Unlocking Supply Chains for Localizing Electric Vehicle Battery Production in India

IISD REPORT

International Institute for Sustainable Development

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November 2024

International Institute for Sustainable Development

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Photo: Shawn Sebastian/Drokpa Films.

Acknowledgements

The International Institute for Sustainable Development (IISD) would like to thank everyone who contributed to this report. We would particularly like to thank the many government officials, industry officials, and thematic experts who agreed to participate in in-depth interviews and share their advice and experiences. We would like to thank Christopher Beaton from IISD for providing editorial comments on the report.

The authors of this report would like to thank the following individuals and institutions for the valuable comments and recommendations that they provided as peer reviewers:

- Amit Panday, Hindalco
- Anjani Sri Mourya Sunkavalli, Altmin
- Anuj Gupta, Agratas
- Dev Ashish Aneja, Ather Energy
- Kalpesh Pandya, Epsilon Advanced Materials
- Pradeep Karuturi, OMI Foundation
- Rohit Laumas, Customized Energy Solutions
- Suresh Babu Muttana, Department of Science and Technology, Government of India

We would also like to thank the ClimateWorks Foundation for their generous support of this publication. The opinions expressed and arguments employed in this update do not necessarily reflect those of peer reviewers, organizations, and funders, nor should they be attributed to them.

Executive Summary

India has aspirations to become a prominent player in the global battery industry. The national government's launch of the Production Linked Incentive Scheme for Advanced Chemistry Cell Battery Storage (PLI-ACC scheme) in 2021 reflects the country's desire to indigenize battery manufacturing. The scheme has allocated INR 18,100 crore (USD 2.5 billion) in subsidies over 5 years, with the aim of installing 50 gigawatt hours (GWh) of domestic battery manufacturing capacity by 2026. This goal is driven by several priorities, such as bolstering energy security, promoting local value addition, and accelerating transport electrification and stationary storage deployment. However, to truly capture value across the battery supply chain, India will need to pursue backward integration with the high-value cell components segment as well as equipment manufacturing. Despite the inclusion of local value-addition requirements under the PLI-ACC scheme, there has been limited progress in these areas, with announcements by companies yet to translate into large-scale production. Hence, there is a strategic imperative to identify the barriers to localizing the supply chain and recalibrate India's industrial and trade policies to build a competitive battery ecosystem.

India largely imports lithium-ion cells, which roughly account for 75%–80% of the total cost of lithium-ion batteries (LiBs), with mainly labour-intensive but low-value battery module assembly and packaging done within the country. S&P Global, a rating agency, estimates that LiB capacity in India was 18 GWh in 2023, a fraction of the total 2.8 TWh global market. Lithium-ion cell and battery imports totalled around USD 3.06 billion in 2023. Based on current trends, S&P Global Mobility expects that only 13% of total battery cell demand is expected to be sourced domestically by 2030, while the rest may be fulfilled by imports. Cell components (cathode, anode, electrolyte, and separators) and equipment used in battery cell manufacturing were also mainly imported in 2023. An overreliance on imports poses significant risks for India since any disruptions could affect the speed of the energy transition and India's future clean energy manufacturing ambitions.

The Russia–Ukraine war and COVID-19 pandemic have underlined the fragility of global supply chains and the need to build resilience by diversifying the manufacturing locations of batteries and components. In order to fully capitalize on shifts in global supply chains, India will have to navigate a few challenges, including (i) China's dominance of the battery supply chain, (ii) resource nationalization in mineral-rich countries, and (iii) localization policies by industrialized economies. China is currently grappling with significant overcapacity across the supply chain, which makes it more challenging for Indian companies to compete. In 2023, global LiB demand across electric vehicles (EVs) and stationary storage was less than half of global manufacturing capacity and will remain so until 2025.

Nevertheless, India has the potential to add value across the global battery supply chain. Its chemical sector expertise; technological prowess; favourable trade and geopolitical relations with key players such as South Korea, Japan, the United States, and the European Union (EU); and growing network of free trade agreements with mineral-rich countries offer several opportunities. As the fourth-largest manufacturer of automobiles, the transition from internal combustion engines to EVs provides a significant economic opportunity if India is able to indigenize battery manufacturing. Interestingly, the country has been increasing its LiB exports over the past year (albeit from a low base) to major automotive hubs, such as Germany and Japan.

This study aims to clarify the key supply chain barriers in localizing EV battery cell components and equipment manufacturing in India. It summarizes consultations with 12 companies working on battery cell and equipment manufacturing, as well as experts and policy-makers, to determine the crucial challenges in localizing manufacturing. The report also assesses trade and geopolitical risks and opportunities and aims to provide targeted policy recommendations to government agencies, including policies and incentive mechanisms that can localize EV and battery supply chains within India and build on the country's comparative advantages.

Companies, both domestic and multinational, have emphasized six major challenges in localizing the production of EV battery cells and components, including the following:

1) A lack of skilled labour across several domains in the battery supply chain, from raw materials development and cell manufacturing to battery management systems.

Interviews with cell manufacturing companies have suggested that this absence of skilled labour has led to safety concerns and delays in investment plans, as well as hindered the speed of innovation. Overcoming this challenge will require greater collaboration between government, industry, and academia to develop dedicated courses and skilling programs on battery technologies and cell manufacturing. For example, China developed an action plan on energy storage for undergraduate majors and cross-disciplinary education from 2020 to 2024 and recently reaffirmed this commitment by introducing several courses on advanced technologies in undergraduate majors to upskill its workforce. It is also essential for India to increase investment in research and development (R&D) to support innovation in a rapidly evolving sector. To put things in perspective, BYD, the world's largest EV producer, has around 110,000 technology and R&D employees.

2) An absence of testing and validation centres for advanced cells and raw materials used in battery cell production.

As of May 2024, Bharat Test House is the only accredited agency in India providing testing for battery cells under the PLI-ACC scheme, with efforts underway for two other agencies to receive this accreditation—the International Centre for Automotive Technology and the Automatic Research Association of India. This underscores the need for investment to build new testing centres and upgrade existing ones, as well as hiring trained scientists in the public sector. A collaborative approach among government, battery companies, and original equipment manufacturers is needed to set standards for testing, product development, and innovation, as well as to shorten the life cycle of product commercialization while maintaining high quality and safety standards.

3) Heavy reliance on imports for critical battery minerals, such as lithium, cobalt, graphite, and nickel.

This dependence exposes the domestic battery industry to price fluctuations and potential supply disruptions. Our interviews suggest this reliance on imported raw materials makes cost competitiveness a challenge for Indian companies vis-à-vis international competitors. China's recent export restrictions on battery-grade graphite also underscores the need for diversification to mitigate trade risks. The government has taken several positive steps, such as streamlining regulations for domestic exploration, signing a Memorandum of Understanding (MoU) with mineral-rich countries, and creating a state-owned company, Khanij Bidesh Limited, to source minerals from overseas. India should pursue increased collaboration with industrialized countries through trilateral partnerships between them and mineral-rich countries, as well as jointly develop refining technologies. Additionally, strategic stockpiling of battery minerals during the ongoing low-price environment could further support India's efforts.

4) The lack of a robust LiB recycling ecosystem, which necessitates a reliance on virgin materials, further straining the supply chain and raising environmental concerns.

Although India introduced the Battery Waste Management Rules in 2022—which include several measures, such as extended producer responsibility mandates for battery companies, recovery rates from used batteries, and recycled content targets for new batteries—interviewed experts highlighted the need for greater coordination between state and central governments, as well as public awareness campaigns to support battery collection. A well-defined strategy is needed to collect, segregate, and recycle used batteries. India should consider integrating a battery passport initiative with the 2022 Battery Waste Management Rules. A battery passport is designed to store relevant data throughout the battery life cycle and is being rolled out by the EU in 2027. Experts also suggested that mandates for on-site recycling at gigafactories and incentives were needed to stimulate the growth of India's recycling industry.

