context of the enforcement of the Corporate Sustainability Due Diligence Directive, is believed to have played a significant role in the decision making of the companies.[234]

Similarly, the EU's Sustainable Batteries Regulation[235] does not limit its impact only within the EU. All batteries that are intended to be sold within the EU market area must comply with the stringent environmental and sustainability standards as introduced in the Sustainable Batteries Regulation. Furthermore, the EU is the first jurisdiction to implement the Global Battery Passport as initially introduced by the Global Battery Alliance.[236] Considering that the EU is a major market for batteries thanks to its ambitious decarbonization policies, and that the rules adopted are applicable also to products produced in third countries, the EU has embraced the role of a 'global regulator'. The regulations adopted by the EU can set a benchmark for global standards that may lead to a situation where other regions might adopt similar regulations, leading to a more uniform approach to sustainability in the battery industry.

For investors, the emerging policies indicate a multifaceted environment characterized by potential risks across the global supply chain. Investors from North America and the EU must consider the regulatory compliance risks associated with their investments in Indonesia. Companies that fail to meet new standards face consequences, such as fines and legal challenges. If Indonesian upstream and downstream battery and EV industry

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[230] For an overview of the clean vehicle standards, see, e.g., US Department of Energy, Alternative Fuels Data Center, "Adoption of California's Clean Vehicle Standards by State", available at https://afdc.energy.gov/laws/california-standards

[231] European Commission, The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050, boosting the economy, improving people's health and quality of life, caring for nature, and leaving no one behind. December 11, 2019. October 9, 2023, <https://ec.europa.eu/commission/presscorner/detail/en/IP_19_6691)>

[232] Directive (EU) 2024/1760 of the European Parliament and of the Council of 13 June 2024 on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859, OJ L 2024/1760, 5.7.2024.

[233] 'BASF decides against investment in nickel-cobalt refining complex in Indonesia' (25 June 2024), <https://www.basf.com/global/en/media/news-releases/2024/06/p-24-224>;

[234] D Hutt, 'EU faces green dilemma in Indonesian Nickel' (16 July 2024, Deutsche Welle), <https://www.dw.com/en/eu-faces-green-dilemma-in-sourcing-nickel-from-indonesia/a-69681557>

[235] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC, OJ L 191, 28.7.2023, p. 1-117.

[236] <https://www.globalbattery.org/battery-passport/>

does not meet the sustainability standards, investors are inclined to move to other destinations. On the other hand, if sustainability criteria are met, the focus on sustainability creates new investment opportunities. Furthermore, investing in companies that prioritize sustainability are likely to be better shielded from regulatory changes, thus yielding long-term value.

For countries, such protectionist measures concerning key minerals have several implications, including:

1) **Supply chain adjustments**: Countries that export key minerals or products that rely on these minerals, such as lithium-ion batteries and EVs, are required to adjust their supply chains to meet the new requirements and standards set by North America and the EU if they wish for access to their markets. This could involve changes in production practices, certification processes, and compliance with environmental and social sustainability standards, which may also lead to enhanced sustainability practices.
2) **Enhanced sustainability practices**: Stringent regulation, such as the EU's Sustainable Batteries Regulation, has the potential to significantly influence industrial processes globally. By demanding high environmental and social sustainability standards for batteries sold within the EU market, these regulations can drive several positive changes and support Indonesia's commitment to 'greener' the EV value chain. Stringent standards imposed by North America and the EU have the potential to drive technological advancements and improvement in mining practices globally.
3) **New opportunities**: Countries with significant reserves of key minerals might find new opportunities to enter or expand their presence in the North American and EU markets. These countries could benefit from increased demand if they are able to meet the exacting standards imposed by these regions.
4) **Geopolitical shifts and diversification:** The focus on securing supply chain resilience is prone to lead to shifts in geopolitical alliances and partnerships. Countries rich in these resources may gain strategic importance, such as the role of Indonesia as a balancing actor between the West and the East. New trade relationships are being looked after to mitigate risks associated with geopolitical tensions. These new governance mechanisms and emerging strategic partnerships are being examined next.

5.6 International governance and strategic partnerships

5.6.1 International governance initiatives and partnerships

As has been witnessed over time in the context of fossil fuels, any country's dominance posesses challenges for security of supply, resource security and geopolitical dynamics. The significant increase in demand for the key transition minerals has greatly impacted geopolitics amidst the low-carbon energy transition.[237] The global developments in this area already signal an increasing focus on geopolitics of critical minerals in addition to 'the traditional geopolitics' of fossil fuel supply and demand.

The increased focus on critical minerals has prompted the establishment of new initiatives at international and transnational levels. This situation has arisen due to the geopolitical implications of China's dominance in the battery supply chain, which has led to more (deepened) cooperation with like-minded allies. Furthermore, the sanctions im-

[237] *IRENA, Geopolitics of the energy transition: Critical Materials (International Renewable Energy Agency, Abu Dhabi 2023), p. 41.*

posed on Russia, following its invasion of The Ukraine have redirected trade in key minerals, particularly nickel, towards Asian countries instead of the EU and the US.[238] For Indonesia, maintaining a neutral stance amidst the formation of these strategic partnerships is crucial.

Perhaps most notably, the Minerals Security Partnership was established in 2022 with Australia, Canada, Finland, France, Germany, Japan, the Republic of Korea, Sweden, the United Kingdom, the United States, and the European Union as the founding members.[239] As the name suggests, the main emphasis is on securing a stable supply of critical raw materials for the economies of its members and improving the sustainability of the supply chain. The Minerals Security Partnership seeks to address the following critical minerals challenges: (1) diversifying and stabilizing global supply chains; (2) investment in those supply chains; (3) promoting high environmental, social and governance standards in the mining, processing and recycling sectors; and (4) increasing recycling of critical minerals.[240]

The Minerals Security Partnership, as discussed above, reflects the move towards a more calculated and coordinated strategy with 'like minded allies' in the global trade of essential minerals. In addition to the objective of diversifying the global supply chains, the Minerals Security Partnership illustrates a convergence of interests and values focused on the responsible production, processing, and recycling of critical minerals, thus increasing the sustainability credentials of the industry.[241] Furthermore, due to the importance of key minerals to national security and defense, the Minerals Security Partnership is not only about resource security, but also represents a unified initiative to realign global supply chains to better serve western interests. It has also been held that the initiative serves as a geopolitical strategy to limit the influence of non-market economies, especially China and Russia, and to prevent them from using their resources and dominance in segments of the supply chain as a means of political and economic leverage.[242]

BRICS+ although with a wider scope not only focused on key minerals, is considered a significant counterbalance to the Western bloc and trade alliances such as the Mineral Security Partnership.[243] BRICS+ refers to the international organization, originally known as the BRICS (Brazil, Russia, India, China, South Africa) that in January 2024 accepted 6 new members to the alliance (Argentina, Iran, Eqypt, Ethiopia, Saudi Arabia and the United Arab Emirates), followed by a group of countries that are granted a 'partner status' (Indonesia, Malaysia, Vietnam, Thailand, Algeria, Belarus, Bolivia, Cuba, Kazakhstan, Nigeria, Türkiye, Uganda and Uzbekistan). The abundant natural resource of the block places the alliance as a central player in supply chains. However, China holds a substantial share of critical minerals' supply chain also within the alliance, which might have a significant impact on the internal dynamics of the alliance. BRICS+ is emerging as a significant player in global trade, with the potential to transform the economic and geopolitical landscape.

It should be noted that Indonesia has been approached by the US to join the Minerals Security Partnership Forum with a view to supporting the development of environmental

[238] *D Guberman, 'Impact of the Russian Invasion of Ukraine on Global Nickel Trade' (U.S. International Trade Commission, Executive Briefings on Trade, April 2024)*
[239] *<https://www.state.gov/minerals-security-partnership/>*
[240] *ibid.*
[241] *V Vivoda, R Matthews and N McGregor, 'A critical minerals perspective on the emergence of geopolitical trade blocs' 89 Resources Policy (2024), 104587.*
[242] *ibid.*
[243] *ibid.*

and social sustainability standards amidst discussions on the free trade agreement.[244] One of the main tools by which the Minerals Security Partnership seeks to carry out its goals relates to the use of financing mechanisms. This could provide Indonesia with significant opportunities to expand the minerals sector, attracting investments and diversifying the investment portfolio outside of China. It would strengthen in particular the industry revolving around nickel-based chemistries. However, the decision to join would also require Indonesia to align with the stringent governance and environmental standards as required by the partnership, which is considered to be the main reason behind Indonesia's hesitation, for now.[245]

In addition to the Minerals Security Partnership and BRICS+, other international governance initiatives concerning key minerals include, among others, Energy Resource Governance Initiative[246], Critical Minerals Mapping Initiative[247], European Raw Materials Alliance[248], Supply Chain Resilience Initiative[249] as well as Sustainable Critical Materials Alliance[250], in addition to the battery-specific initiatives of the Global Battery Alliance[251] and European Battery Alliance[252].

5.6.2 Indonesia amidst the global power play

Indonesia currently enjoys a unique strategic position balancing between China and the United States, Europe and other allies, aligning with the country's foreign policy stance. While the US, the EU, and other members of the 'Western bloc' are actively implementing measures to enhance supply chain resilience and diversify supply sources, Indonesia benefits from diversifying its foreign investments. Specifically, Indonesia benefits from reducing the dominance of Chinese investments in the country, thereby broadening its investment portfolio and fostering a more balanced economic landscape.

Indonesia is currently negotiating a Free Trade Agreement (FTA) with the United States, with the main purpose of allowing Indonesian refined nickel to benefit from the preferential tax benefits as established under the IRA. If the FTA is signed, it is envisaged to expand Indonesia's access to the US markets, strengthening Indonesia's role as a key supplier in the clean tech supply chain while at the same time providing the US access to the world's largest nickel sources.

However, the rules under the IRA also include a provision on projects that are not controlled by a 'foreign entity of concern'. This encompasses any foreign entity that is 'owned by, controlled by or subject to the jurisdiction or direction of a government of a covered nation. Those countries that are under the current regulations that are covered by this

[244] 'US approaches Indonesia for multinational critical mineral partnership' (16 July 2024, Reuters), <https://www.reuters.com/markets/commodities/us-approaches-indonesia-multinational-critical-mineral-partnership-2024-07-15/>
[245] R Walker and H Palaon, 'Why Indonesia should join the Minerals Security Partnership' (18 October 2024, the Jakarta Post), <https://www.thejakartapost.com/opinion/2024/10/18/why-indonesia-should-join-the-minerals-security-partnership.html#:~:text=The%20MSP%20members%20need%20to,the%20world%2C%20must%20be%20included.>
[246] https://ergi.tools/
[247] https://portal.ga.gov.au/persona/cmmi
[248] https://erma.eu/
[249] https://www.dfat.gov.au/trade/for-australian-business/boosting-supply-chain-resilience
[250] https://www.canada.ca/en/campaign/critical-minerals-in-canada/our-critical-minerals-strategic-partnerships.html#scma
[251] https://www.globalbattery.org/
[252] https://www.eba250.com/

rule, are China, Russia, North Korea and Iran. What this essentially means is that key minerals produced by a mine or refinery with 25% of more ownership or control by any Chinese company will not be eligible for the IRA credit despite a signed FTA. The foreign entity of concern rule applies also to battery components.[253] Currently a majority of Indonesian nickel projects have more than a 25% Chinese ownership, making Indonesian nickel fall outside the scope of the lucrative IRA benefits. At the same time, the US is closing more ties with other countries with sizeable reserves, such as Australia, Canada and Brazil.[254]

The European Union has been in the process of negotiating an FTA with Indonesia since 2016. The 19th negotiation round was held in July 2024.[255] The FTA is aimed at deepening the overall relationship between the EU and Indonesia, which has so far been framed by the Partnership and Cooperation Agreement that entered into force in 2014.[256] Securing new partnerships is crucial for the EU, in particular considering the risks that are associated with a single supplier concerning strategic key commodities as revealed by the Russian Invasion on Ukraine and EU's energy security.

Outside of these developments, Indonesia has entered into several free trade agreements both as an independent market and as a Member of the ASEAN.[257] In addition to those FTAs discussed above, Indonesia has recently signed bilateral agreements with countries rich-in raw materials and with those that face increasing demand, including:

1) **Australia:** Under the agreement with Australia, Indonesia and Australia will collaborate on mapping EV supply chains, conducting joint scientific and research studies, and fostering new business-to-business connections.[258] Indonesia has also established agreements with Australia on lithium as this a critical resource required for the batteries and EVs which Indonesia cannot have domestically sourced. The agreement includes lithium processing in Indonesia, with the involvement of Australian expertise and technology. The partnership also involves joint ventures in the battery production sector. This collaboration aims to leverage Indonesia's rich nickel deposits and Australia´s abundant lithium resources to create a robust EV battery supply chain.
2) **United Kingdom:** Indonesia and the UK signed a Memorandum of Understanding to establish a strategic partnership on key minerals. This agreement focuses on policy dialogue, technical knowledge sharing, and sustainable processing of key minerals.[259]

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[253] Department of Treasury, Internal Revenue Service, Clean Vehicle Credits Under Sections 25E and 30D; Transfer of Credits; Critical Minerals and Battery Components; Foreign Entities of Concern, 26 DFR Parts 1 and 301.

[254] A Hotter, 'FEOC Definition leaves most Indonesian nickel outside IRA tax credit' (5 December 2023, Fastmarkets), <https://www.fastmarkets.com/insights/feoc-definition-leaves-indonesian-nickel-outside-ira-tax-credits-andrea-hotter/>

[255] European Commission, 'EU-Indonesia Free Trade Agreement', <https://policy.trade.ec.europa.eu/eu-trade-relationships-country-and-region/countries-and-regions/indonesia/eu-indonesia-agreement_en>

[256] For a summary of the agreement, see <https://eur-lex.europa.eu/EN/legal-content/summary/eu-indonesia-framework-agreement-on-comprehensive-partnership-and-cooperation.html>; Framework Agreement on comprehensive partnership and cooperation between the European Community and its Member States, of the one part, and the Republic of Indonesia, of the other part, OJ L 125, 26.4.2014, p. 17-43.

[257] A full list of Indonesian FTAs as an independent market as well as a part of the ASEAN can be accessed at https://www.aseanbriefing.com/doing-business-guide/indonesia/why-indonesia/indonesia-s-international-free-trade-and-tax-agreements

[258] 'Indonesia and Australia cooperation on electric vehicles' (24 November 2024, Australian Ministry for Industry and Science), <https://www.minister.industry.gov.au/ministers/husic/media-releases/indonesia-and-australia-co-operation-electric-vehicles>

[259] C Jenns, 'UK and Indonesia sign agreement on critical minerals' (19 September 2024, Mining Technology) <https://www.mining-technology.com/news/uk-and-indonesia-sign-agreement-on-critical-minerals/>

3) **Japan:** Japanese companies are involved in Indonesia's EV segment, although their presence is still developing compared to some other international players. Discussions on deepening the cooperation on the minerals and EV segments have been initiated.[260]
4) **Chile:** Indonesia has a Free Trade Agreement in effect with Chile since 2019. The agreement covers, e.g., copper together with close to 8 000 products with reduced or eliminated tariffs. Expressions of interest have been signaled to deepen the trade relations with a particular focus on lithium, from the perspective of Indonesia[261].

The geopolitics of key minerals is a dynamic and complex field that requires continuous monitoring and adaptation. The key factors impacting geopolitical dynamics along the battery supply chain relate to (1) geographical concentration of key minerals required for batteries; (2) supply chain vulnerabilities; (3) technological developments and innovations, including alternative materials and new supply sources; (4) strategic competition; (5) environmental and social concerns; and (6) policies and regulations.

National policies must consider these interconnected dynamics of geopolitics and the strategic importance of the minerals for various industries and the global energy transition as changing dynamics in any of the factors listed above can significantly impact the availability and stability of key minerals' supply chains and impact on geopolitics.

When designing national policies, it is crucial to continuously monitor global developments in this highly dynamic area. This is the role of the government. Considering the geopolitical dynamics of this sector and how geopolitics shape the key materials' value chain development, numerous countries have established governmental agencies dedicated to evaluating the supply of critical materials. These agencies are tasked with monitoring international and transnational developments with geopolitical implications in key minerals. They evaluate the implications of such developments on national security, trade and industrial policies and draft policy actions. Furthermore, in addition to monitoring global developments, it is necessary to adapt national policies accordingly. This includes remaining informed about technological advancements and geopolitical shifts, as well as fostering dialogue and cooperation with key stakeholders in the minerals market.

To effectively address and navigate the intricate geopolitics of key minerals, it is essential to bolster international cooperation through the formation of strategic partnerships and the enhancement of trade agreements. From the perspective of Indonesia and the emerging trends in battery chemistries, it is necessary to diversify foreign investment by attracting investments from a variety of countries to avoid over-reliance on any single country, particularly China. Partnership agreements should incorporate provisions for environmental and social governance standards to promote responsible mining practices, thereby supporting the development of Indonesia's domestic industry. Additionally, it is imperative to secure stable and equitable access to resources that are either not domestically available or whose supply is reliant on a limited number of suppliers. This strategy will enhance Indonesia's position as a key supplier of key minerals and trusted trade partner. Finally, Indonesia should participate actively in global governance frameworks to influence the development of international standards and policies.

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[260] *J Isaacs, 'Indonesia-Japan committed to energy transition, EV investments' (27 March 2024, Indonesia Business Post), <https://indonesiabusinesspost.com/risks-opportunities/indonesia-japan-committed-to-energy-transition-ev-investments/>*

[261] *With its sights on lithium, Indonesia wants to deepen trade with Chile' (9 May 2024, América Economía) < https://www.americaeconomia.com/en/economy-markets/its-sights-lithium-indonesia-wants-deepen-trade-chile>*

Figure 5.3 Recommendations for Indonesia to strengthen its position in the geopolitics of key transition minerals while supporting sustainable economic growth based on current global trends

Geopolitical dynamics	• Understand the geopolitical implications of mineral resource control and the strategic importance of maintaining a neutral stance. • Recognise the impact of global power shifts and align national policies to navigate these changes effectively.
Economic diplomacy	• Continue to leverage Indonesia's strategic location and economic growth to enhance its role as a global middle power. • Use economic diplomacy to build strong bilateral and multilateral relationships that support national interests.
Environmental and social standards	• Prioritise environmental and social governance to ensure sustainable development and maintain international interest. • Address environmental and social sustainability issues to align with emerging global standards and attract responsible investments. • Participate actively in the development of global governance frameworks.
Strategic competition	• Monitor developments closely and position Indonesia to benefit from global demand. • Balance relationships with major economies to maximise economic and strategic advantages.
Regulatory adaptation	• Continuously monitor global regulatory developments and adapt national policies to stay competitive. • Ensure that national regulations support both domestic growth, international market access and a high level of sustainability standards.

Source: Own elaboration

6 Economic analysis of batteries and EV adoption in Indonesia

6.1 Fiscal and non-fiscal incentives for EV development

As described in section 1.5, this report focuses on the EVs as the main end-use of batteries, considering its predominance on the market. Therefore, this section summarizes all fiscal and non-fiscal incentives the GOI has established to this day to boost the adoption of batteries and EVs as part of the country's efforts to develop the battery supply chain. No significant incentives for the government were found aiming to develop battery energy storage systems (BESS) or portable electronics.

The government has implemented investment incentives for downstream businesses such as[262]:

- **Corporate income tax holiday:** reductions of up to 100% for five to 20 years, applicable on investment values between USD $7.2 million and USD $2.1 billion
- **Gross income tax deductions:** up to 300% of costs incurred from R&D, technology innovation activities, and training to enhance capacity building in the EV industry
- **Value Added Tax (VAT) exemptions:** Exemptions on importation of machinery, capital goods and raw materials for EV and battery manufacturing
- **Import duty exemptions:** Waiver of import tax until 2025 for raw materials or equipment for EV battery production. And 0% import duty tariff applicable to Completely Built Up (CBU) and Completely Knock Down (CKD) EVs with a local content value of 20-40%. Until now, EV producers BYD, Vinfast, Aion, Volkswagen and Maxus have benefited from such incentive.
- **Luxury sales tax incentive:** Applicable to companies that import certain completely-built-up (CBU) four-wheeled EVs. Such imports will be eligible for luxury sales tax exemption as well as import duty exemptions until December 2024.

Additional regulations and incentives on the demand side have also been established to promote the adoption of EVs while addressing environmental and energy challenges. Key measures include[263]:

- **Odd-even license plate policy:** In major cities such as Jakarta, this policy restricts vehicle use based on license plate numbers on certain days to alleviate traffic congestion and reduce air pollution, indirectly encouraging EV usage.
- **Tax reductions:** The government provides tax incentives for EVs, including lower import duties and exemptions from luxury goods tax. Electric vehicles benefit from a reduced Value-Added Tax (VAT) of 1%, compared to 11% for conventional vehicles, and are also exempt from luxury and import taxes. Additionally, regional tax reductions are available for EVs.

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[262] *Hirotaka Uchida (2023) Unleashing Indonesia's electric mobility potential. Arthur D. Little. Available at: https://www.adlittle.com/en/insights/report/unleashing-indonesias-electric-mobility-potential#:~:text=The%20government%2C%20as%20per%20Ministry,incentives%20offered%20by%20the%20government.*

[263] *Tampubolon, J.V.; Dalimi, R. Simulating EV Growtvh Scenarios in Jawa-Madura-Bali from 2024 to 2029: Balancing the Power Grid's Supply and Demand. World Electr. Veh. J. 2024, 15, 341. https://doi.org/10.3390/wevj15080341*

- **Parking benefits:** Some cities offer free or discounted parking for EVs, reducing the overall cost of ownership and making EVs more attractive to consumers.
- **Charging infrastructure development:** The government is investing in expanding EV charging infrastructure, including the installation of charging stations in public areas and along highways. However, a low ratio of electric vehicles to charging stations (EV) could hinder economic viability.[264] An appropriate balance is crucial to ensure optimal utilization and satisfaction among EV users. The Indonesian government aims to construct approximately 32,000 electric vehicle charging stations (SPKLU) by 2030 to meet growing demands[265].

To expedite the transition to EVs, the government has introduced additional subsidy programs. These include a 10% VAT deduction for four-wheeled electric vehicles (4WEV) and an IDR 7,000,000 deduction for two-wheeled electric vehicles (2WEV), as specified in recent regulations. Moreover, Presidential Regulation No. 55/2019 mandates a minimum of 40% local components in EV production to access the reduced VAT by 2023 aiming to encourage local manufacturing.

Additionally, the Ministry of Transportation has introduced a financial incentive policy that waives fees for various vehicle testing and certification processes. Specifically, the costs for the KBLBB Type Test Certificate and Type Test Registration have been reduced to IDR 0, significantly lowering the barrier for manufacturers. An overview of the policies related to battery sales and EV development are shown in the following table:

Table 6.1 Overview of policies related to battery sales

Policy / regulation	Description	Fiscal	Non-fiscal
Presidential Regulation 55/2019 on Acceleration of the BEV Program for Road Transportation	The presidential mandate to develop a domestic EV industry as a national priority to increase energy efficiency in the transportation sector[266]. Specifies technical requirements and standards for EVs, including battery charging and related infrastructure.		✓
Government Reg. No. 74/2021	Battery electric vehicle (BEV) is exempted from sales tax on luxury goods (PPnBM)	✓	
Ministry of Home Affair (MoHA) Reg. No. 1/2021:	BEV maximum yearly tax (PKB) and title transfer fee (BBNKB) is only 10% of its imposition fee calculation.	✓	
Presidential Regulation 79/2023 on Amendments to Presidential Regulation Number 55 of 2019 concerning the Acceleration Program of BEV for Road Transportation	It mandates boosting EV use in daily transportation. It additionally addresses technical requirements, safety standards, battery charging infrastructure, and incentives to support the production, distribution, and adoption of electric vehicles in Indonesia.	✓	✓
MOI Regulation 6/2022 on BEV Specification, Roadmap, and TKDN Calculation	It provides a 2020-2030 roadmap for BEV specification, supply chain development policies and strategies, and TKDN targets and calculations.		✓
MOI Regulation 28/2023 on Amendments to MOI Regulation 6/2022 on BEV Specification, Roadmap, and TKDN Calculation	It provides several updates to the MOI Reg 6/2022, notably the inclusion of more EV categories (2W and trucks), revised battery capacity eligible for incentives, revised TKDN components, and the addition of more complex variables related to EV assembly activities.	✓	

[264] *Electric Vehicle Supply Equipment, also known as EV charger.*
[265] *MEMR. Government's Target for the Electric Vehicle sector in 2030. Press release. May 22, 2024. Available at: Ministry of Energy and Mineral Resources of the Republic of Indonesia - Media Center - News Archive - This is the Government's Target for the Electric Vehicle Population in 2030 (esdm.go.id)*
[266] *CSIS (2022). Indonesia's Battery Industrial Strategy.*

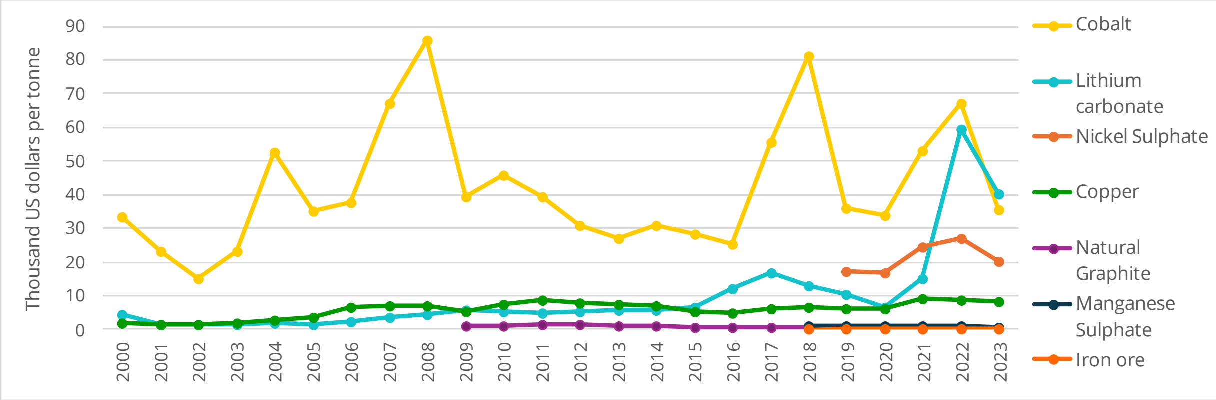
Policy / regulation	Description	Fiscal	Non-fiscal
Minister of Investment (MOInv) 6/2023 on Guidelines and Governance for Providing Incentives for Import and/or Delivery of Four-Wheeled Battery-Based Electric Vehicles in Accelerating Investment	This regulation governs guidelines and governance for providing incentives for the importation and/or delivery of 4W BEVs in order to accelerate investment in Indonesia's EV sector.	✓	
Minister of Transport Decree No. KM 8/2023 concerning the Determination of Climate Change Mitigation Actions within the Transport Sector to Achieve the NDC Target.	The document covers various mitigation action policies, such as road-based urban public transport development, utilizing ATCS (Area Traffic Control System), TOD (Transit Oriented Development), NMT (Non-Motorized Transport) development, promoting electric motorized vehicles (commonly referred to as KBLBB in Indonesia) and charging station facilities, implementing Electronic Road Pricing (ERP), etc.		✓
OJK (Otoritas Jasa Keuangan) Circulation:	Risk Weighted Assets (RWA/ATMR) for EV financing (producing and buying) is reduced from 75% to 50%. EV credit purchase payment could cost 0% (without down payment).	✓	
MEMR Reg. No. 13/2020	Standardization of charging plugs and electricity tariff policy for public electric vehicle charging station and public electric battery vehicle replacement.		✓
Permen ESDM No 1 Tahun 2023 Penyediaan Infrastruktur Pengisian Listrik Untuk Kendaraan Bermotor Listrik Berbasis Batera / Provision of Electric Charging Infrastructure for Battery-based Electric Motor Vehicles	This Regulation from the Minister of Energy and Mineral Resources No. 1 of 2023, includes mandates concerning the provision of electric charging infrastructure for battery-based electric motor vehicles, including technological definition and scope of the infrastructure itself; charging facility that includes private electrical installation and charging station for public transportation; battery exchange facility; and assignment of PT Perusahaan Listrik Negara. This regulation also discusses the electrical tariff for battery-based electric vehicle; electric safety of charging infrastructure for battery-based electric vehicles; guidance and supervision; reporting and evaluation; administrative sanction; as well as transitional provisions. This regulation is in effect starting 13 January 2023.		✓

6.2 Price trends

6.2.1 Raw materials price trends

Raw materials represent a substantial portion of electric vehicle (EV) battery costs, accounting for approximately 70% to 80% of total expenditures. The following figure illustrates the price of key metals and materials required for the manufacture of lithium-ion batteries (Figure 6.1). Despite prices reaching a peak in 2022, lithium prices have since experienced a decline in recent years. This trend may impact overall battery production costs and market dynamics.

Figure 6.1 Selected metals and materials critical to the manufacture of Li-ion batteries



Source: For all materials except Mn: Energy Institute. 2024. Statistical Review of World Energy. For Mn: SC Insights

Data can be summarized as follows:

- **Lithium carbonate (HS 28369100):** The price of lithium carbonate has suffered significant changes over the last decade. Between 2015 and 2017, prices almost tripled reaching a peak in 2000 with a price of USD $ 17,040 per ton. Later prices decreased annually until 2020 reaching similar prices of the year 2015, yet this didn't last long as prices rose abruptly peaking in 2022 at USD $59,430 due to a supply deficit post COVID 19 pandemic. The latest peak prices were largely related to the growing demand for EVs. In 2022, 60% of lithium demand was destined to EV batteries production[267].
- **Unrefined cobalt (HS 26050000):** Historically, cobalt prices have been unstable with two significant and drastic peaks in the last 20 years reaching USD $86,000 and $81,700 per ton in 2008 and 2018, respectively. These peaks were almost twice the last 20-year average USD $44,400 per ton. Price changes have been significantly affected by the concentration of supply as The Democratic Republic of Congo (DRC) accounts for over 70% of global production, making the cobalt market vulnerable to regional challenges to meet demand, especially for EVs. In 2017, 10% of the cobalt demand was for EV batteries. This figure tripled in only five years. Having supply concentration may interfere with meeting demand for growing markets, such as batteries, causing price fluctuations as it has happened in the last decade.
- **Nickel sulphate (HS 28332400**): In the last five years, nickel sulphate prices have been generally increasing mainly driven by the accelerated demand increase of EVs batteries that use nickel-rich cathodes e.g. NMC and NCA. Prices saw a USD $10,000 per ton increase between 2019 and 2022. However, prices dropped in 2023 mainly due to global nickel market surplus and to the demand for non-nickel-based batteries, e.g. LFP, especially by Chinese EV manufacturers.

To achieve price stability and predictability, policymakers are increasingly implementing reference prices for these essential materials. This approach promotes market transparency, allowing stakeholders to make informed decisions in a volatile market.

As a step towards establishing a stable pricing framework, the Ministry of Energy and Resources issued a decree that establishes monthly Reference Metal Mineral Prices (HMA) for various metal minerals and coal, covering key commodities such as: nickel, cobalt, lead, zinc, aluminium, copper, gold, silver, tin, manganese, iron ore, chrome ore, ilmenite concentrate, and titanium concentrate. Table 6.2 shows the annual average HMA

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[267] *IEA (2023), Global EV Outlook 2023, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2023, Licence: CC BY 4.0*

prices for the main components of MNC in the last four years. HMA prices considers the average mineral prices from Beijing, Jakarta, and the London Metal Exchange (LME) hence the similarity of prices shown in Table 6.2 and Figure 6.1.

Table 6.2 Annual average reference metal mineral price issued by the GOI (USD $/dmt)[268]

Year	Nickel	Manganese	Cobalt
2021	$ 18,049.17	$ 3.96	$ 47,218.28
2022	$ 25,386.88	$ 4.15	$ 65,755.57
2023	$ 22,823.75	$ 3.91	$ 36,676.88
2024 (YTD)	$ 17,105.03	$ 3.66	$ 27,701.09

As such a large producer and exporter of nickel, Indonesia is significantly integrated into the global nickel supply chain, meaning that the buyers the country deals with, negotiate based on global market prices. HMA prices provide certainty which is expected to attract new investment.

The Indonesian Nickel Miners Association (APNI) is collaborating with the Coordinating Ministry for Maritime Affairs and Investment (Kemenkomarves) to prepare for the establishment of an Indonesian Nickel Index. Currently, the benchmark mineral price (HPM) is primarily aligned with prices from the London Metal Exchange (LME) and calculated based on the Reference Metal Mineral Prices (HMA). Developing a local index will enhance monitoring of domestic market conditions and enable policymakers to adjust regulations as needed. The implementation of reference prices for raw materials is a critical step toward stabilizing the EV battery market. By fostering transparency and predictability, these initiatives support stakeholders in making informed decisions, ultimately contributing to the growth and sustainability of the electric vehicle sector in Indonesia.

6.2.2 Battery price trends

The global LIBs market size is expected to grow from USD $56.8 billion in 2023 to USD $187.1 billion by 2032, at a CAGR of 14.2% from 2023 to 2032[269]. LIBs market size and expected growth go hand in hand with the 82% price drop that lithium-ion battery packs have experienced in the last decade (Figure 6.2).[270] This decrease is largely due to falling

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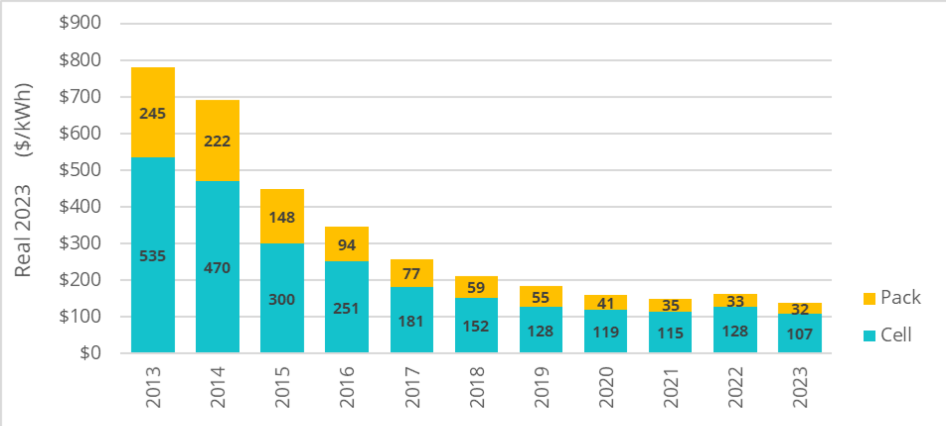
[268] *Direktorat Jeneal Mineral dan Batubara (2024) Harga Acuan. Available at: https://www.minerba.esdm.go.id/harga_acuan*

[269] *MarketsandMarkets, 2023. Lithium-ion Battery Market by Type (NMC, LFP, LCO, LTO, LMO, NCA), Capacity (Below 3,000 mAh, 3,001 mAh–10,000 mAh, 10,001 mAh–60,000 mAh, Above 60,000 mAh), Voltage (Below 12V, 12V–36V, Above 36V), Application and Region - Global Forecast to 2032. Available at: Lithium-ion Battery Market by Type (NMC, LFP, LCO, LTO, LMO, NCA), Capacity (Below 3,000 mAh, 3,001 mAh–10,000 mAh, 10,001 mAh–60,000 mAh, Above 60,000 mAh), Voltage (Below 12V, 12V–36V, Above 36V), Application and Region - Global Forecast to 2032 (marketresearch.com)*

[270] *In 2023, the metal sector experienced a decline in prices due to an oversupply in the global markets. Notably, metals such as cobalt, copper, lithium, palladium, rare earth elements, and zinc saw significant reductions in production value. This decrease of prices led to delays or halts in operations for some mining projects. See U.S. Geological Survey, Mineral Commodity Summaries 2024 (U.S. Geological Survey 2024), p. 5.*

raw materials[271] and component prices — raw materials alone account for 70-80% of the total cost of EV batteries[272] — combined with increased production capacity.[273]

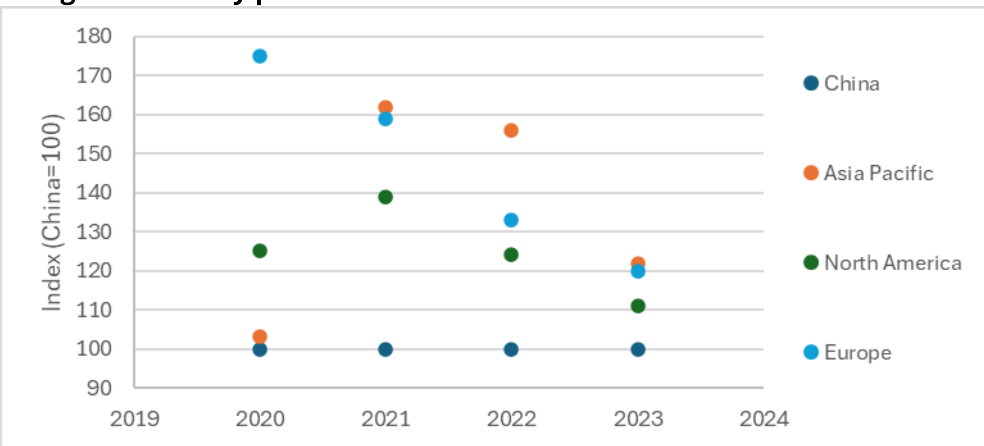
Figure 6.2 Volume-weighted average lithium-ion battery pack and cell price split, 2013-2023



Source: BloombergNEF. Historical prices have been updated to reflect real 2023 dollars. Weighted average survey value includes 303 data points from passenger cars, buses, commercial vehicles and stationary storage.

This trend can be analyzed by region, as illustrated in Figure 6.3, which presents the battery price index by region for 2020-2023, excluding China from the Asia Pacific region. According to the IEA methodology, prices are indexed against the Chinese price, which is set at 100. The battery prices represent the average cost in each region, encompassing both locally produced batteries and imports.

Figure 6.3 Regional battery price index



Source: IEA, Global EV Outlook 2024 (IEA Publications), p. 85.

Regarding lithium-ion battery chemistries, the trend is similar. Figure 6.4 presents the average battery prices indexed again LFP prices in China for the period 2020-2023.