5) Leading companies in international jurisdictions, such as the EU and the United States, are required to comply with stringent environmental, social, and government (ESG) regulations.

For example, the EU's new Sustainable Battery Regulation includes mandatory carbon footprint reporting for batteries, as well as supply chain due diligence requirements. India should look to adopt ESG reporting, disclosure, and certification standards to enhance export competitiveness. The country's open access rules already facilitate access to renewable energy for businesses. However, it is essential for the government to provide additional incentives to companies that invest in a low-carbon manufacturing process in cell manufacturing hubs.

6) High import dependence and supply chain constraints for key equipment and machinery that is used in cell manufacturing.

While there is a significant focus on localizing battery cell components, not enough attention is being paid to key equipment and technologies used in cell manufacturing. A McKinsey & Company analysis found that most incumbent battery cell manufacturers and equipment suppliers were operating at more than 95% capacity in 2022, leaving little room to increase output. India battery manufacturing companies and original equipment manufacturers that enter this sector may face bottlenecks in securing equipment that could place their planned start of production at risk. Although there are limitations in interpreting trade data for equipment, our analysis found that imports of equipment used in battery cell manufacturing from China totalled USD 1.5 billion in 2022. There is room for India to diversify away from China for some equipment through collaboration with free trade agreement partners, but it will need to consider the cost implications on downstream battery companies.

Based on the analysis undertaken in this report, we recommend that the government focus on maximizing India's comparative advantages in the battery supply chains, through the following steps:

- India should prioritize the localization of specific battery components, such as synthetic anodes, electrolytes, and cell casings and pouches, through supportive regulations and trade and industrial policies. The presence of domestic suppliers, high cost competitiveness, and low intellectual property and tech reliance create an opportunity for India to scale up its production.
- The government should also incentivize the development of domestic cathodes since these are the highest-value components in a cell. Although India's technology-agnostic approach can help build domestic capabilities for different battery types, it should prioritize the development of lithium ferro phosphate cathodes since they are lower cost and more suitable for India's climatic conditions. The adoption of lithium ferro phosphate batteries can offset the increased imports of critical minerals, such as cobalt and nickel.
- The government should support R&D efforts and incentivize the commercialization of the next generation of battery technologies, such as sodium-ion and solid-state, to seize potential opportunities created by the next evolution of the battery industry.
- India must adopt clearer ESG guidelines and targets, as well as establish robust reporting frameworks to enhance the export competitiveness of domestic battery companies.
- Increased public investment in setting up cell fabrication and testing centres with trained manpower is essential to validate the quality of raw materials, components, and equipment.
- The government should incentivize a circular economy ecosystem by enabling the recycling of end-of-life batteries and improving the collection efficiency of used batteries.
- The government also needs to prioritize the localization of critical equipment used in cell manufacturing through technology partnerships and trade agreements with key allies.

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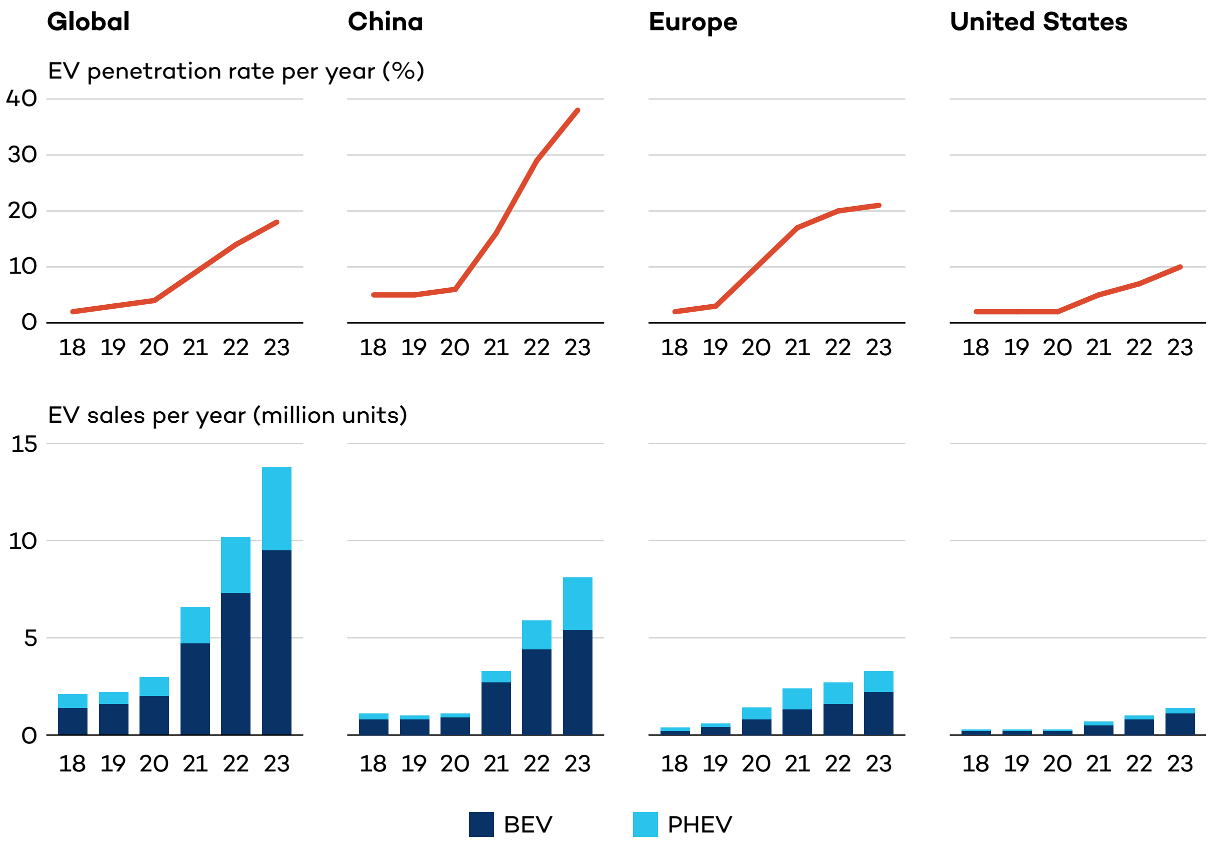
Abbreviations and Acronyms

ARAI	Automatic Research Association of India
CAM	cathode active material
EU	European Union
EV	electric vehicle
FAME II	Faster Adoption and Manufacturing of Electric Vehicles
FTA	free trade agreement
HS	Harmonized System
ICAT	International Centre for Automotive Technology
IEA	International Energy Agency
IRA	Inflation Reduction Act
LiB	lithium-ion battery
LFP	lithium ferro phosphate
MHI	Ministry of Heavy Industries
MoU	Memorandum of Understanding
NMC	nickel manganese cobalt
OEM	original equipment manufacturer
PLI	Production Linked Incentive
PLI-ACC	Production Linked Incentive Scheme for Advanced Chemistry Cell Battery Storage
R&D	research and development

1.0 Introduction

Electric vehicles (EVs) will play a critical role in driving the global transition away from fossil fuels in the transport sector—and they are demonstrating growing momentum. Indeed, electric car sales reached close to 14 million units globally in 2023, constituting 18% of total car sales. These numbers were mainly driven by sales in China (60%), the European Union (EU) (25%), and the United States (10%) (International Energy Agency [IEA], 2024c).