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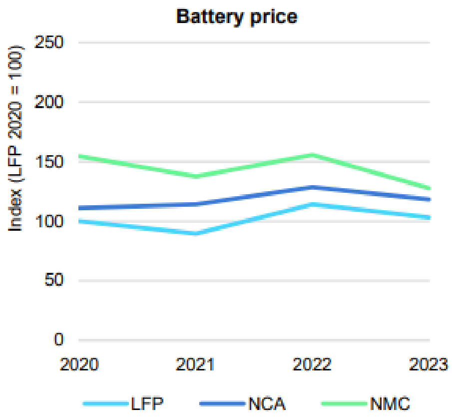
[271] *In particular the cost of lithium and nickel, see E Silva, 'Decline in battery metal costs drives down electric vehicle prices' March 4, 2024, SPGlobal, available at https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/decline-in-battery-metal-costs-drives-down-electric-vehicle-prices-80664889*

[272] *S&P Global, 2023. Asian Battery Makers are shifting strategies to hold onto global lead. Available at: Asian Battery Makers Are Shifting Strategies To Hold Onto Global Lead | S&P Global Ratings (spglobal.com)*

[273] *'Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh' November 26, 2023, BloombergNEF, available at Lithium-Ion Battery Pack Prices Hit Record Low of $139/kWh | BloombergNEF (bnef.com)*

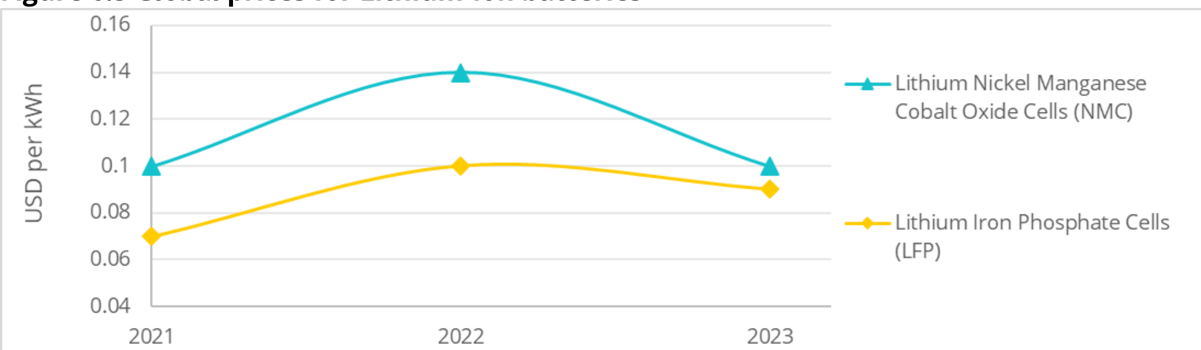
Figure 6.4 Battery price by selected chemistries



Source: IEA, Global EV Outlook 2024 (IEA Publications), p. 85.

In 2023, prices for both LFP and NCM battery cells have declined compared to 2022 (Figure 6.5). The effect of increased battery material prices differed across various battery chemistries in 2022, with the strongest increase being observed for LFP batteries (over 25%), while NMC batteries experienced an increase of less than 15%[274].. However, overall LFP cells remain at lower prices that NMC cells since they don't contain nickel or cobalt, which have higher costs than iron and phosphorus. Additionally, due to lithium prices increasing at a higher rate than the price of nickel and cobalt, LFPs had higher price increases than NMC.

Figure 6.5 Global prices for Lithium-ion batteries



Source: Own elaboration

6.2.3 EVs price trends

In the last decade, especially in the last 5 years, the adoption of electric vehicles has increased significantly driven by a downwards trend of its prices. However, the cost of owning an EV is still above the overall market average of owning a vehicle. Major EVs automakers such as BYD and Tesla have reduced its prices through strategic cost reductions, forcing other companies to follow them in order to remain competitive in the market. One of the main factors for such price reductions has been the reduction in battery costs, which accounts for around 40% of EV's price[275].

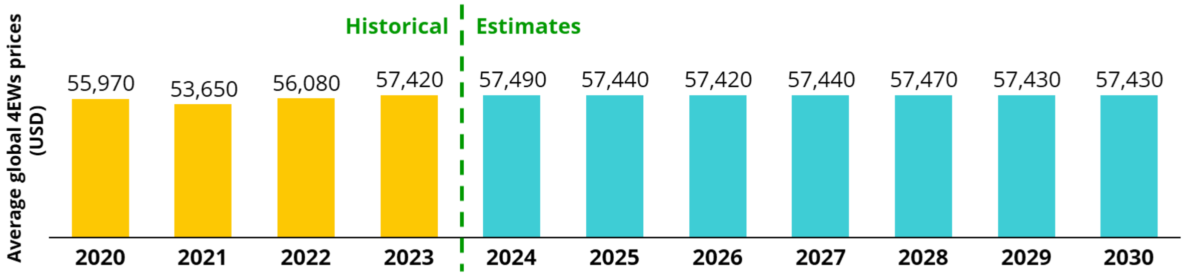
According to Statista's forecast of the average global prices, EVs will remain quite flat until 2030 since any technological advances that could translate into lower EV prices would

[274] *IEA (2024), Global EV Outlook 2024, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2024, Licence: CC BY 4.0*

[275] *N. Rivero. (2024) It's never been cheaper to buy an EV. Here's why. The Washington Post. Available at: https://www.washingtonpost.com/climate-solutions/2024/03/18/electric-vehicle-price-drop/*

take more time to be reflected in the global average. Under this projection, the global average price for EVs would be around USD $57.4 thousand by 2030[276].

Figure 6.6 Historic and estimated projection of average EV global prices[277]



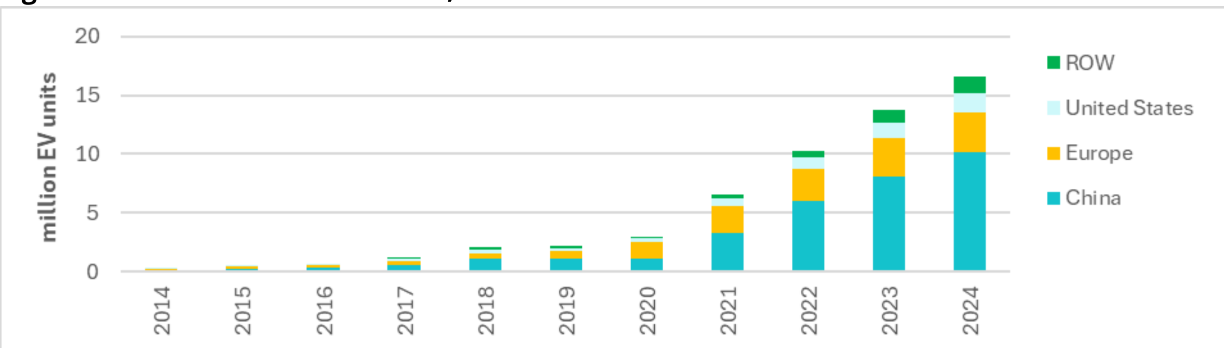
Source: Own elaboration

Specifically in Indonesia, and presumably as a result of the VAT reduction incentive, the starting prices of the most affordable EV, the Hyundai Ioniq 5, has decreased from USD $51,000 to under USD $45,000 since the incentive started. Although this is a very attractive incentive and its positive effects in the development of national electromobility have started to show, the price difference between internal combustion engine vehicles (ICEVs) is still significant since the least expensive gasoline vehicle in Indonesia, the Daihatsu Ayla, has a price of under USD $9,000[278].

6.3 Potential electromobility market in Indonesia

In the last decade, electric vehicle sales have been on the rise in China, Europe, the United States, and across the globe (See Figure 6.7). Consequently, the demand for EV batteries is also expected to grow rapidly.

Figure 6.7 Global electric car sales, 2014 - 2024



Source: IEA (2024), Electric car sales, 2012-2024, IEA, Paris https://www.iea.org/data-and-statistics/charts/electric-car-sales-2012-2024, Licence: CC BY 4.0

In the global EV market, passenger EVs are projected to dominate lithium-ion battery consumption, capturing a 67% market share, according to BNEF. Additionally, the market share for electric buses and commercial transport vehicle market share is expected to rise to 24%. In contrast, other battery related markets, such as energy storage systems,

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[276] *Statista (2024) Average electric vehicles price worldwide from 2019 to 2029(in thousand U.S. dollars). Available at: https://www.statista.com/forecasts/1309622/worldwide-e-vehicles-average-price*
[277] *Statista (2024) Average electric vehicles price worldwide from 2019 to 2029(in thousand U.S. dollars). Available at: https://www.statista.com/forecasts/1309622/worldwide-e-vehicles-average-price*
[278] *ASEAN Briefing (2023) Indonesia Market Prospects for EV Sales and Manufacturing. Available at: https://www.aseanbriefing.com/news/indonesia-market-prospects-for-electric-vehicles-sales-manufacturing-investments/*

indicate that stationary storage is expected to account for only 9% of the lithium-ion battery market. Since EVs are the main end use option of batteries, this project will focus on the development of a battery supply chain for electric vehicles.

6.3.1 National state of play

Traditional transport modes in Indonesia have relied on diesel and gasoline engine technologies. Motorbikes are the primary mode of transportation in Indonesia, with a rate of 325 motorbikes per 1,000 inhabitants, significantly higher than the global average of 93 per 1,000. In contrast, car ownership in Indonesia stands at about 40 cars per 1,000 inhabitants, which is only a quarter of the global average. This disparity is evident from the latest data on motor vehicles and motorcycles in Indonesia. Additionally, less than 10 percent of the vehicles on Indonesian roads are domestically assembled, with passenger cars representing the highest percentage of locally manufactured vehicles. The countries of origin for the imported vehicle fleet include Japan, China, India, and Thailand[279].

The mobility sector accounts for around 20% of the country's carbon emissions. However, the road transport emission inventory and the baseline of Indonesia's road transport have never been officially established[280]. In relation to this, Indonesia's Net-Zero Emission (NZE) Roadmap[281] for the Energy Sector 2060 mandates that the transport sector emission levels in 2060 should not exceed 52 million tons of CO_2.

The mitigation actions for the transport sector are stipulated in the Minister of Transport Decree No. KM 8/2023 concerning the Determination of Climate Change Mitigation Actions within the Transport Sector to reach the country's NDC target. The document covers various mitigation action policies, including Transit Oriented Development (TOD), NMT (Non-Motorized Transport) development, promoting electric motorized vehicles (commonly referred to as KBLBB in Indonesia) and charging station facilities, implementing Electronic Road Pricing (ERP), etc.

Currently, EVs only account for about 2% of Indonesia's auto market but are expected to reach a double-digit share by 2030. Presidential Regulation No. 55/2019 mandates domestic EV industry as a national priority to increase energy efficiency in the transportation sector. In regard to the battery supply chain, Indonesia plans to have 2,200,000 four-wheeled (4W) EVs and 13,000,000 two-wheeled (2W) EV units on the road by 2030[282], and to produce 600,000 EVs by 2030[283].

The development of an EV market in the country currently has promising opportunities, as the facilitators outweigh the barriers. Both the public and private sectors can collaborate to enhance this potential further (See Table 6.3)

[279] Ministry of Finance (Directorate General of Customs and Excise). Exports and imports declaration document.
[280] WRI (2024). Indonesia's Path to Net-Zero Emission: Measuring Road Transport Emissions as the Foundation for a Sustainable Transport Policy. Available at: https://wri-indonesia.org/en/insights/indonesias-path-net-zero-emission-measuring-road-transport-emissions-foundation
[281] IEA (2022) IEA (2022), An Energy Sector Roadmap to Net Zero Emissions in Indonesia, IEA, Paris https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia, Licence: CC BY 4.0. Available at: https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia
[282] Ini Target Pemerintah untuk Populasi Kendaraan Listrik di Tahun 2030 -- MEMR Press Release, 2024
[283] ASEAN Energy Database System (AEDS). 2024. Available at: https://aseanenergy.org/news-clipping/indonesia-targets-production-of-600000-ev-units-by-2030/

Table 6.3 Facilitators and barriers to EV adoption in Indonesia

Facilitators	Tax breaks
	Subsidies
	Strategic infrastructure development
	Consumer preferences toward environmentally friendly vehicles
	Expanding middle class with increasing purchasing power
	Significant advances in battery technologies, with a focus on increasing energy density, longevity and recyclability
	Rising alternatives in battery material to reduce environmental footprint
	Lower maintenance costs
	Fuel economy standards, and CO2 emissions standards are drivers that facilitates the uptake of EVs
Barriers	Limited charging infrastructure
	Battery technology constraints
	Consumer apprehension regarding range and affordability
	Raw material extraction for batteries is linked to social and environmental concerns

Source: AEML, 2023 & IEA 2022.

In 2022, the demand for batteries in Indonesia reached 329 MWh, with LFP batteries accounting for 57.7% of this demand, followed by NCM batteries at 42.2%, and lead-acid batteries at 0.1%. Unfortunately, the domestic battery production capacity is only a fraction of this demand, highlighting a significant supply gap.

Despite the growing global trend towards electric vehicles (EVs), Indonesia's adoption rate remains low. Until 2019, annual sales of electric cars in the country were consistently below 100 units. However, this figure saw a significant increase between 2020 and 2021. In 2023, Chinese manufacturers dominated the market, accounting for 45% of total car sales. The majority of these imported vehicles utilize LFP batteries. Notable local bestsellers include Toyota's Kijang and Hyundai's Ioniq. Specifically, Hyundai reported sales of 7,176 units of the Ioniq 5, while Wuling sold 5,575 units of the Air EV[284]. This diverse market preference is expected to influence manufacturers to offer a wide range of EV models to cater to varying consumer demands.

Currently, Indonesia's EV production capacity significantly lags behind targets. Given the existing fleet of domestically assembled cars, the conversion rate to EVs, and the number of operational battery factories, the expected production volume does not align with the country's high levels of nickel production (See Table 6.4). The potential national production capacity along with the gap between the current conditions and the country's NDC targets showcase the potential EV's market that could be unlocked if the battery's supply chain is developed.

Table 6.4 State of play of the battery supply chain in Indonesia

Strategy	Description	Significant progress	In progress	Not started / Not available data
Mining	Regulations and investment in place to promote supply chain development.		✓	
	Provision of key raw materials.	✓		
Raw materials processing	Formulate fiscal and non-fiscal incentives.		✓	

[284] *The Association of Indonesia Automotive Industries. Indonesian Automotive Industry Data 2023; GAIKINDO: Jakarta, Indonesia, 2024.*

Strategy	Description	Significant progress	In progress	Not started / Not available data
Battery cell & Battery pack assembly	Battery cell and pack development through incentivizing battery producers.		✓	
End use	Formulate fiscal and non-fiscal incentives.		✓	
	EV charging station development.		✓	
	Enforce mandatory EV usage on a large scale.			✓
	Enforce EV-exclusive zones in the country.			✓
	Establish FTAs with prospective buyer countries.		✓	
	4W EV production.		✓	
	2W EV production.		✓	
	Charging station production.		✓	
Recycling / second life use	Battery management system development.			✓
	Provision of battery materials.			✓
	Development of battery end-of-life schemes.			✓

Source: Own elaboration based on the MOI Roadmap - Regulation 28/2023

6.3.2 Future demand trends

According to an analysis released by the Indonesian Electric Mobility Ecosystem Association (AEML) in 2023, the EV sector is projected to experience a compound annual growth rate (CAGR) of 58.5% from 2023 to 2030. The largest absolute increase in electricity demand is anticipated to come from electromobility, with transportation projected to be the second-largest component of electricity demand by 2060, requiring approximately 350 TWh.

Due to consistently high nickel prices, many automakers are shifting away from nickel-based batteries in favour of more cost-effective, nickel-free alternatives, such as LFP batteries. Notably, companies like China's BYD are planning to establish manufacturing operations in Indonesia, which could significantly influence the local battery market landscape.

Looking ahead, the development of solid-state batteries is emerging as a key trend, promising higher energy densities, faster charging times, and enhanced safety features. However, it is important to consider potential headwinds. Factors such as rising interest rates and economic uncertainty may adversely impact the growth of global electric vehicle sales in 2024.

Regarding battery energy storage systems, as of 2023, the global capacity for grid-scale battery energy storage systems (BESS) has reached 56 GW, with nearly 50% of this capacity installed in China. Other leading countries include Australia, South Korea, and Japan. In stark contrast, the combined capacity of other Asia-Pacific nations, including Indonesia, stands at only 0.4 GW[285] (refer to Table 9.4 for detailed data).

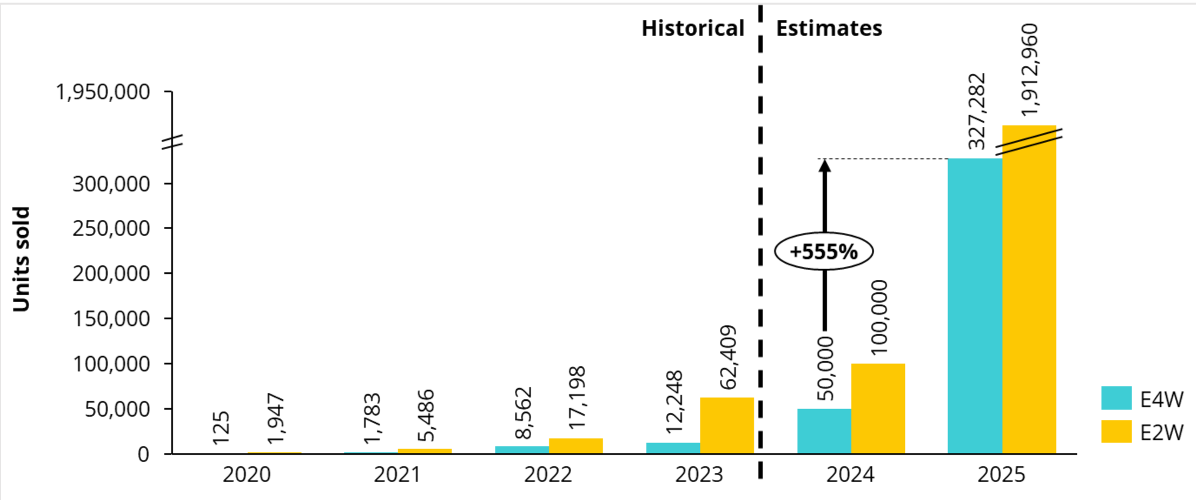
Thus, the battery sector is poised for increased significance in the coming years. Notably, 2024 will mark the first inclusion of data related to battery storage, battery cells, and their

[285] *Energy Institute. 2024. Statistical Review of World Energy. 73rd Edition. Available at: https://www.energyinst.org/statistical-review*

key minerals and materials in the Statistical Review of World Energy[286]. However, the Review indicates a decline in the demand for lithium-ion battery-related minerals and metals in 2023. This decrease can be attributed to multiple factors, including increased supply, shifts in demand in major markets like China, changes in battery chemistry, and market corrections following the price surges observed in 2021 and 2022.

The Indonesian government is actively working on meeting the target to have 2 million electric four-wheel vehicles (E4W) and 13 million electric two-wheel vehicles (E2W) on the road by 2030. The EV market in Indonesia is still far from meeting the targets set, however, the increase reported in E4W and E2W sales in the last years seem promising, as shown in Figure 6.8. In 2023, 12,248 units of EVs were sold in the country, which represented a 43% increase from the previous year.[287] In addition, the total sales of electric 2W vehicles in 2023 showed a threefold increase from 2022 sales.

Figure 6.8 Annual sales of electric four-wheels (E4W) and two-wheels vehicles (E2W)



Source: Own elaboration

In addition to the accelerated increase in EV sales in the previous years the government has set the minimum target of closing 2024 with 50,000 E4W sold and 100,000 E2W. According to the National Energy Masterplan (RUEN) the GOI is aiming to have 2.1 million E2W and 400,000 E4W on the road by 2025[288]. Such increments are expected to be part of the global trend toward electromobility, but also supported by the government's efforts and incentives implemented so far, such as the reduction of VAT and the elimination of the luxury tax, described in chapter 6.1. The 11% VAT reduction incentive is only applicable if 40% of the components are produced locally, but such local content will gradually increase up to 60% by 2027. However, this target seems unlikely to be met timely since it would require sales of E4Ws to have an increase of over 500% in 2025 compared to the previous year, according to government expectations (Figure 6.9).

6.3.3 Production of EVs

Currently, production of E4Ws in Indonesia is quite low. However, the government's efforts to develop the supply chain for batteries plus the EVs production targets set to be met in the next decade aim to change this.

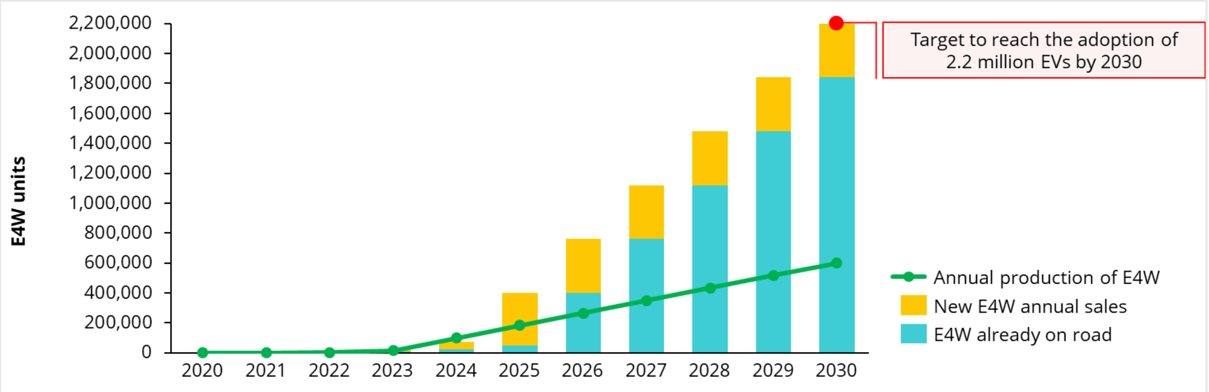
[286] The Review has been providing data to the energy community around the world since 1952.

[287] Suryacipta. The Rise of Electric Vehicle in Indonesia
Published On - 8 July 2024 https://suryacipta.com/en/the-rise-of-electric-vehicle-in-indonesia/

[288] AFMA, Indonesia Sets Sights on 50,000 EV Sales in 2024. Available at: https://afma.org.au/indonesia-sets-sights-on-50000-ev-sales-in-2024/

Figure 6.9 shows an estimated projection of how domestic demand and production would have to evolve to meet the adoption targets, described in section 6.3.2, considering the historical sales of E4W in the country and assuming a lineal progress.

Figure 6.9 Estimated annual E4W production and adoption in Indonesia



Source: Own elaboration

In addition to the adoption targets described in section 6.3.2 the GOI aims to become the third largest producer of electric batteries in the world by 2027[289], and to have 20% of its components manufactured locally[290]. This means that the 327,282 units pending to be sold to meet such expectations would not qualify to benefit from the VAT reduction incentive described in section 6.1.

The domestic EV industry faces significant challenges, particularly in production capacity and reliance on imported components, making it less competitive compared to internal combustion engine vehicles (ICEVs) [291]. Although the government has introduced incentives—such as the purchase subsidies and tax holidays for manufacturers described in section 6.1—to encourage EV adoption, these initiatives have placed pressure on the national budget[292]. The Ministry of Energy and Mineral Resources (MEMR) has allocated USD $455 million to subsidize the sale of electric motorcycles, including the introduction of 800,000 new electric motorcycles and the conversion of 200,000 combustion engine motorcycles.

Indonesia is in the early stages of establishing its battery cell manufacturing capabilities[293]. In the context of electric vehicle (EV) batteries, the Indonesian Electric Mobility Ecosystem Association (AEML) projects that Indonesia's market for cell manufacturing and battery management systems could reach approximately USD $3 to USD $4.5 billion by 2030. Additionally, the charging infrastructure sector is expected to contribute an estimated USD $2 to USD $3 billion. However, significant challenges remain, including rising commodity costs and regulatory changes impacting the private sector. Furthermore, the battery recycling market, which includes battery maintenance and services, is projected to be valued between USD $0.5 billion and USD $1.5 billion by 2030.

The state-owned company, Indonesia Battery Corporation (IBC), has been established to lead domestic battery cell production. A key component of IBC's strategy is a joint venture

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289 ASEAN Briefing (2024). Available at: https://www.aseanbriefing.com/news/indonesia-issues-new-tax-incentives-to-spur-ev-production-and-sales/

290 Indonesia Investment Promotion Center (IIPC), (2024) Available at: https://www.iipcnewyork.org/post/charging-up-indonesia-the-rapid-rise-of-evs-in-indonesia

291 Sasongko, T. W., Ciptomulyono, U., Wirjodirdjo, B., & Prastawa, A. (2024). Identification of electric vehicle adoption and production factors based on an ecosystem perspective in Indonesia. Cogent Business & Management, 11(1).

292 Battery technology, 2024. Solid State Batteries: The Future of Energy Storage? Solid State Batteries: The Future of Energy Storage? (batterytechonline.com).

293 Indonesia Battery Corporation corporate website with Hyundai and LG, through PT HLI Green Power[294]., located in Karawang, West Java. This facility is designed to produce 32.6 million battery cells, equivalent to 10 GWh.

6.4 Workforce characteristics

In Indonesia, Java and particularly Jakarta, significantly dominate Indonesia's economy, with nearly one-sixth of all non-agricultural firms located in the capital[295]. As for the workforce in mining and quarrying, the most recent detailed data was collected during the 2016 economic census. This census revealed that while Java Island has the highest number of mining and quarrying establishments, the majority of workers in this sector are located in the Sumatra region, accounting for approximately 28% of all mining and quarrying workers in the country. This concentration of economic activity is crucial for understanding the dynamics of the battery supply chain.

Economic activities associated with the battery supply chain primarily involve the mining and quarrying sector (A), the manufacturing sector (C), and wholesale and retail trade, including the repair of motor vehicles and motorcycles (G). However, specific data on job creation within the battery production sector is limited; existing reports generally encompass broader industry figures. As shown in Table 6.5, the manufacturing sectors accounts for most of the labor force within the battery supply chain, including formal employees and casual workers (not permanent employees).

Table 6.5 Total workers in 2023 in industries related to the battery supply chain

Employment status	Sector			
	Mining and Quarrying (B)	Manufacturing (C)	Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	Water supply; sewerage, waste management and remediation activities [E]
Employee	1.010.896	10.827.030	7.209.912	209.089
Casual worker	211.906	856.481	479.354	28.873

Source: Badan Pusat Statistik, Survei Angkatan Kerja Nasional (Sakernas) Agustus/BPS-Statistics Indonesia, August National Labor Force Survey. Retrieved from: Statistical Yearbook of Indonesia, 2024

Economic activities related to battery production in the country are categorized under several ISIC classifications, specifically:

- Mining of metal ores (ISIC 07)
- Manufacturing of basic metals (ISIC 24)
- Manufacturing of electrical equipment (ISIC 27)
- Manufacturing of motor vehicles, trailers, and semitrailers (ISIC 29)[296]

The industrial manufacturing sector offers the most detailed information, down to the class level. These sub-sectors collectively account for less than 7% of all manufacturing establishments and employ approximately 10% of the nation's workforce. Regarding gender and social inclusion considerations related to battery production, a brief analysis has been included in Annex 4. Gender and social inclusion considerations related to battery production.

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[294] *Jadi Produsen Baterai Kendaraan Listrik, RI Mulai Produksi April 2024 – detikFinance, 2024*
[295] *IMF (2024). IMF Country Report No. 24/271 for Indonesia.*
[296] *Further information on classes and descriptions of ISIC Rev. 4.*

6.5 Economic impact

As it has been described throughout this report, Indonesia has the mineral resources to develop a battery supply chain and has implemented a set of fiscal incentives to do so. This section shows a high-level short to mid-term analysis of the economic impact that meeting the government's EVs production targets would have considering the creation of new jobs and the cost on the government's revenue from establishing the VAT reduction incentive.

The analysis is built under the assumption that the following national targets are met in time and following a lineal trend starting from 2024: (i) 400,000 EVs on the road by 2025, (ii) 2,200,000 million EVs on the road by 2030 and (iii) 600,000 E4W produced in Indonesia by 2030.

Table 6.6 Historic and estimated projection of EVs sales and national production

Year	Sales of E4W			Production
	Already on road	Accumulated adoption	New E4W annual sales	Annual production of E4W
2020	104	229	125	-
2021	229	2,012	1,783	-
2022	2,012	10,574	8,562	,500
2023	10,574	22,822	12,248	15,358
2024	22,822	72,822	**50,000**	98,878
2025	50,000	**400,000**	350,000	182,399
2026	400,000	760,000	360,000	265,919
2027	760,000	1,120,000	360,000	349,439
2028	1,120,000	1,480,000	360,000	432,959
2029	1,480,000	1,840,000	360,000	516,480
2030	1,840,000	**2,200,000**	360,000	**600,000**

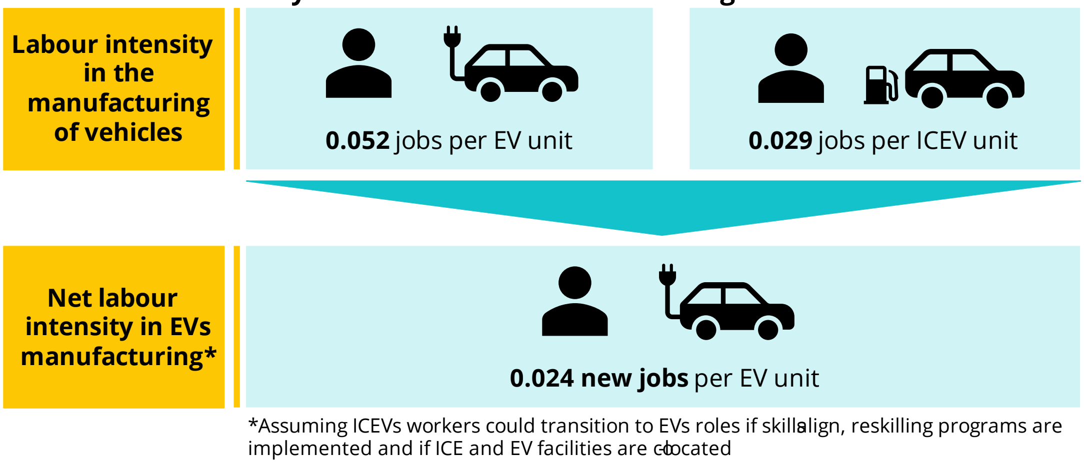
As previously described in this report, the VAT reduction incentive is only applicable to EVs with over 40% of local components by 2025 and over 60% by 2027 and onwards. Currently, the local component of EVs is lower than 20%, and although highly optimistic, this analysis assumes that from 2027 onwards the 60% of local component condition is meet and therefore all EVs sold in Indonesia between 2027 and 2030 can access the 10% VAT reduction.

The VAT revenue loss from establishing such reduction is calculated under two main assumptions. One, the average price of EVs sold in Indonesia until 2030 behave as the global average price projections presented in section 6.2.3, and two, that each EV from 2027 forward will replace one internal combustion engine vehicle (ICEV) of similar price. Under these conditions, the estimated accumulated VAT revenue loss between 2027-2030 rises to USD $8.21 billion.

To estimate the impact that meeting these EVs production targets would have on employment two main job sources are analysed: (i) battery manufacturing factories and (ii) EVs manufacturing factories.

It is estimated that to meet domestic EVs production targets, new battery manufacturing facilities that account for 15.03 GWh of new battery manufacturing capacity should start operating between 2027-2030, assuming each EV produced in Indonesia has an average battery capacity of 45kWh, which is the average battery capacity in EVs worldwide from 2017 to 2025[297]. Considering that on average new lithium-ion battery factories generate 80 jobs per GWh of capacity produced[298], new factories could generate around 1,200 jobs between 2027-2030 to meet such targets.

Figure 6.10 Labour intensity of EVs and ICEVs manufacturing



Source: Own elaboration based on data from already operating EVs and ICEVs' plants. Data used to estimate the ratios can be found in Annex 5. EVs and ICEVs production plants and its labour intensity.

In addition, jobs resulting from the increase of domestic EV manufacturing are estimated by comparing how labour intensive are large-already-operating EVs and ICEVs manufacturing plants. Labour intensity ratios were calculated using samples of annually produced units and total employees in existing plants. The data and references used in this estimation can be found in Annex 5. EVs and ICEVs production plants and its labour intensity. The ratios of jobs per EV and ICEV produced are 0.052 jobs per unit and 0.029 jobs per unit, respectively (Figure 1.1). The higher job per unit ratio for EVs is due to the additional power electronics required. It is estimated that around 99,465 total jobs required to meet the national target for domestic EV production. However, it is feasible that some ICEVs manufacturing workers could transitions to EV manufacturing roles if their skills match with those required, if reskilling programs are set in place and if EV manufacturing facilities are co-located with the existing ICEVs powertrain facilities[299]. Assuming these three conditions occur and ICEV workers can transfer to EV facilities, 44,745 net jobs would be created. Hence, if these conditions occur 45,950 new jobs could be created from the manufacturing of batteries and EVs.

Implementing the fiscal incentive of VAT reduction could represent and estimated loss of USD $8.21 billion of the government's revenue. However, if national targets are meet, this could represent the generation of at least 45,590 new jobs between 2027-2030 only from the manufacture of batteries and EVs. Although not considered in this analysis due to lack of data, the increase in mining and refining required to meet the targets would also result in the creation of new jobs. The high cost of implementing the incentive to reach target

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[297] Statista (2023). Estimated average battery capacity in electric vehicles worldwide from 2017 to 2025, by type of vehicle (in kilowatt hours). Available at: https://www.statista.com/statistics/309584/battery-capacity-estimates-for-electric-vehicles-worldwide/

[298] N. Campagnol, A. Pfeiffer, and C. Tryggestad, "Capturing the battery value-chain opportunity", January, 2022. McKinsey & Company, available at: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/capturing-the-battery-value-chain-opportunity

[299] Turner Cotterman, Erica R.H. Fuchs, Kate S. Whitefoot, Christophe Combemale, The transition to electrified vehicles: Evaluating the labor demand of manufacturing conventional versus battery electric vehicle powertrains, Energy Policy, Volume 188, 2024, 114064, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2024.114064.

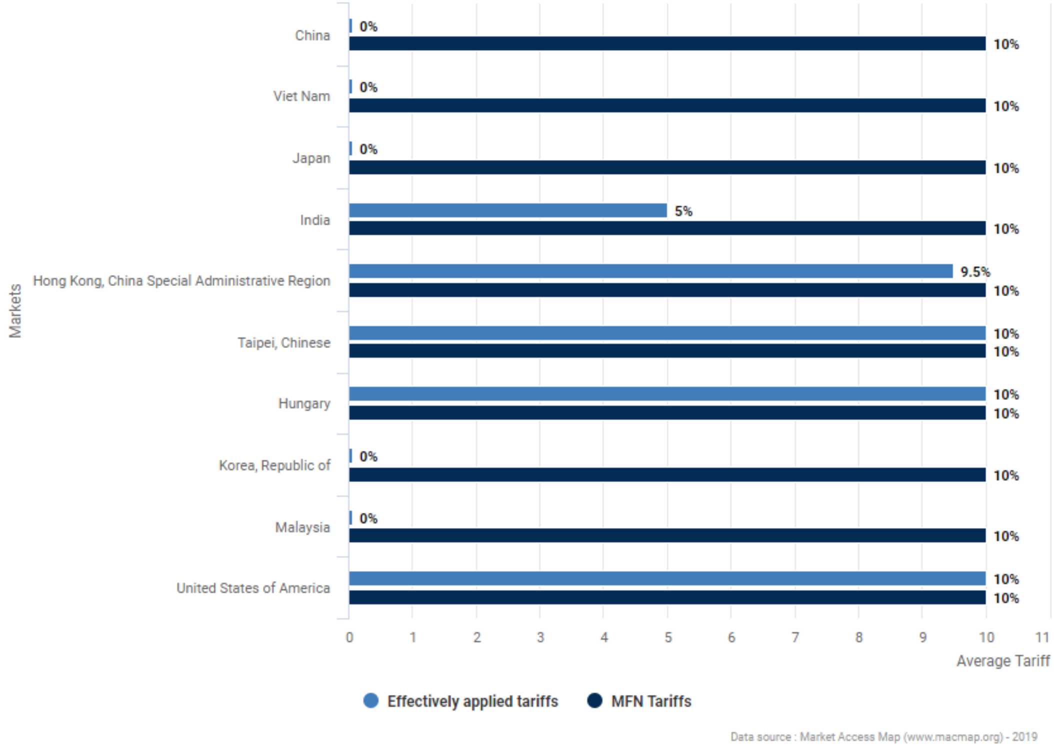
would not only be compensated by the jobs generated but also from the economic activity that such jobs would create and the additional collected taxes from those jobs, since they would be formal employment. Additionally, the collection of taxes that don't have any reduction due to incentives such as additional taxes from battery production and the increase in mining and refining activities would counterbalance the cost of establishing the VAT reduction incentive.

The estimation of the costs and benefits of additional concepts like the jobs created from mining and refining, the economic activity and tax collection from the creation of new jobs and tax collection from activities without fiscal incentives like battery production, additional mining and refining of minerals is not part of the scope of this report nor this project. However, it is acknowledged that it would be useful for the government and stakeholders of the battery supply chain to have in depth study of these concepts.

6.6 Implications related to imported materials and exports

The implementation of policies such as import duty exemptions has resulted in a notable increase in electric vehicle imports, particularly from China. While these measures have made EVs more accessible, the Domestic Component Level (TKDN) regulations pose challenges for the development of local EV manufacturing capabilities[300]. Figure 6.11 illustrates the average tariffs applied to the top ten markets based on trade volume and distance for lithium-ion batteries.

Figure 6.11 Average tariff applied on top 10 markets based on trade and distance, for product 850760 – Electric accumulators: Lithium-ion



Source: Market Access Map. www.macmap.org

[300] *A Myriad of Challenges Holding Indonesia's Dream of Becoming a World EV Battery Player. Available at: https://www.voaindonesia.com/a/segudang-tantangan-mengadang-mimpi-indonesia-jadi-pemain-baterai-ev-dunia/7684783.html*

According to the World Bank Enterprise Survey (WBES), factors such as firm age, foreign ownership, and website availability positively influence export diversification. However, Indonesia currently lags behind the East Asia and Pacific region in the percentage of firms engaged in direct exports. To enhance export capabilities, it is critical to improve customs procedures that facilitate smoother import and export processes. Limited access to financial resources adversely affects sales growth and labor productivity, particularly among domestic firms, although managerial experience can help mitigate these challenges.

Other implications related to imported materials and exports of EV Batteries are:

- **Market dependence:** The increase in EV imports highlights Indonesia's reliance on foreign manufacturers, particularly for advanced technologies and components. This dependence could hinder the growth of local industries and innovation in the long term.
- **Trade balance:** A surge in imports, while beneficial for consumer choice and market penetration, may negatively impact Indonesia's trade balance. This could lead to a greater trade deficit if local production does not scale up to meet domestic demand.
- **Local manufacturing development:** The TKDN regulations aim to encourage local manufacturing by requiring a certain percentage of domestic components. However, if not adequately supported, these regulations could deter foreign investment and slow down the establishment of a competitive local manufacturing base.
- **Export potential:** To enhance Indonesia's position in the global battery supply chain, improving export capabilities is essential. Streamlining customs processes and providing better access to financing can empower local firms to participate more actively in international markets. This can lead to increased exports of locally manufactured batteries and components, ultimately contributing to economic growth.
- **Sustainability and resource management**: As Indonesia expands its EV battery market, the need for sustainable sourcing of materials becomes critical. Strengthening regulations and partnerships can ensure that imported materials meet environmental and ethical standards, fostering a more sustainable supply chain.

By addressing these implications, Indonesia can work towards developing a robust local battery supply chain while enhancing its competitiveness in the global market for electric vehicles.

7 Opportunities for Indonesia battery supply chain development

Based on the previous analysis, this section outlines the gaps and potential opportunities for the development of the national battery supply chain. The findings are limited to the aspects covered in this report, specifically: i) Battery materials, ii) the stages of the battery supply chain, and iii) relevant policies. Additionally, insights gathered from national stakeholders during an engagement event in December 2024 (PE2) are included.

This serves as the first step toward providing more detailed recommendations in the next phase of this project (Workstream B & C), which will focus on developing a strategic framework for potential investors, stakeholders, and the Indonesian government to establish a robust battery supply chain. As it has been mentioned, this report focuses exclusively on nickel and iron-based chemistries of secondary battery technologies and their supply chains, as well as sodium-ion batteries.