Figure 1. EV sales and penetration rate (globally and in key geographies)

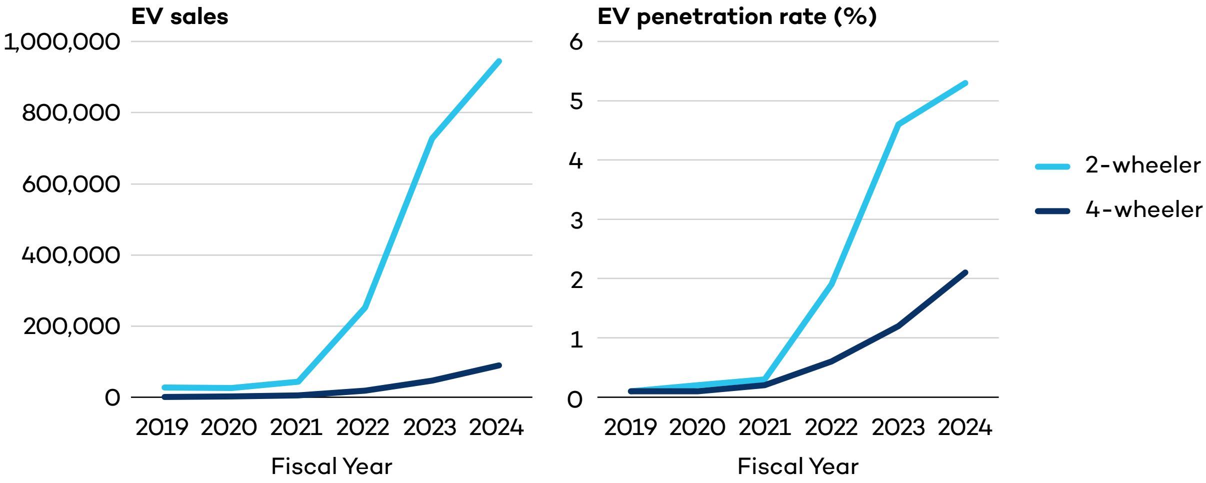


Source: IEA, 2024c.

EV sales have also been accelerating in India—1.53 million vehicles were purchased in 2023, an increase of around 50% from 2022, largely driven by the two- and three-wheeler segments (India Brand Equity Foundation, n.d.). One in five three-wheelers sold globally in 2023 was electric, and nearly 60% of those sales in India were supported by the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) subsidy scheme, India's flagship scheme for incentivizing EV demand (IEA, 2024c). With over 300 million vehicles currently on the road and another 200 million forecast to be added in the next 2 decades, India faces a massive challenge to electrify its road vehicles and reach its goal of net-zero emissions by 2070 (IEA, 2022).

It also presents an enormous opportunity. As the fourth-largest manufacturer of automobiles (International Organization of Motor Vehicle Manufacturers, n.d.), the transition from internal combustion engines to EVs can bolster jobs and local value creation if India is able to indigenize battery manufacturing.

Figure 2. Two- and four-wheeler EV sales in India



Source: Society of Indian Automobile Manufacturers, n.d.

Despite impressive sales growth, domestic EV and battery cell manufacturing has been slow to ramp up, with a high reliance on imports of battery components and equipment. India largely imports lithium-ion cells, which roughly account for 75%–80% of the total cost of lithium-ion batteries (LiBs), as well as key equipment and technology, with mainly labour-intensive but low-value battery module assembly and packaging done within India (Gulia et al., 2022).

An electric three-wheeler in India at Log9 Materials. (Shawn Sebastian/Drokpa Films)

The slow pace of this capacity growth is mainly due to the high capital investment requirements and technical complexities involved in cell manufacturing. This import dependency has resulted in supply chain challenges, including disruptions due to reliance on a few countries. It has also led to automakers (or original equipment manufacturers [OEMs]) having to deal with volatile lithium-ion cell prices, along with the limited availability of cells that are well suited for the extreme temperatures specific to India (Gulia et al., 2022). Given that NITI Aayog, the Indian government's think tank, anticipates that battery demand could rise to between 108 GWh and 260 GWh by 2030, it is essential for the country to build a robust domestic cell manufacturing industry both to secure energy security and to capitalize on opportunities for domestic value and job creation (NITI Aayog et al., 2022a).

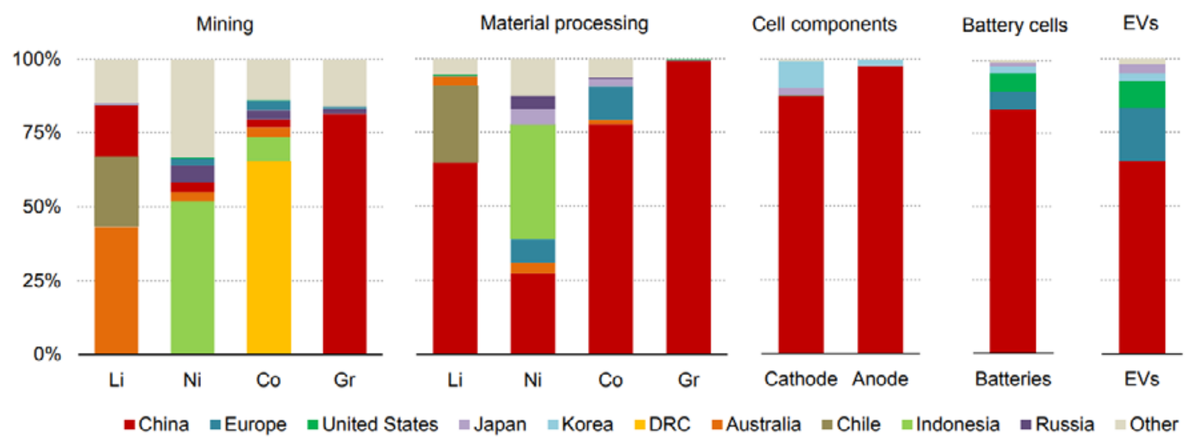
Although India's EV cell production is in its early stages, government support and industry interest hint at significant progress in the coming years. In order to capture value across the battery supply chain, India will need to pursue backward integration toward the high-value cell components segment and equipment manufacturing. Despite the inclusion of local value-addition requirements under the Production Linked Incentive Scheme for Advanced Chemistry Cell Battery Storage (PLI-ACC scheme), there has been limited progress in these areas, with announcements by companies yet to translate into large-scale production. Hence, there is a strategic imperative to identify barriers to localizing the supply chain and recalibrate India's industrial and trade policies to build a competitive battery ecosystem.

This paper aims to understand the key supply chain barriers in localizing EV battery cell components and equipment manufacturing in India. It summarizes consultations with over 12 companies working on battery cell and equipment manufacturing, as well as experts and policy-makers, to determine the crucial challenges that need to be addressed to localize battery manufacturing. The report also assesses trade and geopolitical risks and aims to provide targeted policy recommendations to government agencies and actionable insights for businesses. Finally, this report provides targeted recommendations, including policies and incentive mechanisms required to localize EV and battery supply chains in India that build on the country's comparative advantages.

2.0 Current Global Battery Production

China currently dominates the global LiB value chain, with 85% of the global capacity for battery cell production. Europe, the United States, and Korea possess a modest 10% or less of the supply chain for certain battery metals and cells (IEA, 2024a). In the battery components segment, China hosts 90% of cathode and 98% of anode material production (IEA, 2024b). China also dominates the processing segment of critical minerals used in battery cells, with a market share of over 50% of lithium processing, 75% of cobalt, and more than 90% of graphite (IEA, 2024b). This end-to-end control of the supply chain affords the country unique advantages in terms of cost competitiveness and scale. On the flip side, for India and industrialized countries, an overdependence on one supplier creates geopolitical, trade, and economic vulnerabilities.

Figure 3. Geographical distribution of the EV battery value chain (2023)



Source: IEA, 2024b, CC BY 4.0.

Notes: Li = lithium; Ni = nickel; Co = cobalt; Gr = graphite; DRC = Democratic Republic of the Congo. Geographical breakdown refers to the country where the production occurs. Mining is based on production data. Material processing is based on refining production data. Cell component production is based on cathode and anode material production capacity data. Battery cells are based on battery cell production capacity data. EVs is based on electric cars production data. For all minerals mining and refining shows total production not only that used in EVs. Graphite refining refers to spherical graphite production only. IEA analysis based on EV Volumes, Benchmark Mineral Intelligence, and BloombergNEF.

To address the supply chain concentration and build resilience, major global industrial powers have introduced several industrial policies and incentives, such as the U.S. Inflation Reduction Act (IRA) and the EU's Net Zero Industry Act, which both aim to encourage the localization of the EV and battery industry to promote domestic content value addition and job creation. These policies have resulted in Europe and the United States developing around 13% of global capacity for LiB manufacturing globally (IEA, 2024a).

In a similar vein, India announced the PLI-ACC scheme in 2021 to spur the production of 50 GWh battery cell capacity by 2026, as well as the PLI scheme for auto components manufacturing (Press Information Bureau [PIB], 2022a). The PLI-ACC scheme prioritizes ACC batteries, which boast superior range and faster charging capabilities, compared to traditional LiBs. The scheme aims to position India competitively in the evolving EV landscape to boost job creation and economic growth. A study by the Council on Energy, Environment and Water found that the impact of the automotive sector transition from internal combustion engine vehicles to EVs on jobs and economic growth will depend on the level of localization of EV and battery manufacturing, making it imperative to develop local manufacturing capabilities (Soman et al., 2019).

3.0 Current Battery Production in India

3.1 LiB Production

As of 2023, India had around 18 GWh of announced LiB manufacturing capacity, which is expected by S&P Global to grow to 145 GWH by 2030 (Marjolin, 2023). The PLI-ACC scheme has played an important role in kick-starting cell manufacturing and has attracted around USD 8.3 billion in investments for 30 GWh (Ministry of Heavy Industries [MHI], 2022). Under the PLI-ACC scheme, three Indian companies with a combined production capacity of 30 GWh have been selected. Following the initial allotment, the MHI has tendered an additional 10 GWh in capacity and selected a successful bidder, after having received seven bids from companies (PIB, 2024a). However, cell manufacturing is still at a nascent stage. Based on current trends, S&P Global Mobility expects that, by 2030, only 13% of total battery cell demand is expected to be sourced domestically, while the rest may be fulfilled by imports (Das, 2024).

India has comparative advantages in battery cell production that have not been fully tapped. India's cell manufacturing costs could potentially be competitive when compared with the EU, the United States, and developed Asian economies, considering India's comparative advantages in manufacturing based on relatively cheaper labour, competitive industrial tariffs, lower overheads, and competitive capital intensity. Indeed, an IEA study found that capital costs in India for five clean energy technologies, including batteries, were significantly lower than the EU and the United States, but around 20%–90% higher than China (IEA, 2024d).

On an operational cost basis, experts suggest India could even be competitive with China. The gross monthly minimum wage levels in India in 2019 were USD 65 compared to USD 217 in China (Gulia et al., 2022). Despite these comparative advantages, India faces a disadvantage in building economies of scale in cell manufacturing, given the limited maturity of its EV market versus other leading geographies and its lack of access to critical minerals and battery component technology. According to Porsche Consulting (2024), "size matters when it comes to building battery cell factories [and] smaller players are generally at a 15%–20% disadvantage in costs per cell compared to large-scale volume manufacturers" (p. 23). In the short term, Indian companies will unlikely be able to compete with their Asian counterparts without supportive fiscal, industrial, and trade policies to promote localization.

In terms of value, the annual market for stationary and mobile batteries in India could range between USD 6 billion and USD 15 billion by 2030, with almost USD 12 billion from cells and USD 3 billion from pack assembly and integration (NITI Aayog et al., 2022a).

Table 1 summarizes the current projects by major battery cell companies based on author interviews with companies and experts. The table indicates that most of the announced plants are either at the small-scale pilot production level or in the planning and construction phases.

Table 1. Major companies planning cell manufacturing in India

Company name	Location	Project details	Project status	Battery chemistries	Form factors
Toshiba Denso Suzuki	Gujarat	Battery pack assembly plant in the first phase	Already set up	Lithium titanate oxide (LTO)	n/a
BHEL	Bangalore	Small pilot production	Already set up	n/a	n/a
HBL	Hyderabad	100 MWh production for captive use	Already set up	Lithium ferro phosphate (LFP)	Cylindrical/ prismatic/ others
Amperex Technology Limited (ATL)	Haryana	Gigafactory planned	Pilot plant already set up, planning expansion	n/a	n/a
Munoth Industries	Andhra Pradesh	Gigafactory planned	Pilot plant already set up, planning expansion	n/a	Prismatic
Log9 Materials	Bangalore	2 GWh/year planned	Pilot plant already set up, planning expansion	LTO/LFP	Cylindrical
Exide Industries	Bangalore	12 GWh/year planned	6 GWh/ year under construction	Nickel manganese cobalt (NMC)/LFP	Cylindrical
Amara Raja	Hyderabad	16 GWh/year planned	Pilot production under construction	NMC/LFP	Cylindrical
Ola Electric	Tamil Nadu	Received PLI-ACC for 20 GWh/ year and announced plans for another 100 GWh	Operational, Phase 1a – 1.4 GWh Ramp-up Phase 1b – 5 GWh (Oct 2024) Phase 2 – 6.4 GWh (Apr 2025) Phase 3 – 20 GWh (mid-2026) Long term – 100 GWh	NMC	Cylindrical

Company name	Location	Project details	Project status	Battery chemistries	Form factors
Agratas Energy	Gujarat	Gigafactory planned by 2026	Pilot plant under construction	NMC/LFP	Prismatic/ cylindrical
Reliance	Gujarat	Received PLI-ACC for 15 GWh/year capacity	Pilot plant under construction	LFP	Cylindrical
Rajesh Exports	Karnataka	Received PLI-ACC for 5 GWh/year	Gigafactory under construction	n/a	n/a
Nsure Energy	Bangalore	5 GWh/year planned	Pilot plant under construction	LFP	Prismatic/ cylindrical/ pouch
Nash Energy	Karnataka	600 MWH/ year plant planned	Under construction	LFP	Cylindrical
Lucas TVS	Tamil Nadu	10 GWh/year planned	Pilot plant under construction	NMC/LFP/ Others	Prismatic/ pouch

Source: Based on expert interviews and consultations.

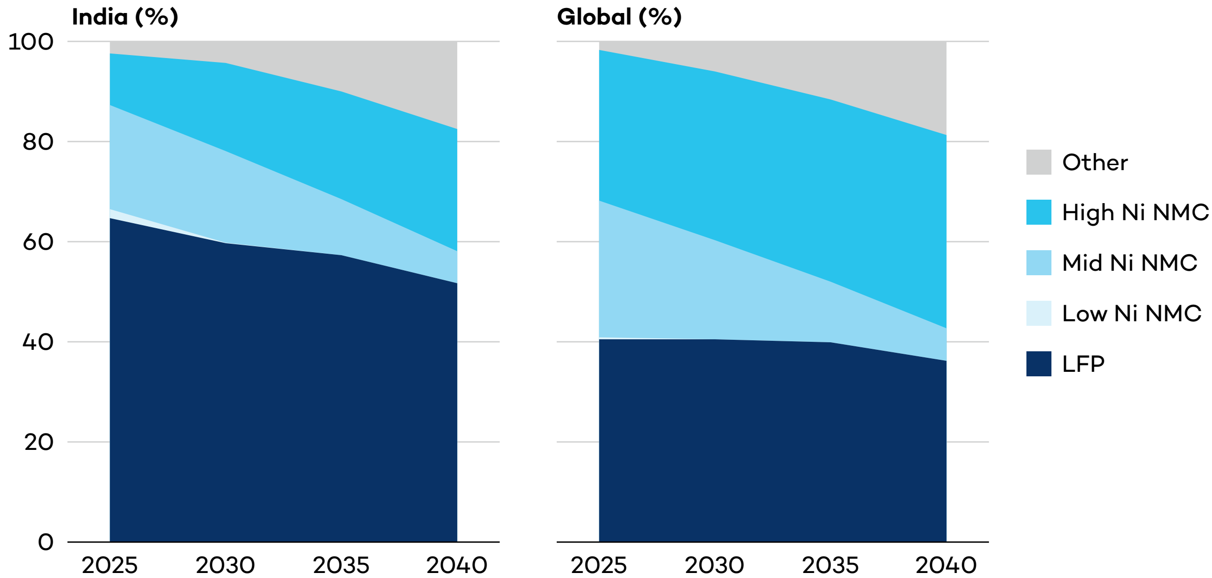
A scientist walks through Log9 Materials. (Shawn Sebastian/Drokpa Films)