Battery materials

The analysis confirms that Indonesia possesses vast reserves of key minerals, such as nickel, cobalt, and manganese (according to the USGS 42% of global nickel resources and 2% of global cobalt resources), which are crucial for lithium battery production, particularly for nickel-based chemistries. The country also presents exploration opportunities, as detailed in Section 3.3.1. However, Indonesia lacks domestic production of lithium and graphite, which are equally vital for battery manufacturing.

Despite these advantages, challenges remain in scaling up production capacity for these essential minerals for domestic battery production, as well as in implementing environmentally sustainable refining processes.

Table 7.1 presents a preliminary set of recommendations for the key battery materials. These include fostering robust bilateral and multilateral relationships that align with national interests. Establishing bilateral cooperation with strategic countries to ensure stable and diversified supply chains, while engaging multilateral cooperation offers added advantages, such as reducing reliance on a single supplier and enhancing resource security. Furthermore, multilateral cooperation can provide a more comprehensive and resilient framework for addressing security and sustainability risks associated with the global supply chains of key minerals, complementing advantages of traditional bilateral relationships.

Table 7.1 Recommendations for key battery materials

Context	Recommendation
Imported materials: **Lithium:** Indonesia has no domestic production. Meanwhile, Australia, a leading global producer, export most of their lithium production being exported directly to China. **Graphite:** Indonesia also lacks domestic production of graphite- The anode industry relies heavily on imports, with China domi-	Secure reliable suppliers: To build a robust national battery industry, Indonesia should focus on securing reliable supplies of lithium and graphite (natural or artificial). Leverage strategic location: Indonesia's proximity to major Asian markets provides a unique opportunity to attract investors for refining operations, reducing dependency on external suppliers. Diversify supply chain: Indonesia should establish multilateral and bilateral partnerships to diversify suppliers and

Context	Recommendation
nating global graphite production and holding 30% of global reserves. This dominance underscores Indonesia´s vulnerability to supply chain disruptions.	attract investment in domestic refining operations. This approach will minimize reliance on a single supplier, mitigating risks from geopolitical tensions or trade disruptions.
Domestically available minerals: **Nickel:** Investment in Indonesia's nickel processing and manufacturing sector increased dramatically from USD $3.56 billion in 2019 to USD $10.96 billion in 2022, a 207.9% growth driven primarily by Chinese companies relocating operations following the 2020 export ban. However, international investment has slowed due to concerns over environmental and social issues, particularly regarding workers' rights, livelihoods, and health. **Cobalt:** Indonesia accounts for 7.2% of global cobalt reserves, primarily extracted through laterite limonite nickel. **Manganese:** While domestic production has been reported (a smelter exists in NTT), there is limited data regarding the current demand for manganese in the battery industry. In 2023, manganese ore was imported from Australia, likely due to high logistics costs associated with domestic production.	Enhance compliance and sustainability: Indonesia should enhance compliance with good mining practices as regulated by the MEMR decree, implement technological advancements, and introduce regulatory reforms to improve resource efficiency and promote sustainable practices. Additionally, global regulatory trends are increasingly focused on mitigating environmental and social sustainability risks, particularly in the upstream supply chain. Multilateral cooperation can help Indonesia engage in these discussions to ensure the developing global standards align with its national interests. For instance, the Minerals Security Partnership emphasizes enhancing social and environmental sustainability standards for key mineral supply chains. Foster strategic partnerships: Indonesia should build strong bilateral and multilateral partnerships to attract investment in extraction and refining operations. These partnerships should align with Indonesia´s national interests, ensuring the country retains control over its resources beyond the processing stage. Strengthen domestic refining operations: Enhance, the capacity of domestic refining operations, particularly in NTT, through multilateral cooperation. Partnerships should focus on: Knowledge sharing, adoption of best practices, education and training for skilled professionals. Improve monitoring and reporting: Indonesia should reinforce monitoring and reporting mechanisms for key minerals in collaboration with MEMR to ensure efficient and transparent management of resources. Address cost and logistics challenges: Evaluate and address high logistic costs to optimize domestic production and reduce liance on imports, such as manganese ore from Australia.

Battery supply chain

Indonesia's battery supply chain development can be strengthened by aligning it with electric vehicle (EV) production. While key battery materials are secured, investments in the manufacturing supply chain must increase to create a fully integrated and connected system. The following provides a summary of findings for each stage of the battery supply chain finding, and preliminary recommendations (See Table 7.2).

Table 7.2 Recommendations for domestic battery supply chain

Stage	Context and recommendation
Extraction	The rapid expansion of Indonesia's battery supply chain has raised concerns among international stakeholders regarding environmental and social impacts, as well as inefficiencies in government administrative processes. Issues related to environmental

Stage	Context and recommendation
	assessments (AMDAL), forest degradation, land acquisition, and certification need urgent attention. To address these challenges, the government should enforce stricter regulations to ensure compliance with green mining standards and prioritize the efficient approval of government projects. A comprehensive analysis of environmental and social challenges, to be conducted in Workstream D, will provide valuable insights into the implementation and enforcement of these measures, ensuring alignment with international sustainability standards.
Refining	Refining and cathode active material (CAM) industries are under pressure due to Chinese dominance in the sector and the limited maturity of refining capabilities for non-nickel minerals. Furthermore, Indonesian minerals are ineligible for U.S. tax credits due to the lack of a free trade agreement. Please refer to Section 5.6.2 Indonesia amidst the global power play for more information. To reduce reliance on China and strengthen domestic refining capacity, the government should consider revising tax incentives, such as tax holidays for pyrometallurgy, and support the development of robust manganese smelter operations, particularly in NTT.
CAM	Asian EV manufacturers heavily rely on NCM batteries, which dominate 40–60% of the global market. Indonesia, rich in the key minerals needed for nickel-intensive NCM batteries (such as NCM9.5.5 and NCM811), is well-positioned to capitalize on this demand. However, stakeholders have highlighted the lack of structural components for EV batteries, including aluminum-based materials. Indonesia should prioritize investments in its NCM/NCA battery supply chain, focusing on developing domestic production capacity. The country should also foster multilateral cooperation with major battery-consuming nations, including the U.S. and EU, to encourage investments and technology partnerships. Strengthening collaborations with key players like LG Chem, which is already expanding CAM capacity in Indonesia, will further boost the country's battery manufacturing sector.
Anodes	Currently, the industry remains heavily dependent on China for anode production, with Indonesia importing graphite from Africa rather than developing domestic production. While coal-to-artificial graphite conversion is being explored, significant progress is needed. Indonesia should strengthen investments in anode manufacturing facilities, focusing on both synthetic and natural graphite options. This will reduce dependence on China and enhance domestic production capabilities.
LIB Cell manufacturing	Battery cell manufacturing is currently dominated by a few global players, including CATL, LG Chem, and BYD. Indonesia has the potential to expand its cell manufacturing projects beyond China, supported by partnerships like PT HLI Green Power, a joint venture between Hyundai Motor Company, LG Energy Solution, and IBC. To enhance manufacturing capacity, Indonesia should encourage multilateral cooperation with CATL to refine strategies for nickel-based cell chemistries, especially in competition with LFP cells. Strengthening partnerships between battery material producers and companies like LG Chem will diversify manufacturing capacity and reduce reliance on China. In addition to fostering these partnerships, Indonesia must prioritize research and development (R&D) in battery technology to maintain its competitive edge. Multilateral cooperation can play a key role in facilitating knowledge exchange, advancing technology, and supporting the development of a skilled workforce through international collaborations. Furthermore, it is essential to monitor and analyze best practices globally, adapting them to fit Indonesia's specific context. Cross-sectional collaboration between ministries can be implemented. While some practices may be highly effective in Indonesia, others might not be as suitable. For example, China started with an R&D model that emphasized investment in technology development, which works well in nascent markets but may not be the ideal approach for more mature markets. By fine-tuning global

Stage	Context and recommendation
	insights to the local environment, Indonesia can create a more robust and competitive battery cell manufacturing industry.
End of Life	Battery recycling and the development of a circular economy are critical for improving supply chain efficiency and reducing environmental impacts. Indonesia's approach to managing its mineral resources in the context of energy transition, as highlighted by the MEMR during the Engagement Event 2, prioritizes sustainable practices and the optimization of resource recovery. This includes the reuse of mining by-products and the exploitation of marginal reserves. A key aspect of this strategy is the concept of urban mining, which involves the extraction of valuable materials from urban waste, including electronic waste (e-waste) and end-of-life products, thereby decreasing reliance on traditional mining operations. Despite significant potential, Indonesia's EV battery recycling programs remain underdeveloped, with only one operational company (PT Indonesia Puqing Recycling Technology) and limited data on feedstock origin and production. Government regulations that classify waste batteries as hazardous waste pose a major obstacle for the recycling industry, both for imports and local sourcing. Indonesia should revise this classification to facilitate material procurement and align its LIB recycling strategy with global trends toward sustainable energy. It is also recommended that the country develops urban mining to contribute to promote circular economy by enhancing resource recovery and reducing waste, to support resource security by providing a more independent source of raw materials and to minimize transportation costs. These measures will help overcome current barriers and foster growth in the recycling sector.

Demand side relevant policies

Indonesia's market penetration of domestically assembled electric vehicles (EVs) has yet to fully realize its potential. To achieve national EV adoption targets, the development of a comprehensive and supportive ecosystem is essential. This includes not only the production of EVs but also the necessary infrastructure to support their widespread use. One key challenge identified by international stakeholders is the lack of competitive incentive policies that would support the growth of the EV industry. These policies should address the needs of consumers, manufacturers, and infrastructure providers to foster a sustainable and integrated EV market.

To accelerate EV adoption and ensure the growth of the industry, the following recommendations are proposed:

1. **Expand EV Infrastructure**: It is critical to establish EV charging stations across both urban and rural areas to ensure accessibility and convenience for consumers. Expanding charging infrastructure will help remove barriers to EV adoption and increase consumer confidence in the feasibility of switching to electric mobility.

2. **Subsidy Policies**: Enhancing subsidy policies for EV consumers, manufacturers, and infrastructure providers will significantly reduce financial barriers. For consumers, subsidies could make EVs more affordable, thereby stimulating demand. Similarly, providing incentives to manufacturers and infrastructure developers will encourage investment in the sector, supporting both production capacity and the establishment of essential charging networks.

By addressing these areas of opportunity, Indonesia can create a more favorable environment for EV growth, thereby accelerating its transition to sustainable transportation.

Annex 1. Battery technologies technical specifications and Technological Readiness Levels

Several technical specifications are used to describe battery cells, modules and packs. The most common specifications are described in Annex Table 1.

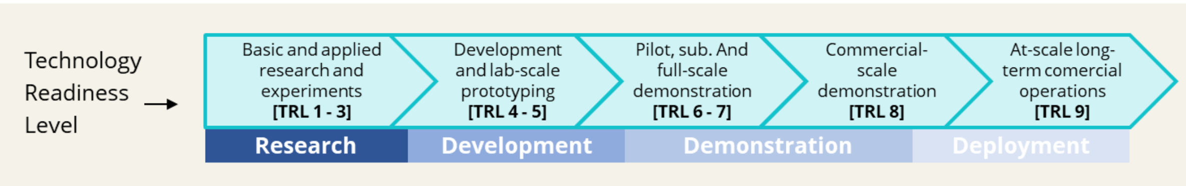
Annex Table 1 Technical specifications of batteries

Specification	Description
Nominal voltage [V]	Reported voltage of the battery
Capacity or Nominal capacity [Ah for a specific C-rate]	The Amp-hours available when the battery is discharged at a certain discharge current (specified as a C-rate) from 100 state of charge to the cut-off voltage.
Energy or nominal energy [Wh for a specific C rate]	The total Wh available when the battery is discharged at a certain discharge current (C-rate) from 100 percent state of charge to the cut-off voltage.
Cycle life	The number of discharge-charge cycles the battery can experience before it fails to meet specific performance criteria. Cycle life is estimated for specific charge and discharge conditions.
Energy density [Wh/kg]	Nominal battery energy per unit mass or volume. Provides an insight into the storage capacity of batteries.
Power density [W/kg]	Maximum amount of energy that can be discharged per battery unit in a given unit of time. It is a characteristic of the battery chemistry and packaging. It determines the battery weight required to achieve a given performance target.

Source: Extracted from MIT. A guide to understanding battery specifications.

The Technology Readiness Level (TRLs) are the most common measure for systematically communicating the readiness of new technologies or new applications of existing ones to be incorporated into a system or program[301], from basic research to fully deployed systems. In general, TRLs are measured on a 1-9 scale, where level 1 generally represents paper studies of the basic concept, moving to laboratory demonstrations around level 4, and ending at level 9, where the technology is tested and proven, integrated into a product.

Annex Figure 1 TRLs according to the US Government Accountability Office (GAO)



Source: GAO, 2020. Technology Readiness Assessment Guide. Best practices for evaluating the readiness of technology for use in acquisition programs and projects. https://www.gao.gov/assets/d2048G.pdf

In the context of secondary batteries, TRLs help stakeholders understand the development stage and readiness for commercialization (See Annex Table 2).

Annex Table 2 Examples of Technology Readiness Levels (TRL) for secondary batteries

Level	Description	Example
TRL 1	Basic principles observed	Scientific research is conducted, and basic principles of battery chemistry are understood, but no practical applications have been developed.

[301] *GAO, 2020. Technology Readiness Assessment Guide. Best practices for evaluating the readiness of technology for use in acquisition programs and projects.* https://www.gao.gov/assets/d2048G.pdf

Level	Description	Example
TRL 2	Technology concept formulated	Concepts for new battery materials or designs are proposed, but no experimental proof exists yet.
TRL 3	Experimental proof of concept	Laboratory tests demonstrate the feasibility of the new battery technology. Initial prototypes may be created.
TRL 4	Technology validated in lab	The battery technology has been validated in a controlled lab environment. Performance metrics are measured, but it hasn't been tested in real-world conditions.
TRL 5	Technology validated in relevant environment	The battery technology is tested in conditions that closely resemble real-world applications, such as in small-scale prototypes.
TRL 6	Technology demonstrated in relevant environment	Full-scale prototypes are built and tested in relevant environments, demonstrating performance and reliability.
TRL 7	System prototype demonstration in operational environment	A prototype of the battery system is demonstrated in an operational environment, such as within an EV, showing its effectiveness in real-world conditions.
TRL 8	Actual system completed and qualified	The battery technology is fully developed and has been tested in its intended operational environment, meeting all necessary specifications.
TRL 9	Actual system proven in operational environment	The technology is successfully deployed and used in real-world applications, with a proven track record of performance and reliability.

Source: Own elaboration based on GAO, 2020

Annex 2. Technical characteristics of each type of chemistries

This Annex presents the technical characteristics of battery cells with the chemistries analysed in section 1 of this report.

Annex Table 3 Technical characteristics of NCA batteries

Key active material	Lithium nickel cobalt aluminium
Technology acronym	**NCA**
Cathode	$LiNiCoAlO_2$
Anode	C (graphite)
Electrolytes	Liquid
Safety	High risk of causing thermal runaway
Power density (discharge rate)	~250 a 340 W/kg
Energy density (Storage related)	Typically, under 300 Wh/kg
Cells costs	More expensive due to high cost of cobalt and manufacturing processes
Lifetime	Limited lifespan (1000 – 2000 cycles) compared to LFP
TRL	TRL 9 – Full maturity and widespread commercial use – extensively deployed in the EV market. TRL 6-7 e.g. high nickel cathodes variants
Commercial viability	Commercially viable and widely used in high-performance applications like Tesla vehicles. Their high energy density and long life make them a preferred choice for premium EVs.

Source: Own elaboration

Annex Table 4 Technical characteristics of NMC batteries

Key active material	Nickel Manganese Cobalt
Technology acronym	**NMC**
Cathode	Can vary, common formulations are: NMC111; NMC532; NMC622; NMC811
Anode	C (graphite)
Electrolytes	Liquid
Safety	High risk of causing thermal runaway
Power density (Discharge rate)	~340-420 W/kg
Energy density (Storage related)	150-220 Wh/kg
Cells costs	More expensive than LFP
Lifetime	Limited lifespan (1000 – 2000 cycles) compared to LFP
TRL	TRL 9 – Full maturity and widespread commercial use – extensively deployed in the EV market. TRL 6-7 e.g. high nickel cathodes variants – Indicating advanced development but not yet fully commercialized.
Commercial viability	Fully deployed for the EV market

Source: Own elaboration

Annex Table 5 Technical characteristics of NCA batteries

Key active material	Lithium nickel cobalt aluminium
Technology acronym	**NCA**
Cathode	$LiNiCoAlO_2$
Anode	C (graphite)
Electrolytes	Liquid
Safety	High risk of causing thermal runaway
Power density (discharge rate)	~250 a 340 W/kg
Energy density (Storage related)	Typically, under 300 Wh/kg
Cells costs	More expensive due to high cost of cobalt and manufacturing processes
Lifetime	Limited lifespan (1000 – 2000 cycles) compared to LFP
TRL	TRL 9 – Full maturity and widespread commercial use – extensively deployed in the EV market. TRL 6-7 e.g. high nickel cathodes variants
Commercial viability	Commercially viable and widely used in high-performance applications like Tesla vehicles. Their high energy density and long life make them a preferred choice for premium EVs.

Source: Own elaboration

Annex Table 6 Technical characteristics of LFP batteries

Key active material	Lithium iron phosphate
Technology acronym	**LFP**
Cathode	$LiFePO_4$
Anode	C (graphite)
Electrolytes	Liquid
Safety	Resistant to thermal runaway
Power density (discharge rate)	~175-425 W/kg
Energy density (Storage related)	Ranging from 90 -120 Wh/kg
Cells costs	Less expensive due to abundance of Iron
Lifetime	Longer lifespan than NMC (8000 – 10000 cycles).
TRL	TRL 9 particularly in electric vehicles (EVs) and stationary energy storage, especially in China.
Commercial viability	Widely used in transportation sector, ESS, portable electronics (power tools). Key players in the global LFP battery market include BYD Company Ltd. (China), Contemporary Amperex Technology Co. (CATL, China), K2 Energy (U.S.), A123 Systems (U.S.), and Lithium Werks Inc. (China)[302].

Source: Own elaboration

Annex Table 7 Technical characteristics of LNMO batteries

Key active material	Lithium Nickel Manganese Spinel
Technology acronym	**LNMO**
Cathode	$LiNi_{0.5}Mn_{1.5}O_4$
Anode	C (graphite)
Electrolytes	Liquid
Safety	Good thermal stability
Power density (discharge rate)	Depends on the specific model and design of the battery.
Energy density (Storage related)	650 Wh/kg - Theoretical

[302] *MarketsandMarkets, 2023. Lithium Iron Phosphate Batteries Market Size to Reach $24.6 Billion, at a 13.7% CAGR by 2027. Lithium Iron Phosphate Batteries Market Size to Reach $24.6 (globenewswire.com)*

Key active material	Lithium Nickel Manganese Spinel
Cells costs	Low fabrication costs due to cobalt free and low nickel content
Lifetime	Limited lifespan due to rapid capacity decay during cycling.
TRL	6 – Demonstration of performance – Prototypes with high energy density and specific cycle life.
Commercial viability	There are still challenges to overcome before it can be fully commercialized. Such as: capacity degradation and cost-effectiveness.