3.2 Battery Chemistries

LFP and NMC are the two most prevalent types of LiBs. NMC batteries hold a commanding 60% market share, making them the most widely used LiBs, while LFP batteries represent about 40% of the market (IEA, 2024a). China is a key player in both battery chemistries, particularly excelling in LFP production, where it commands 95% of the market for light-duty vehicles, largely due to previous patent protections. However, with the expiration of LFP patents in 2022, more non-Chinese companies are starting to enter the LFP battery market (Moerenhout et al., 2023).

India's EV battery chemistry profile is likely to differ from its global counterparts in the future, tilting more toward LFP, whereas the global mix is relatively evenly balanced between LFP and NMC. These differences are broadly due to product suitability aligned to consumer behaviour, climate conditions, and demographics. For example, LFP batteries are relatively cheaper than NMC batteries (32% cheaper), have a longer cycle life, and tend to perform better in extreme temperatures, making them more suitable for India's context (Moerenhout et al., 2023; Warrior et al., 2024). However, NMC batteries have a higher energy density than LFP, making them more suitable for longer-range vehicles.

Figure 4. The forecasted future battery chemistry mix in India vs. global counterparts



Source: BloombergNEF, 2024.

With LFP likely to capture a greater market share in the future, particularly in cost-sensitive markets in the Global South, India has a unique opportunity to become a diversified supplier of LFP cathode active material (CAM), particularly since many major markets for NMC are not generally manufacturing LFP (Volta, 2023), likely because different market requirements in industrialized countries have traditionally favoured NMC battery chemistries. Moreover, the LFP and NMC processes are not interchangeable and require different precursor synthesis procedures and calcination conditions (Schmuch et al., 2018).

3.2.1 Next-Generation Battery Technologies

Innovation has been at the forefront of battery technology development, with a focus on increasing energy density, cycle life, stability, and safety characteristics. In LiBs, historic improvements in energy density have primarily been due to cell design and cathode material development. As the cathode technology improvement plateaus, there has been an increasing focus on improving the anode using silicon up to a limit. With an increase in specific capacity from silicon, lithium metal anodes are considered the highest-energy density material that can be used commercially. The next evolution after silicon anodes is expected to be lithium metal anodes and solid electrolytes (aka, "solid-state" batteries), but they will need to overcome technical and commercial barriers to scale up (IEA, 2024a).

Aside from solid-state batteries, sodium-ion battery technology development has accelerated over the last few years. Sodium-ion batteries use sodium cathode materials and hard carbons in the anode due to the incompatibility of sodium ions with graphite. Traditionally, Chinese companies have primarily driven the development of sodium-ion batteries at scale (Reid, 2023). Sodium-ion batteries have a lower energy density compared to LFP and NMC batteries, which results in a shorter range. Consequently, they are seen as a promising option for stationary grid storage applications. By 2030, there are plans for over 100 GWh of sodium-ion battery production, with the majority of this capacity being established in China (Benchmark Minerals Intelligence, 2023). In India, companies such as Reliance, KPIT, Indie Energy, Rechargion, and Sodion have been working on sodium-ion battery development.

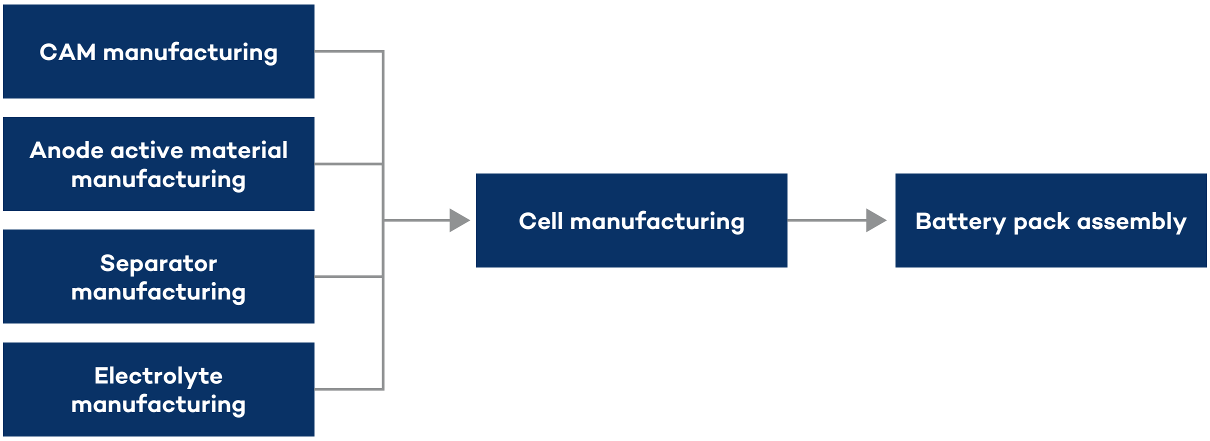
The Indian government has recognized the importance of emerging battery chemistries under the PLI-ACC scheme, which earmarks 5 GWh of cumulative capacity to be offered to niche ACC technologies of higher performance with a minimum threshold capacity of 500 MWh. This component would be technologically agnostic (IFCI Limited & MHI, n.d.). It is essential for India to also build cell fabrication and testing centres that can help in the commercialization of emerging battery technologies (Warrior et al., 2024).

4.0 Battery Components

4.1 Definitions

Battery cell production is the essential component of the battery value chain. It necessitates collaboration between OEMs and several interconnected value chains, including the manufacturing industry, where equipment manufacturers supply the required machinery; the materials value chain that encompasses mining, refining, and the active materials that serve as key ingredients for batteries; and other related industries and services (Porsche Consulting, 2024).

Figure 5. Components used in LiB manufacturing



Source: Author's analysis based on Warrior et al., 2024.

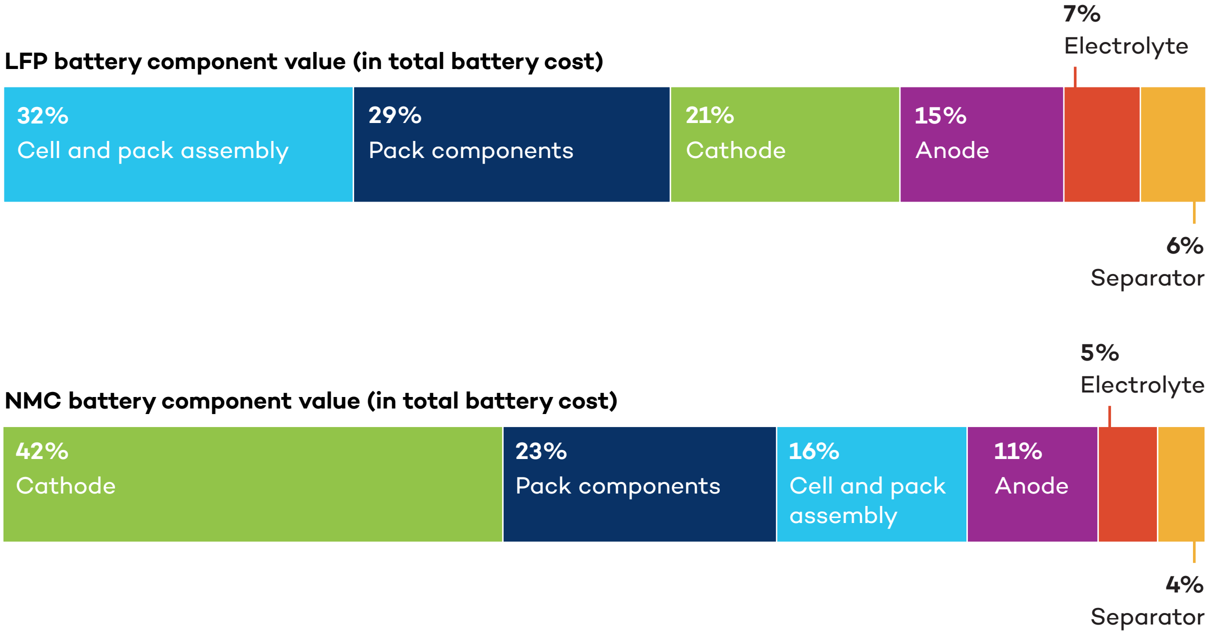
An LiB cell consists largely of four components that are processed into a cylindrical, prismatic, or pouch shape and encased in a shell with an aluminum or plastic casing. In addition, an LiB cell also contains cell casings, electronics, and other cell components.

Table 2. Battery cell components and cost breakdown

Battery component	LFP battery – Cost breakdown (%)	NMC 532 battery – Cost breakdown (%)
Cathode: The cathode is the positively charged electrode in a battery cell where reduction takes place during discharge. It determines the capacity and the average voltage of a battery. Cathode electrodes include CAM; inactive materials such as binders, solvents, etc.; and current collectors (i.e., aluminum foils)	21%	42%
Anode: The anode is the negatively charged electrode in a battery cell where oxidation takes place during discharge. There are several types of anodes, including synthetic graphite, natural graphite, and silicon-based graphite. Anode electrodes include anode active material; inactive materials such as binders, solvents, etc.; and current collectors (i.e., copper foils)	15%	11%
Separator: A membrane that separates the anode and cathode in a battery cell, allowing the flow of ions while preventing the electrodes from touching. A separator determines the safety of a battery and prevents the battery from short-circuiting and overheating.	6%	4%
Electrolyte: A substance (usually a liquid or gel) in a battery cell that conducts ions between the anode and cathode, completing the circuit and generating an electric current. It is usually made up of a lithium-based salt along with organic solvents and additives	7%	5%
Pack components: Monitoring and control equipment within a pack assembly adjusts electricity flow or provides interconnectivity.	29%	23%
Cell + Pack Assembly: Several cells are combined in a pack in order to provide charging and discharging potential to a device and integrate with the device's electrical needs.	32%	16%

Source: NITI Aayog et al., 2022b.

Figure 6. Cost breakdown of components for LFP and NMC batteries



Source: NITI Aayog et al., 2022b.

4.2 Global Production

The production of battery components is highly concentrated both geographically and within a small number of companies.

Cathodes

Globally, around 90% of CAM production takes place in China, followed by South Korea and Japan (IEA, 2024b). Moreover, only seven companies produce 55% of global cathode capacity. Overall, the leading cathode producers are Tianjin B&M Science and Technology and Shenzhen Dynanonic in China and Sumitomo in Japan (IEA, 2022). In India, Altmin has started LFP CAM production at a pilot scale and has announced plans to construct a commercial-scale facility with a production capacity of 18,000 tonnes per annum. In addition, Himadri Speciality Chemicals has announced plans to produce 200,000 tonnes per annum of LFP CAM in phases over the next 5–6 years (Autocar Pro News Desk, 2023).

Anodes

Global anode production is highly concentrated, with 97% of capacity based in China and just 3% in South Korea (IEA, 2024a). Four companies dominate the market, producing over 50% of global anode capacity. The largest producers are three Chinese companies: Ningbo Shanshan, BTR New Energy Materials, and Shanghai Putailai New Energy Technology (IEA, 2022). Japan also plays a significant role in the industry, with key suppliers including Hitachi Chemical, JFE, Mitsubishi Chemical, Nippon Carbon, and Nippon Steel. In India, three companies—Epsilon Advanced Materials, Himadri and HEC TACC—have expertise in manufacturing synthetic graphite using coal tar-based feedstock to produce precursor anode materials for global customers in China, Japan, and Europe (Moerenhout et al., 2023).

Electrolytes

Global electrolyte production is heavily concentrated in China, with the top three lithium hexafluorophosphate producers ($LiPF_6$)—Tinci, DND, and Tonze—capturing 80%–90% of the global market share (Daiwa Capital Markets, 2024). In India, Neogen has signed an agreement with MUIS, a Japanese company, to acquire a technology licence to produce electrolytes in India (The Hindu Bureau, 2023). In addition, GFCL, another Indian company, is planning to produce electrolyte salts for LiBs.

Separators

The global separator market is relatively fragmented; however, Asian companies have the major share of the market, with over 90% of the production base in China, Japan and South Korea. Some of the key players include Entek, SK Innovation, Toray, Asahi Kasei, and Sumitomo Chemical Co. Ltd (Daiwa Capital Markets, 2024). Neogen, an Indian company, has signed an agreement with noco-noco, an international company based in Singapore, to manufacture battery separators in India (noco-noco Inc., 2024).

4.3 Supply Chain Challenges

Understanding supply chain challenges and the role that government policy can play in addressing supply chain constraints will be critical to stimulating the greater localization of battery cell manufacturing in India. In this section, we have summarized the key challenges identified in our consultations with OEMs, cell and component manufacturers, and equipment suppliers.

4.3.1 Skilled Labour Shortages

Several Indian companies that we interviewed highlighted a lack of skilled workforce trained in research and development (R&D) and advanced battery manufacturing processes as a major constraint in localizing battery component production in India. They mentioned that the lack of qualified personnel had led to a dependence on foreign workers and that the dearth of skilled manpower was felt across several domains, from raw material development and cell manufacturing to battery management systems. In addition, a major Indian cell manufacturer specifically highlighted the absence of battery cell designers in India, who play an essential role given the microscopic detail needed to develop LiB cells.

A few companies across the battery supply chain that were interviewed also highlighted the intense competition for existing talent across the industry, which is leading to increased wage demands and a high rate of employee attrition. The impacts of skilled labour shortages on India's cell manufacturing ambitions also lead to other challenges, including

1. **Increased safety risks:** In specialized battery component operations, a shortage of skilled workers can lead to higher safety hazards, such as accidents and injuries due to inadequate training and supervision.

2. **Reduced productivity:** The lack of skilled labour can hamper productivity in battery cell production. Without experienced personnel, meeting project deadlines and maintaining quality output may become challenging for companies.
3. **Missed innovation opportunities:** Skill gaps can lead to missed opportunities for innovation and growth, thereby impeding the competitiveness of Indian companies and their ability to expand operations or adapt to dynamic market conditions.

In interviews, local cell manufacturing companies indicated that although there is an often-discussed need for collaboration between government, industry, and academia to overcome the skill gap problem, it is essential to overcome this challenge in the short to medium term, given the length of time needed to train engineers in advanced battery technologies. A battery component manufacturer mentioned that training engineers to work with LiBs can take up to 18 months, and there is a need to explore faster and more innovative training approaches, such as apprenticeship programs.