Source: Own elaboration

Annex Table 8 Technical characteristics of LCO batteries

Key active material	Lithium cobalt oxide
Technology acronym	**LCO**
Cathode	$LiCoO_2$
Anode	C (graphite)
Electrolytes	Liquid
Safety	Low thermal stability
Power density (Discharge rate)	High power density. Up to 2000 W/kg – Related to the low thermal stability
Energy density (Storage related)	150–200 Wh/kg
Cells costs	Tend to have higher costs due to cobalt use in the cathode
Lifetime	Limited lifespan, typically in the range of 500 to 1,000 cycles, related to depth of discharge, load, temperature
TRL	9 – Mature technology
Commercial viability	Popular in the portable electronic sector

Source: Own elaboration

Annex Table 9 Technical characteristics of LTO batteries

Key active material	Lithium titanate
Technology acronym	**LTO**
Cathode	NMC or LMO
Anode	Lithium titanate nanocrystals
Electrolytes	Liquid
Safety	High thermal stability
Power density (discharge rate)	2000 – 7500 W/kg
Energy density (Storage related)	70-90 Wh/kg
Cells costs	Tend to have higher costs due to cathode chemistries
Lifetime	Long lifespan, 3000 to 10,000 cycles – but low energy density
TRL	9 – Mature technology
Commercial viability	Fully available: Used in the transportation sector, power grids, military applications and backup power systems.

Source: Own elaboration

Annex Table 10 Technical characteristics related to SSLB

Battery type	Solid-state lithium batteries
Technology acronym	**SSLB**
Cathode	Nickel and Cobalt based chemistries
Anode	Lithium
Electrolytes	Solid
Safety	Resistant to leakage and combustion
Power density (discharge rate)	1000 W/kg

Battery type	Solid-state lithium batteries
Energy density (Storage related)	Typically, over 350 Wh/kg providing higher charge capacity than graphite anodes.
Cells costs	Higher cost due to solid electrolyte material costs
Lifetime	Longer lifespan than NMC/NCA batteries
TRL	4-5**.** In development stage with on-going research to overcome technical challenges, such as obtain cost-effective and highly efficient electrodes. As well as designing a stable and chemically sound solid electrolyte is also a complex task.
Commercial viability	SSLBs are not yet widely commercialized. Major players investing in the R&D of solid-sate batteries include automotive manufacturers, battery manufacturers, and technology firms: Toyota, BMW, and QuantumScape are actively investing in research and development[303].

Source: Own elaboration

Annex Table 11 Technical characteristics related to solid state batteries with lithium metal anodes

Battery type	Solid-state lithium metal batteries
Technology acronym	**LMA**
Cathode	Can include a wide range of chemistries (NMC, LMO, LFP, fluorides or sulphides)[304]
Anode	Lithium metal
Electrolytes	Solid
Safety	Susceptible to thermal runaways at high operating temperatures, lithium dendrite formation, and equipment failure.
Power density (discharge rate)	Over 400 W/kg when combined with commercial cathode materials.
Energy density (Storage related)	~500 Wh/kg
Cells costs	The cell cost is heavily influenced by the price of lithium metal and the choice of cathode material.
Lifetime	300 cycles. Cycle lifespan is reduced due to lithium deposition and an unstable solid electrolyte interface
TRL	4-5**.** In development stage with on-going research focused on overcoming technical challenges, such as thermal runaway, dendrite formation and the unstable solid electrolyte interface.
Commercial viability	Manufacturers in both American and Asian markets are actively investing in R&D, particularly for applications in the transportation sector and the ESS.

Source: Own elaboration

Annex Table 12 Technical characteristics of sodium ion batteries

Key active material	Sodium-ion
Technology acronym	SIB
Cathode	Sodium layered oxides and polyanionic compounds
Anode	Hard carbon
Safety	Better thermal stability than lithium-ion batteries
Power density (discharge rate)	~1000 W/kg,
Energy density (Storage related)	~75 to 160 Wh/kg

303 Fortune Business insights. Solid-state battery market size, share and Industry analysis, by type (single layer and multilayer), by application (consumer electronics, electric vehicles, medical devices, and others), and regional forecast, 2024-2032. Available at: [Solid-State Battery Market Size, Share, Growth | Forecast [2032] (fortunebusinessinsights.com)]

304 Yang, Li & Hagh, Nader & Roy, Jesse & Macciomei, Eric & Klein, J.R. & Viswanathan, Umamaheswari & Fortier, Mary. (2024). Review—Challenges and Opportunities in Lithium Metal Battery Technology. Journal of The Electrochemical Society. 171. 10.1149/1945-7111/ad4ff2.

Key active material	Sodium-ion
Cells costs advantage	~25 to 30% lower material costs than lithium batteries
Lifetime	5000 – 6000 cycles
TRL	TRL varies based on their specific applications
Commercial viability	**Asia markets:** • First low speed electric vehicle powered by a SIB was introduce in 2023 in China by the JAC Group and Volkswagen´s joint venture [305]. • Other announced large-scale manufacturers (GW scale) included: CATL, AGM Batteries, HiNa Battery Technology Co., Zoolnasm, Faradion (Reliance), and Tiamat (with Neogy)[306]. **American markets:** • Natron Energy, the first sodium-battery manufacturer in the U.S. for the ESS sector, began operations in early 2024 with funding from the Department of Energy. [307]

Source: Own elaboration based on Energy & Environmental Science. Improvement of cycle life for layered oxide cathodes in sodium-ion batteries; and DOE/OE-0035 – Sodium batteries technology strategy assessment. Available at: Technology Strategy Assessment - Sodium Batteries (energy.gov)

[305] *TimesLIVE (2023). The JAC Hua Xianzi is the world's first sodium-ion battery vehicle. March 2023. Available at: The JAC Hua Xianzi is the world's first sodium-ion battery vehicle (timeslive.co.za)*

[306] *DOE/OE-0035 – Sodium batteries technology strategy assessment. Available at: Technology Strategy Assessment - Sodium Batteries (energy.gov)*

[307] *E&E News. 'Battery revolution'? First US sodium-ion plant comes online.*

Annex 3. Sankey diagrams for overall trade flows of materials

This annex presents the Sankey diagrams for the export trade flows of materials used in battery production and of already ensembled battery packs, listed in Annex Table 13. The trade flows in these diagrams are not filtered to only consider battery usage, meaning the diagrams consider all possible uses each of the materials have. These diagrams were built using ITC's Trade Map data using 6-digit HS codes from 2019-2023 in total value export (USD million). The calculation is based on the countries with the highest percentage in each stage and based on the largest exporter in the next stage.

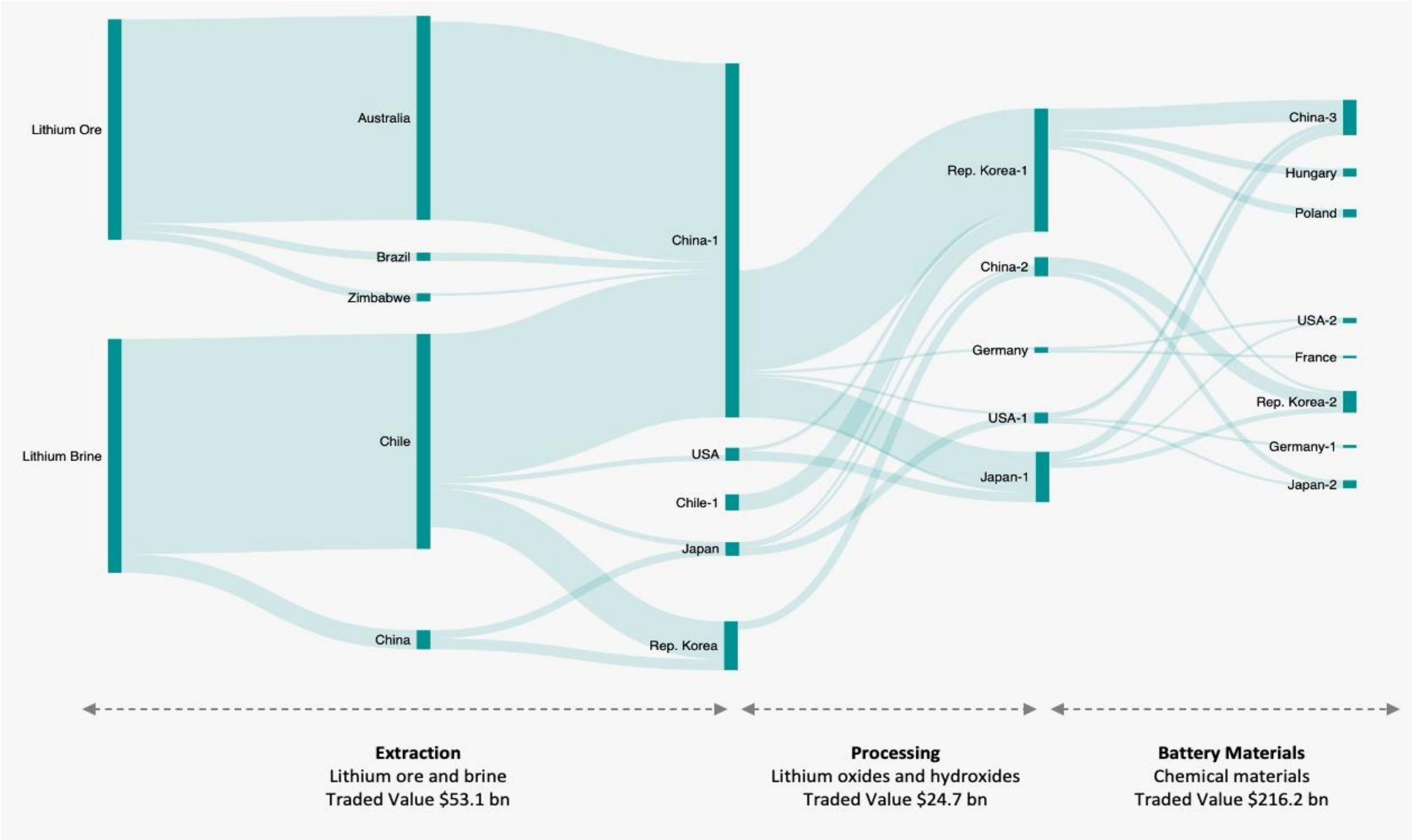
As a disclaimer, these Sankey diagrams portray the export flows at each stage, and it does not consider any domestic production that is no exported or that is processed within each country's domestic supply chain.

Annex Table 13 Product classification of selected critical mineral products at different processing stages

Critical Mineral	Raw minerals or minerals that underwent only initial beneficiation	Processed minerals	Battery Materials
Lithium	253090 - Arsenic sulfides, alunite, pozzuolana, earth colours and other mineral substances, n.e.s. 283691 - Lithium carbonates	282520 - Lithium oxide and hydroxide 282739 - Chlorides (excl. ammonium, calcium, magnesium, aluminium, nickel, and mercury chloride) 282690 - Fluorosilicates, fluoroaluminates and other complex fluorine salts (excl. sodium hexafluoroaluminate "synthetic cryolite" and inorganic or organic compounds of mercury) 282619 - Fluorides (excl. of aluminium and mercury)	284290 - Salts of inorganic acids or peroxoacids, incl. aluminosilicates whether chemically defined (excl. of oxometallic or peroxometallic acides, and inorganic or organic compounds of mercury) 284169 - Manganites, manganates, and permanganates (excl. potassium permanganate) 382499 - Chemical products and preparations of the chemical or allied industries, incl. those consisting of mixtures of natural products, n.e.s.

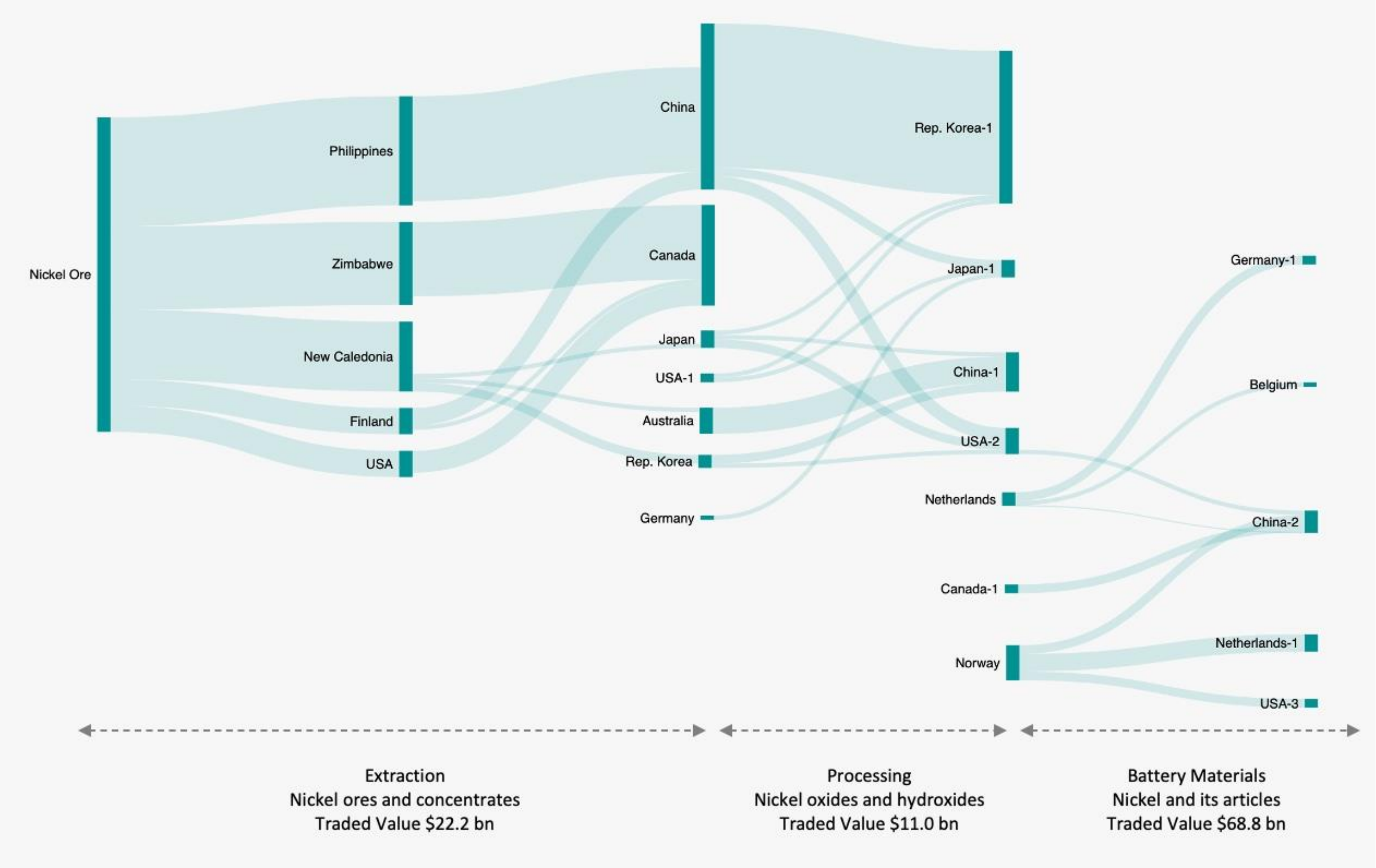
Cobalt	260500 - Cobalt ores and concentrates	282200 - Cobalt oxides and hydroxides; commercial cobalt oxides 810520 - Cobalt mattes and other intermediate products of cobalt metallurgy; unwrought cobalt; cobalt powders	284190 – Salts of oxometallic or peroxometallic acids (excl. chromates, dichromates, peroxochromates, manganites, manganates, permanganates, molybdates and tungstates “wolframamtes”) 285390 - Phosphides, whether chemically defined (excl. ferrophosphorus); inorganic compounds, incl. distilled or conductivity water and water of similar purity, n.e.s.; liquid air, whether rare gases have been removed; compressed air; amalgams (excl. amalgams of precious metals)
Graphite	250410 - Natural graphite in powder or in flakes 271312 - Petroleum coke, calcined 270810 - Pitch obtained from coal tar or from other mineral tars	380110 - Artificial graphite (excl. retort graphite, retort carbon and goods of artificial graphite, incl. Refractory materials based on artificial graphite)	854519 - Electrodes of graphite or other carbon, for electrical purposes (excl. those used for furnaces)
Nickel	260400 - Nickel ores and concentrates	282540 – nickel oxides and hydroxides 282735 – Nickel Chloride 282739 - Chlorides (excl. ammonium, calcium, magnesium, aluminium, nickel and mercury chloride) 282690 – Fluorosilicates (Other Than Of Sodium Or Potassium), Fluoroaluminates And Other Complex Fluorine Salts	750210 – Nickel, not alloyed 750890 - Other Articles Of Nickel, Others (excluding Cloth, Grill & Netting Of Nickel Wire)
Iron	260112 - Iron ores and concentrates that are agglomerated, but not roasted iron pyrites	282110 – Iron oxide and hydroxide	850740 - Nickel-Iron Storage Batteries
Manganese	260200 - Manganese ores and concentrates	282010 - Manganese dioxide 282090 - Manganese oxides, Other, Other	850611 - Manganese dioxide primary cells and batteries
Sodium	250100 - Salt, including table salt, denatured salt, pure sodium chloride, and sea water	281511 - Sodium hydroxide (caustic soda); potassium hydroxide (caustic potash); peroxides of sodium or potassium - Sodium hydroxide (caustic soda)	284290 - salts of inorganic acids or peroxoacids, excluding azides
Aluminium	260600 - Aluminium ores and concentrates	281820 - Aluminum oxide, other than artificial corundum 282732 - Aluminum chloride 283322 - Aluminium sulphate	760719 - Aluminum foil that is not backed and has a thickness of no more than 0.2 millimeters 760711 - Aluminum Foil, Not Over 0.2 Mm Thick, Not Backed, Rolled But Not Further Worked.

Annex Figure 2 Global Lithium trade flows



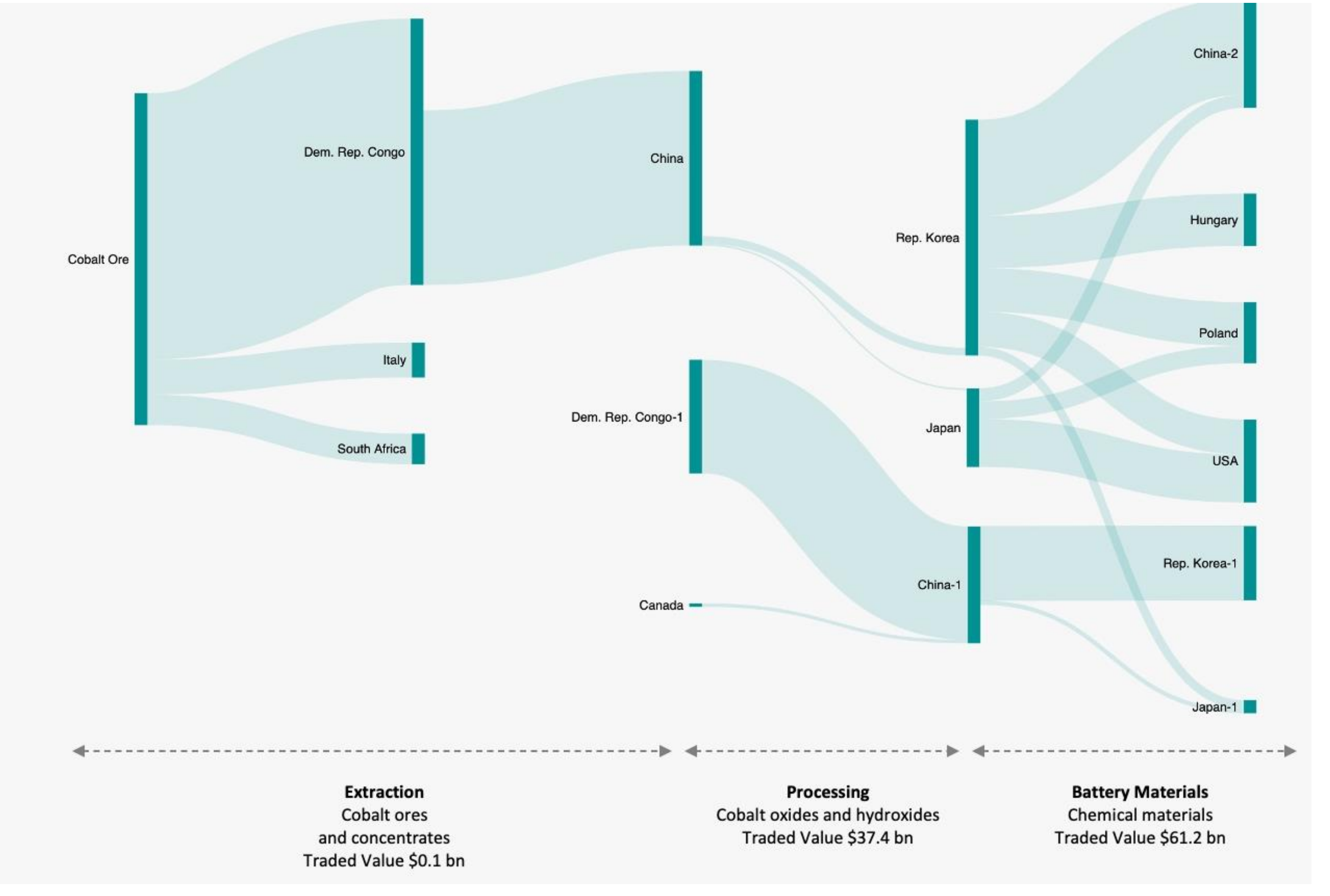
While Australia and Chile are the primary exporters of lithium ore and brine (over 77%), China is the major importer, taking in over 70% of global trade. Australia, the leading global exporter of lithium ore, sends its product to China for refining into lithium oxide and hydroxide. In contrast, Chile, the top exporter of lithium brine, possesses its own refining capabilities and is a significant exporter of these refined lithium compounds. Chilean and Chinese companies together dominate lithium mining, controlling 86% of worldwide lithium brine production. At the processing stage, China accounts for 60% of global lithium oxide and hydroxide exports, however, rather than exporting battery materials, it imports them from the Republic of Korea, the United States, and Japan, likely for domestic use in battery pack manufacturing.