India's advanced technical universities and engineering schools can provide the workforce to support the country's ambitions in the battery supply chain. However, to unlock this potential, universities need to establish dedicated courses on the battery supply chain. For example, China developed an action plan on energy storage for undergraduate majors and cross-disciplinary education from 2020 to 2024. It recently reaffirmed this commitment by introducing several courses on advanced technologies in undergraduate majors to upskill its workforce (British Council, 2020, 2024).

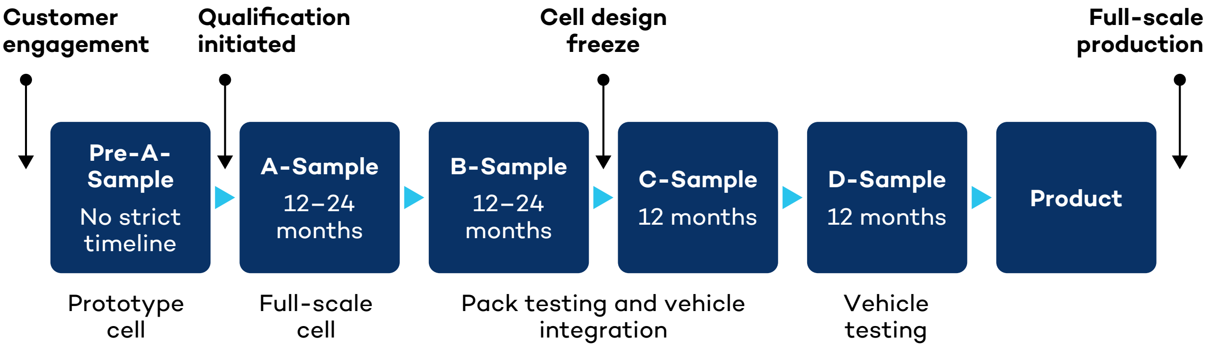
There is a need for more dynamic collaboration between companies and universities to quickly expand the talent pool and foster more investment into R&D. A study by the Society of Indian Automobile Manufacturers found that India will need to double its current EV workforce and create 60 automotive R&D centres by 2030 to meet industry needs (ANI, 2024). It is essential for increased public and private investment in R&D to support innovation in a rapidly evolving sector. To put things in perspective, BYD, the world's largest EV producer, has around 110,000 technology and R&D employees (Reuters, 2024).

Many states have implemented skill-development initiatives and are providing subsidies, allowing companies to receive a monthly reimbursement for employee training. These programs are designed to address the shortage of skilled workers in the labour market. For instance, Karnataka plans to create EV skill-development centres that will provide technical training accompanied by stipends for workers to gain hands-on experience at EV manufacturing plants (Moerenhout et al., 2023). Meanwhile, Tamil Nadu intends to introduce EV engineering courses in collaboration with OEMs, which will offer internships for students (Ray et al., 2022).

4.3.2 Limited Raw Material Testing and Validation Centres

The development of battery materials and components involves particularly laborious qualification requirements that can be time-consuming and costly. Along with the lack of domestic access to processing or manufacturing technology available to Indian companies, it is emerging as a bottleneck that is affecting the pace of raw material development needed in EV battery cells. This process requires a significant level of investment in R&D testing and validation and for component manufacturers to work in close collaboration with end customers, such as battery makers and automotive OEMs, on qualification cycles going through various sampling stages—from Sample A to D stages lasting 4–6 years (see Figure 7). While sample testing during the first cycle of product development is an arduous process, the process cycle shortens as the relationship between product developers and consumers matures and moves to the next cycle of product development.

Figure 7. Lab-to-vehicle qualification timelines



Source: Frith et al., 2023.

Several companies that were interviewed highlighted that India currently lacks a comprehensive ecosystem for testing and developing raw materials specifically for EV battery cell production. This situation has resulted in LFP cathode active material powder produced in India being sent to international labs, including in countries like the United Kingdom and Japan, for material validation in battery cells (Garg, 2024).

Government agencies are undertaking efforts to develop testing ecosystems, but these will need to be strengthened. The limited availability of testing facilities with the capacity and capability for advanced battery technologies affects India's battery manufacturing plans. At present, two agencies provide testing services for EVs and their batteries—the International Centre for Automotive Technology (ICAT) based in Manesar and the Automatic Research Association of India (ARAI) based in Pune. As of May 2024, only one testing agency, Bharat Test House, is capable of testing advanced battery cells. A newspaper article highlights that the MHI has urged ICAT and ARAI to receive accreditation to be eligible to test battery cells under the PLI-ACC scheme (Kumar, 2024). The National Testing House has plans to open testing centres in Mumbai and Kolkata and recently commenced the construction of an EV battery and charging facility in Bengaluru (DHNS, 2024; Sarkar, 2022).

Companies also highlighted their inability to collect and analyze performance data related to cell development using raw materials, hindering long-term product validation and highlighting the need for state-of-the-art testing centres and laboratories alongside a skilled labour pool, including trained scientists in the public sector. It is imperative that more testing centres are opened and existing centres strengthened for the development of battery cells that are well suited for the Indian market. Public and private sector investment is crucial, as well as a collaborative approach between battery makers, OEMs, and state-and central-level governments in setting standards for testing, product development, and innovation, as well as shortening the life cycle of product commercialization while maintaining quality and safety standards.

4.3.3 A Lack of Access to Critical Minerals and Processing Technology to Produce EV Battery Components

India currently relies heavily on imports for critical battery raw materials like lithium, cobalt, graphite, and nickel. This dependence exposes the industry to price fluctuations and potential supply disruptions. An Indian battery company that was interviewed highlighted that the heavy reliance on imported raw materials makes cost competitiveness a challenge for them. This not only increases production costs but also makes India vulnerable to external factors beyond its control. India could mitigate some of this risk by prioritizing LFP batteries, which do not require nickel or cobalt. Many interviewees considered LFP batteries as potentially the strongest choice for India, specifically since India produces 100% (and more) of its domestic iron ore demand (Ministry of Mines, 2023). However, India will still need to depend on imports of lithium and phosphoric acid from international sources. LFP batteries can bring additional benefits, such as lower cost—32% cheaper than NMC—and beneficial performance characteristics, such as a longer life cycle and improved thermal stability (BloombergNEF, 2023; Warrior et al., 2024).

Graphite is the dominant material used in anodes and can either be found naturally or produced synthetically. Natural graphite mining is dominated by China (80%) (IEA, 2022), but global production is becoming more diversified as countries localize production for EVs. Currently, Indian companies, such as Epsilon Advanced Materials, Himadri Speciality Chemicals, and HEG Limited, have expertise in manufacturing synthetic graphite from coal tar-based feedstock and exporting precursor anode material to China, Japan, and Europe. This means that international cell manufacturers have the option of looking to India for diversified anode material suppliers. At the same time, Indian companies will need to undertake significant efforts to produce the 99.95% pure, spherical, battery-grade graphite that is needed for anodes (Warrior et al., 2024).

Ensuring access to processed minerals for local suppliers (e.g., cathode and anode manufacturers) will become increasingly important, and India currently still lags on securing their critical mineral supply chain compared to countries such as China, the EU, the United States, and Indonesia. As a result, the national government has announced several initiatives over the past year, including launching India's critical minerals list, creating a new National Critical Minerals Mission within the Ministry of Mines, and supporting international collaboration through participation in the U.S.-led Mineral Security Partnership.