Annex Figure 3 Global Nickel trade flows



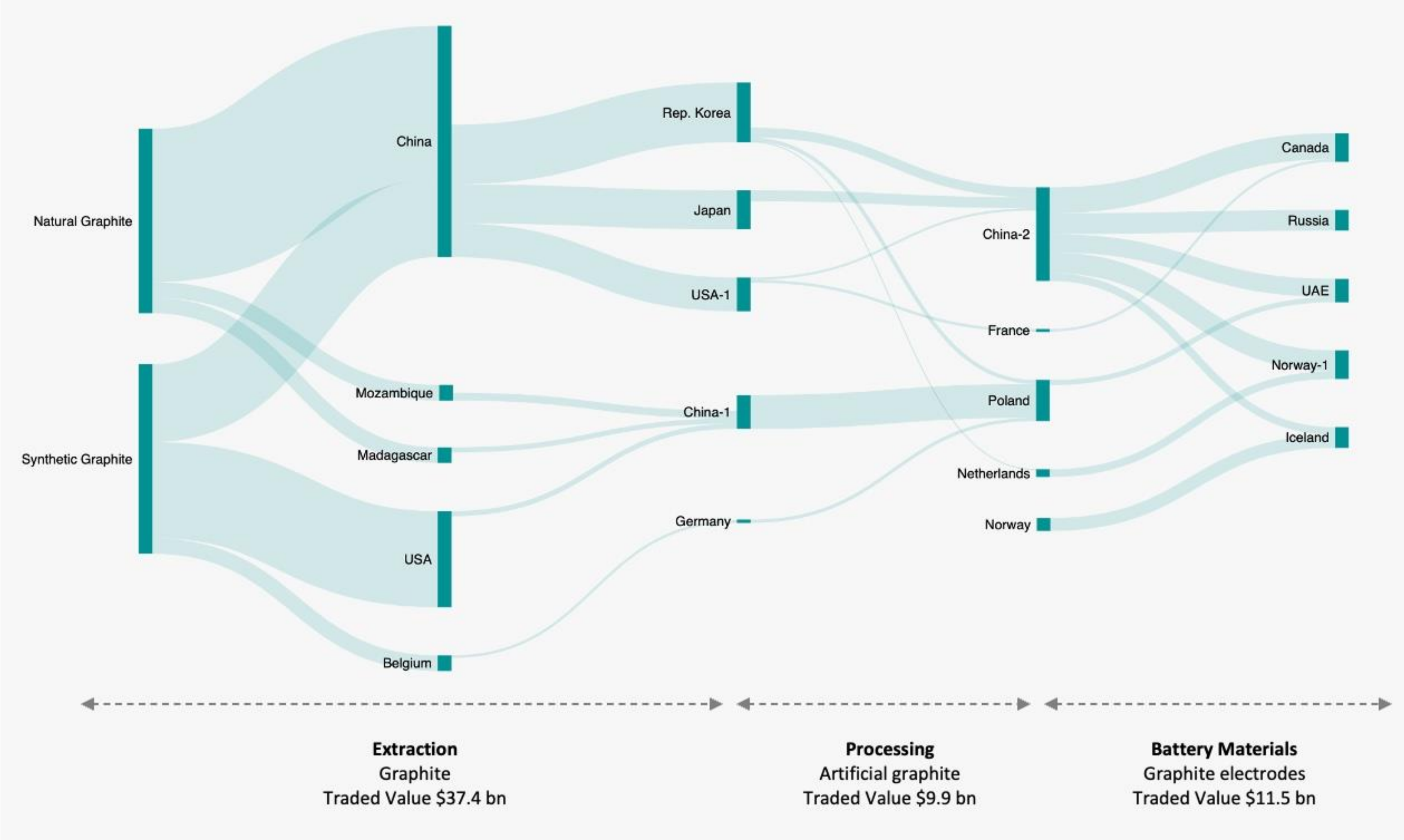
With Indonesia's export ban in place, the Philippines, Zimbabwe, and New Caledonia have become the primary exporters of nickel ore, collectively accounting for 60% of global exports. China dominates the nickel oxide and hydroxide market, responsible for nearly half of all global exports, followed by Australia (7%) and Germany (6%). Korea and Japan are major importers of these refined nickel products from China for further processing. Finally, the USA, Netherlands, Canada, and Norway export battery materials to countries like Germany, Belgium, and the Netherlands.

Annex Figure 4 Global Cobalt trade flows



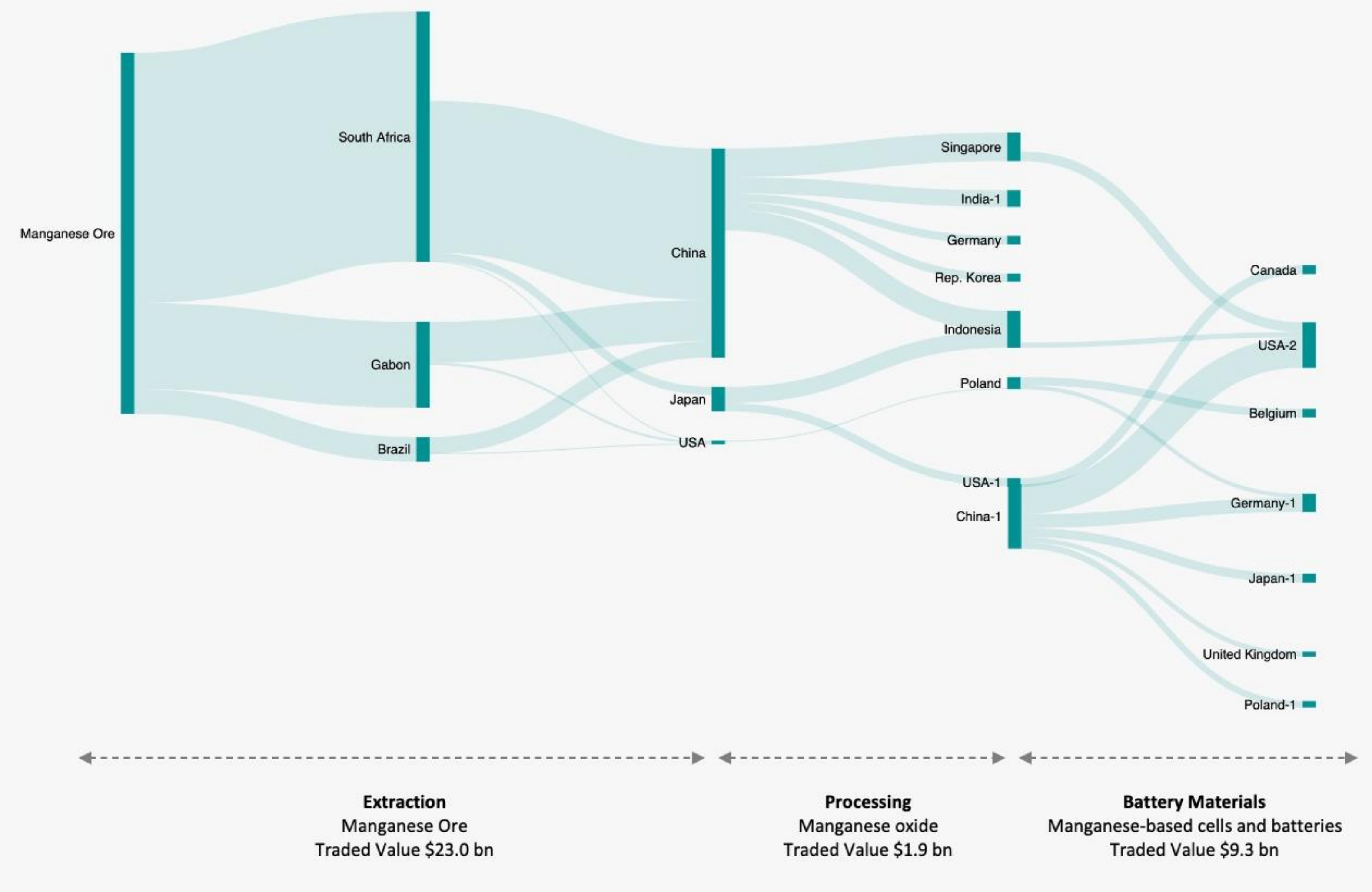
The refining stage of cobalt is heavily concentrated in a single trade relationship: the Democratic Republic of the Congo (DRC), responsible for 61% of global cobalt ore exports, also accounts for 68% of worldwide cobalt hydroxide exports, primarily destined for China. This indicates substantial value addition occurring within the DRC. At the manufacturing stage, however, the market is dominated by China, Korea, and Japan, with Korea leading in cobalt-based battery material exports (55%), followed by Japan (20%) and China (19%). Poland and the USA are the primary importers of these materi-als from Korea and Japan.

Annex Figure 5 Global Graphite trade flows



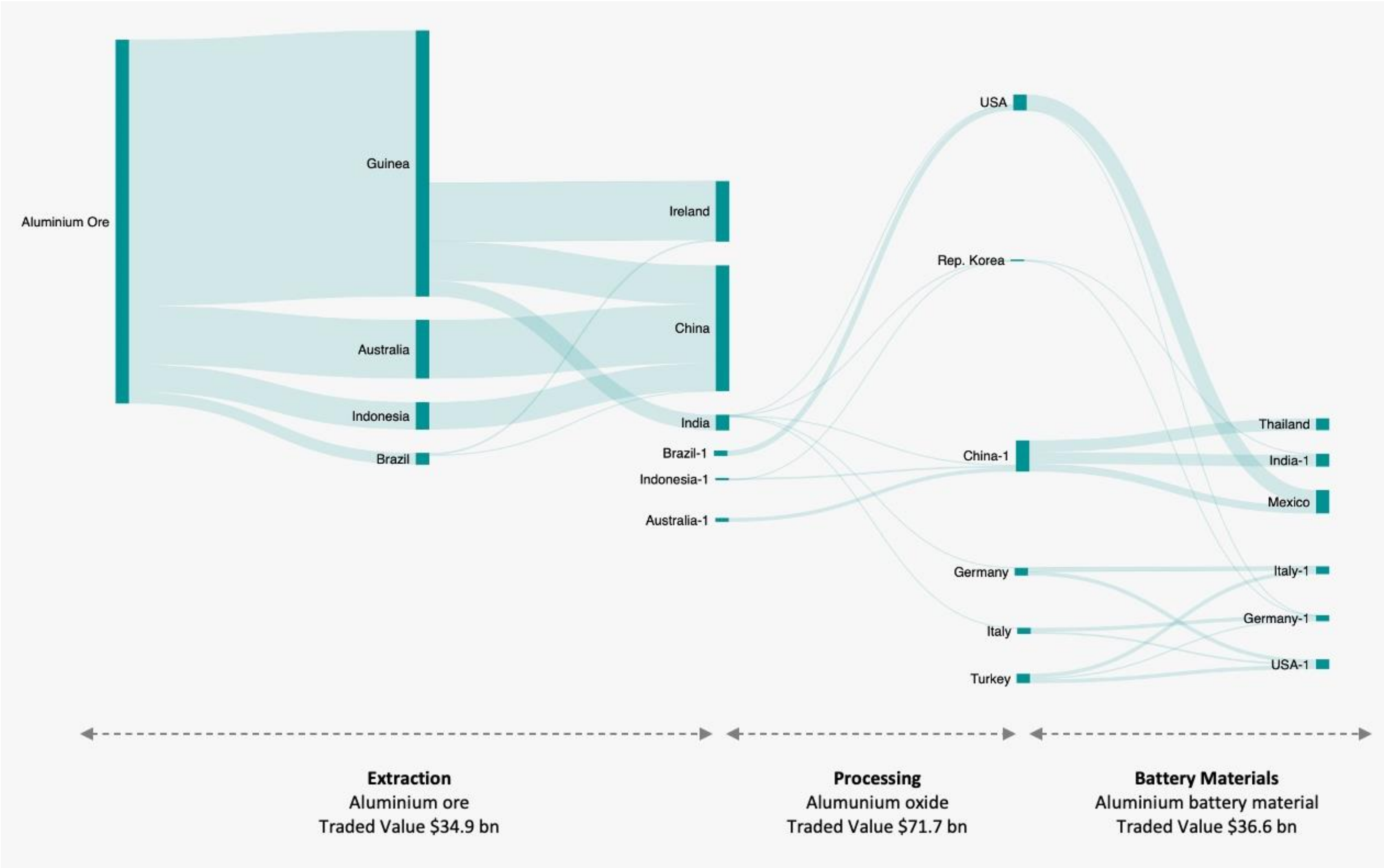
China dominates natural graphite exports with a 59% share, significantly outpacing Mozambique and Madagascar, which each hold 6%. In the synthetic graphite market, the United States leads with 37% of exports, followed by China (30%) and Germany (5%). This concentration in up-stream trade persists even with the availability of a manufactured substitute (synthetic graphite) for the natural mineral. Similarly, China leads in exports of both artificial graphite and graphite battery materials at the processing and manufacturing stages. This indicates that refined graphite exports are no more diversified than those of lithium and cobalt.

Annex Figure 6 Global Manganese trade flows



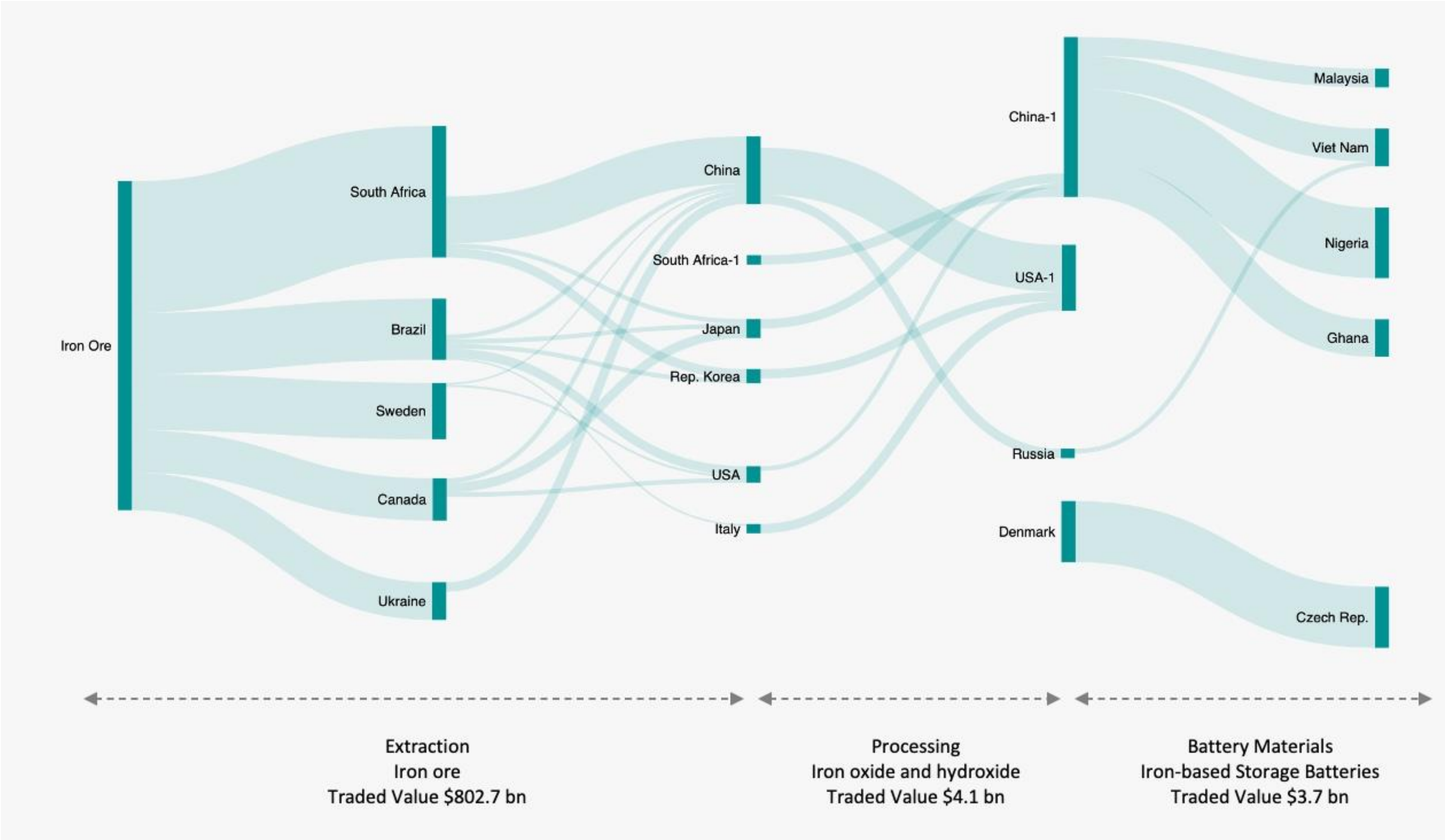
South Africa, Gabon, and Brazil export 88% of the world's manganese ore, primarily to China for processing into manganese oxide. Some of this processed material is then exported by China, primarily to Indonesia and Singapore. The resulting battery materials are subsequently imported by countries such as the USA, Germany, and Japan.

Annex Figure 7 Global Aluminium trade flows



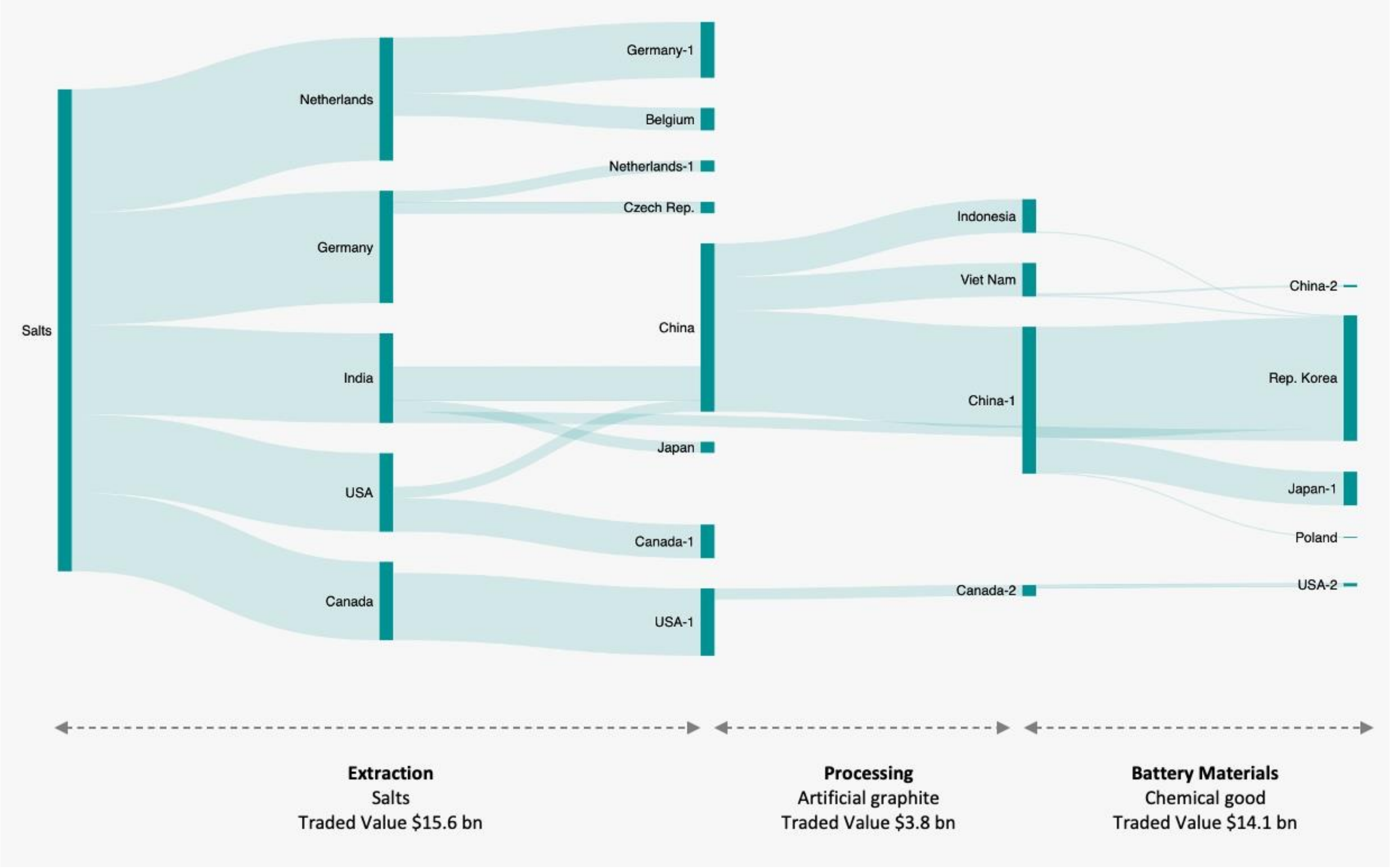
Guinea, Australia, Indonesia, and Brazil export 92% of the world's aluminium ore, mainly to China for processing. Aluminium hydroxide exports, primarily from Australia, Brazil, India, Ireland, and Indonesia, also flow mainly to China for further processing. China and Germany together export 50% of the world's aluminium battery materials.

Annex Figure 8 Global Iron trade flows



Five countries are responsible for over 60% of global iron ore exports (based on the selected HS codes). China is the main importer, processing this ore into iron oxide and hydroxide, with some of this processed material being exported to the USA. China also handles the domestic production of iron-based battery materials. In a separate trade flow, the Czech Republic imports a significant 87% of iron-based storage battery materials.

Annex Figure 9 Global Sodium trade flows



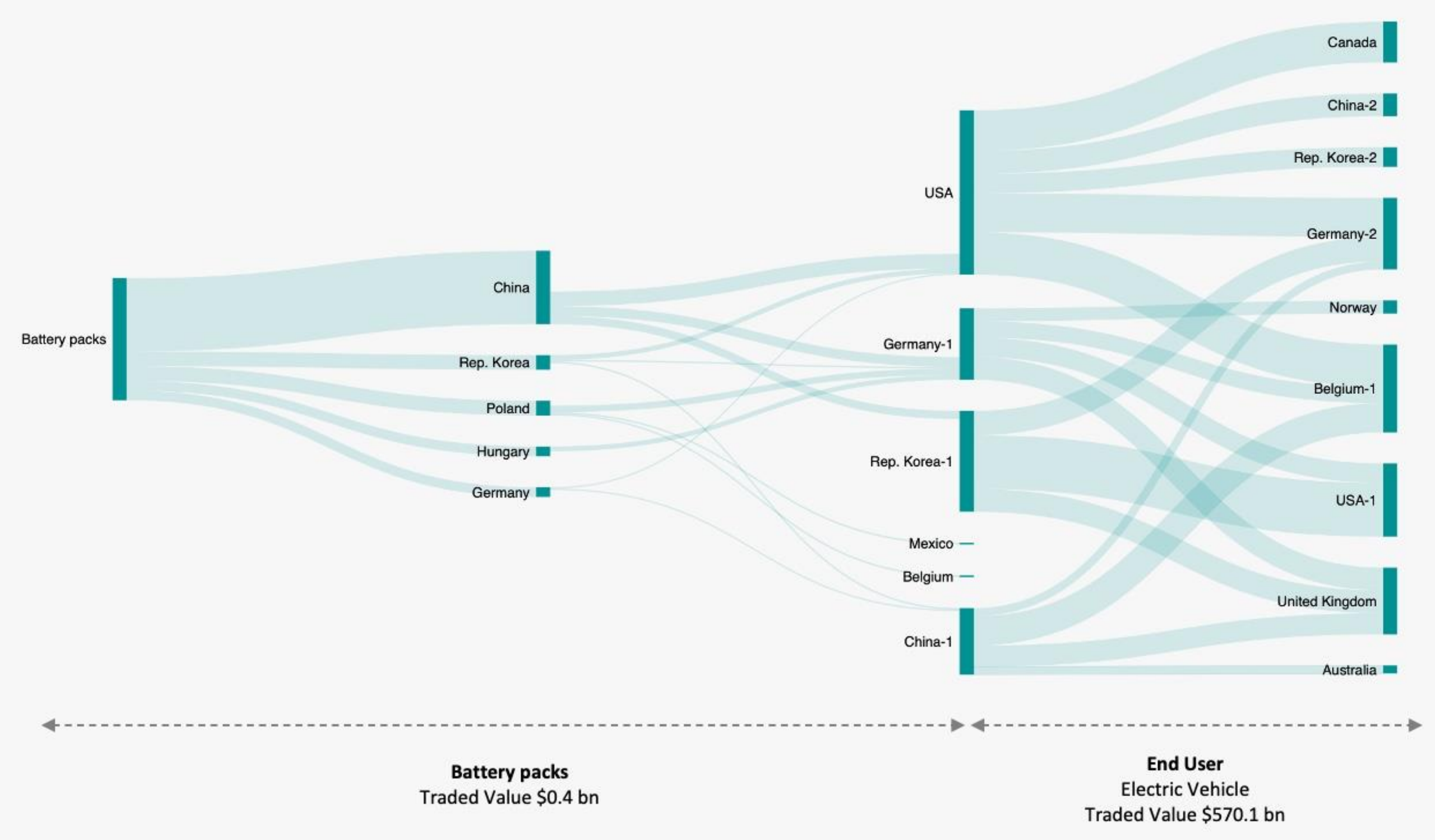
While a group of five countries (Netherlands, Germany, India, USA, and Canada) leads in the export of raw salt, contributing nearly 50% to the global total, the processing and further refinement of salt is concentrated in other regions. China and India together export 45% of processed salt, with China holding the larger share (33%). This concentration is even more pronounced in the export of sodium materials for battery production, where China holds a dominant 85% market share.

In addition, the exports of battery pack that are destined for electric vehicles were also tracked and presented in Annex Figure 10. However, this figure has a similar caveat than the other figures previously presented in this Annex, the Sankey diagram does not reflect the domestic production of battery packs that may exist in some countries.

The HS codes of tracked to build Annex Figure 10, are the following:

Battery packs	850790 - Plates, separators, and other parts of electric accumulators, n.e.s. 850760 - Lithium-ion accumulators (excl. spent)
Electric vehicles	870240 - Motor vehicles for the transport of >= 10 persons, incl. driver, with only electric motor for propulsion 870360 - Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with both spark-ignition internal combustion reciprocating piston engine and electric motor as motors for propulsion, capable of being charged by plugging to external source of electric power (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 870310) 870370 - Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with both diesel engine and electric motor as motors for propulsion, capable of being charged by plugging to external source of electric power (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 870310) 870380 - Motor cars and other motor vehicles principally designed for the transport of <10 persons, incl. station wagons and racing cars, with only electric motor for propulsion (excl. vehicles for travelling on snow and other specially designed vehicles of subheading 870310)

Annex Figure 10 Global trade flows of battery packs

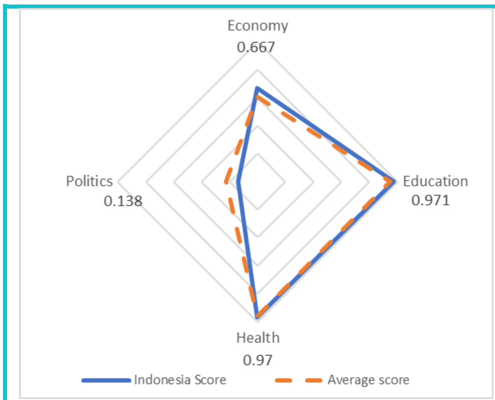


Five countries—China, Korea, Poland, Hungary, and Germany—account for 75% of global battery pack exports, representing the flow of these products to end users. China is the leading exporter among these, holding a 45% share of global battery pack exports over the past five years, and primarily ships to major EV exporting nations like the United States, Germany, and Korea.

Annex 4. Gender and social inclusion considerations related to battery production

In 2024, Indonesia achieved a gender parity score of 0.686 out of 1.0, ranking it 11th within the East Asia and Pacific region[308]. The labour force participation rate reaches 64.5%. with more women in professional and technical roles but lacks parity for senior official, and managerial positions. Furthermore, women´s estimated earned income is just half that of men´s (SeeAnnex Table 14).

Annex Table 14 Indonesia 's results in the Gender Gap Index and its subindices



Subindex	Score	Global rank
Economic participation and opportunity	**0.667**	**89**
Labour-force participation rate [%]	0.645	112
Wage equality for similar work	0.755	15
Estimated earned income	0.517	113
Educational attainment	**0.971**	**105**
Health and survival	**0.970**	**72**
Political empowerment	**0.138**	**107**

Although SMEs generally employ fewer women compared to larger firms, a higher proportion of small businesses are either fully or partially owned and managed by women. Women hold 12.3% of board positions, and 52.9% of firms have female majority ownership. Despite these advances, women still make up only 22% of top managerial roles.

For the manufacturing sector in 2023, the workforce was composed of 61% male and 39% female workers, a distribution that mirrors the gender breakdown of the unemployed. Among individuals not participating in the labour force, women represent a significant majority at 74%. Additionally, women represent 91% of those involved in housekeeping activities. In contrast, the education sector demonstrates a more balanced gender distribution, with 48% male and 52% female students[309]. Notably, female representation is even higher in secondary and tertiary enrolment, where gender parity has been fully achieved.

Annex Table 15 Labour force divided by sex in the country, 2023

Type of activity	Male [%]	Female [%]
Working	61%	39%
Unemployment	62%	38%

Source: Badan Pusat Statistik, Survei Angkatan Kerja Nasional (Sakernas) Agustus/BPS-Statistics Indonesia, August National Labor Force Survey

There is limited gender disaggregated data on stages of the EV battery supply chain. While the number of total workers is available for the mining and quarrying sector through the *annual survey of non-petroleum and natural gas mining company*, up-to-date information

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[308] *WEF (2024). Global Gender Gap 2024. Insight report. Available at: https://www3.weforum.org/docs/WEF_GGGR_2024.pdf*

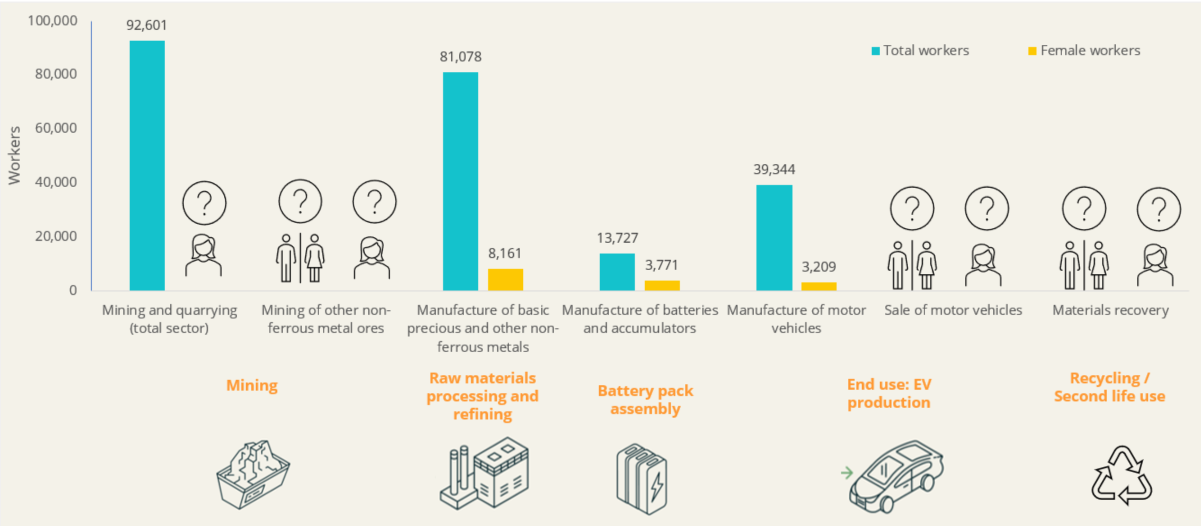
[309] *WEF (2024). Global Gender Gap. Insight Report. June 2024. Available at: https://www.weforum.org/publications/gender-gap-report-2024/.*

on the number of female workers and their decision-making roles within this sector is not available. A somewhat better scenario exists for the *manufacture of basic precious and non-ferrous materials*, which includes *raw material processing- stage*, where the country collects data on female employment. However, this data does not accurately represent workers specifically involved in the battery supply chain.

For the *manufacture of batteries and accumulators*, including EV battery production, recent data shows approximately 13,000 workers in the industry, with women comprising around 27% of this workforce. Similarly, in the *motor vehicle manufacturing sector*, the latest data indicates roughly 39,000 workers, of whom 8% are women.

For other categories, there is no disaggregated data on women employed in motor vehicle/EV sales or in battery recycling activities.

Annex Figure 11 Gender disaggregated data in the EV battery supply chain



Source: Mining and Quarrying sector: Annual survey of Non-Petroleum and Natural Gas Mining Company. Retrieved from BPS-Statistics Indonesia. Mining Statistics of Non-Petroleum and Natural Gas 2018-2022. Manufacturing sector: BPS-Statistics Indonesia. Statistics of Indonesia Manufacturing Industry. 2022. Volume 11. 2024

Wholesale and retail trade: Results of Trade, Repair of Motor Vehicles and Motorcycles Establishments Data Collection EC2016-Continued.

Main recommendations for strengthening the gender considerations into the EV battery supply chain

- The country could benefit from developing a monitoring system to track the workforce in the mining industry, particularly within nickel mining. This should include the collection of disaggregated gender data to identify the number of female workers and understand their conditions in the sector. Key areas to assess include decision-making roles, job types, gender pay gaps, caregiving responsibilities, access to childcare services, and differential health impacts. Focusing on the mining sector is essential due to the workforce's exposure to health risks, labor rights issues, limited access to services and education, and risks of gender-based violence.
- For women in the manufacturing sector and materials recovery subsector, a targeted survey is recommended to gather both quantitative and qualitative data on women's participation in the EV battery supply chain. This survey, inspired by international studies, aims to establish a baseline for women's participation and to identify challenges faced by women in the sector. Insights from this data could

inform a specific action plan to improve conditions for women and other disadvantaged groups. The survey should be directed both to individuals, capturing personal details, perceptions, and challenges, and to organizational representatives to gather workforce gender distribution data as well as existing policies and measures that support gender equality.

- Potential organizations to disseminate the survey might comprise large unions, company level unions, Mining Industry Indonesia (MIND ID), Indonesia Battery Corporation (IBC), Indonesian Nickel Miners' Association (APNI), Electric Mobility Ecosystem Association (AEML), Gaikindo (Association of Indonesian Automotive Industries).
- Key survey questions should cover areas such as gender, family status, educational background (technical or non-technical), involvement in the supply chain, organization type and size, access to employment benefits, and levels of decision-making authority. These insights will support stakeholders in developing a comprehensive gender action plan for the industry.

Annex 5. EVs and ICEVs production plants and its labour intensity

Annex Table 16 Sample of EVs production factories

Company	Location	Production	Employees	Calculated labour intensity (Jobs per EV produced)
Tesla[310]	Fremont Factory (California, USA)	500,000	12,000	0.024
	Gigafactory Shanghai (China)	750,000	15,000	0.020
	Gigafactory Berlin (Germany)	500,000	12,000	0.024
BYD[311]	Shenzhen Headquarters and Factory (Guangdong, China)	300,000	20000	0.067
	Xi'an Factory (Shaanxi, China)	300,000	15000	0.050
	Changsha Factory (Hunan, China)	200,000	10000	0.050
	Changzhou Factory (Jiangsu, China)	150,000	10000	0.067
	Hefei Factory (Anhui, China)	150,000	9,000	0.060
VW[312]	Emden Factory (Germany)	250,000	500	0.002
	Dresden Factory (Germany)	35,000	8,000	0.229
	Zwickau Factory (Germany)	300,000	6,000	0.020
	Anting Factory (China) (SAIC-VW joint venture)	300,000	5,000	0.017
			Average	***0.052***

Annex Table 17 Sample of ICEVs production factories

Company	Location	Production	Employees	Calculated labour intensity (Jobs per ICEV produced)
Toyota[313]	Toyota Motor Manufacturing Indonesia (TMMIN)	180,000	5,700	0.032
Mitsubishi[314]	Mitsubishi Motors Krama Yudha Indonesia (MMKI)	160,000	3,000	0.019
Honda[315]	Honda Prospect Motor (HPM)	200,000	7,000	0.035
Suzuki[316]	Suzuki Indomobil Motor (SIM)	134,000	4,000	0.030
			Average	***0.028***

310 Tesla Outfitters (2024) TESLA FACTORIES OVERVIEW. Available at: https://tesla-outfitters.com/blogs/tesla-infos/tesla-factories

311 BYD Global (2024) Periodic Reports. Available at: https://www.byd-global.com/cn/en/BYD_ENInvestor/InvestorAnnals_mob.html

312 Reuters (2024) Which Volkswagen factories in Germany could be affected by layoffs?. Available at: https://www.reuters.com/business/autos-transportation/which-volkswagen-factories-germany-could-be-affected-by-layoffs-2024-09-03/#:~:text=4.,in%20the%20city%20of%20Emden.

313 Toyota (2011) Toyota to Build Second Vehicle Plant in Indonesia. Available at: https://global.toyota/en/detail/218914

314 Mitsubishi Motors (2017) Mitsubishi Motors inaugurates new manufacturing plant in Indonesia. Available at: https://www.mitsubishi-motors.com/en/newsroom/newsrelease/2017/20170425_1.html

315 Honda global (2014) Honda Prospect Motor Opens Second Factory in Indonesia. Available at: https://global.honda/en/newsroom/worldnews/2014/c140115Second-Factory-Indonesia.html

316 Suzuki (2023) Suzuki Achieves Accumulated Automobile Production of 3 Million Units in Indonesia. Available at: https://www.globalsuzuki.com/globalnews/2023/0117.html