India should pursue increased collaboration with industrialized countries through trilateral partnerships with resource-rich countries, which can result in mutually beneficial partnerships. The recently announced *Roadmap for U.S.-India Initiative to Build Safe and Secure Global Clean Energy Supply Chains* specifically highlights building trilateral partnerships with African partners on clean energy deployment as a key priority. This could extend to critical minerals since many African countries are looking for investment from international partners, while U.S. agencies can provide low-cost financing and technologies for refining critical minerals

(U.S. Embassy & Consulates in India, 2024). In the 2024/2025 financial budget, India's Central Government has exempted 25 critical minerals from customs duties, including battery metals such as cobalt, copper, and lithium. It has also reduced the basic customs duty on artificial and natural graphite (Choo, 2024). These measures will support the development of a midstream battery industry by likely lowering the cost of inputs used in producing cathode and anode active materials. Furthermore, India's state-owned company, Khanij Bidesh Limited (KABIL), is engaging with key mineral producers such as Australia, Argentina, Bolivia, and Chile for joint exploration and production of critical minerals. KABIL signed a Memorandum of Understanding (MoU) with Australia that outlines a detailed collaborative framework for India to invest in lithium and cobalt assets in Australia. The Central Government has also undertaken bilateral engagements in Latin America. For example, in 2022, the government signed an MoU with Argentina, with a focus on critical minerals, such as lithium (Ministry of Mines, 2023).

4.3.4 A Lack of Recycling Infrastructure

India currently lacks a robust LiB recycling infrastructure. This necessitates a reliance on virgin materials, further straining the supply chain and raising environmental concerns. Aside from reducing mineral dependence, a local battery cell manufacturer highlighted in an interview that providing recycling guidelines for cell manufacturers can help mitigate environmental hazards, given the carcinogenic nature of CAM. It can also address concerns about LiBs being dumped in landfills. Environmentally friendly recycling technologies that require less water and energy consumption need to be developed to reduce impacts on health and the environment.

Given the unavailability of critical minerals in the near term, India should pursue battery recycling and urban mining. As 90% of lithium, cobalt, nickel, manganese, and graphite are recoverable, urban mining can help reduce dependence on raw minerals in the medium term (Moerenhout et al., 2023). Collectively, India's battery recycling capacity currently stands at 44,000 tonnes (Benchmark Source, 2024). According to estimates by NITI Aayog, the expected growth of new batteries would create a recycling volume of 128 GWh by 2030, of which around 46% will come from EVs. This means that current recycling capacities would need to increase significantly to meet future demand (NITI Aayog & Green Growth Equity Fund Technical Cooperation Facility, 2022).

The Indian government notified the Battery Waste Management Rules in 2022, which mandate extended producer responsibility and tracking mechanisms for batteries. They include several measures, such as 1) extended producer responsibility mandates for battery companies with penalties for non-compliance; 2) minimum recovery rates from used batteries—70% in 2024/2025, 80% in 2025/2026, and 90% from 2026/2027 onwards; and 3) recycled content targets for new batteries. Despite its positive intent, a well-defined strategy is needed to collect, segregate, and recycle used batteries to effectively implement the 2022 Battery Waste Management Rules. One option to bolster traceability is to consider implementing the battery passport initiative. The initiative, launched by the Global Battery Alliance, aims to increase transparency across the supply chain by creating a "digital twin of the physical battery that conveys information about all applicable sustainability and lifecycle requirements based on a comprehensive definition of a sustainable battery" (Global Battery Alliance, n.d.). Under the Sustainable Batteries Regulation, the EU will be mandating the adoption of a battery passport by February 2027.

Interviewed experts highlighted the need for greater coordination between state and central governments, as well as public awareness campaigns to support used battery collection (PIB, 2022b). In addition, according to Gulia et al. (2022), "various states have announced incentives for battery recycling in their respective EV policies." Concepts such as battery leasing—where the battery is returned at the end of the lease period and the onus to repurpose and recycle lies with the manufacturer—are also already coming up (Moerenhout et al., 2023). Experts suggested that mandates for on-site recycling at gigafactories and PLI incentives are needed to scale up India's battery recycling industry.

4.3.5 The Need for ESG Standards to Boost Export Competitiveness

As India seeks to attract investment from global multinationals to the country and also support its domestic cell manufacturers in exporting to markets like the United States and the EU, ESG factors will become crucial in determining investment decisions and export competitiveness. Multinational corporations, particularly those based in Europe and the United States, are facing stricter ESG regulations concerning their supply chains and production practices. This shift has significant influence over their investment decisions. For instance, the EU's new Sustainable Battery Regulation includes mandatory carbon footprint reporting for batteries, as well as supply chain due diligence requirements (Kupferschmid, 2023). India must adopt clearer ESG guidelines and targets, as well as establish robust reporting frameworks to enhance its export competitiveness in the battery sector (Moerenhout et al., 2023).

A scientist conducts research at Log9 Materials. (Shawn Sebastian/Drokpa Films)

Companies involved in mineral processing and battery cell manufacturing are actively seeking renewable energy sources to sustainably power their energy-intensive operations. This shift toward renewable electricity is particularly vital for those aiming to comply with ESG standards, which provides an opportunity for India to leverage its renewable energy resources (Moerenhout et al., 2023). In 2022, the Indian government streamlined access to clean energy for small industries and commercial consumers by implementing the Green Open Access Rule (PIB, 2022c). Several states have already adopted these regulations. The government can further foster the development of low-carbon manufacturing processes by offering tax incentives and increased PLI-ACC subsidies for companies that adopt environmentally friendly production processes in battery manufacturing. Although adopting these practices may increase costs, it will help Indian companies access low-cost international financing and find new sources of competitive advantages in the medium-to-long term.

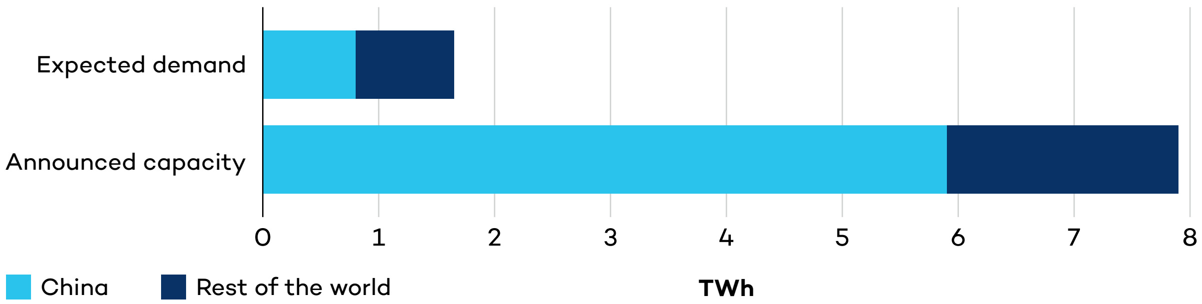
4.4 Geopolitical Challenges

The Russia–Ukraine war and COVID-19 pandemic have underlined the fragility of global supply chains and the need for policy-makers to build greater resilience by diversifying the manufacturing locations of batteries and components. With the effects of climate change becoming more visible and trade-related tensions rising, it has become essential for companies to set up diversified supply chains, opening an opportunity for India. However, to fully capitalize on these shifts in global supply chains, India will have to navigate a few geopolitical challenges, including (i) China's dominance in the battery supply chain, (ii) resource nationalization in mineral-rich countries, and (iii) localization policies by industrialized economies.

China currently dominates the battery supply chain and is the primary supplier of processed minerals, cathodes, anodes, and cells. As India seeks to build its domestic EV batteries energy industry, it must navigate this tension of relying on China and Chinese companies to kick-start its battery cell industry in a way that reduces systemic risk and vulnerability by investing in local R&D and supporting its companies in localizing cell and equipment manufacturing.

China is currently grappling with significant overcapacity across the battery supply chain, which makes it more challenging for Indian companies to compete in a saturated market. According to BloombergNEF, LiB demand across EVs and stationary storage was around 950 GWh in 2023, whereas global battery manufacturing capacity was more than twice that, at close to 2,600 GWh (McKerracher, 2024). They also forecast that this demand-supply mismatch will continue to rise by 2025, putting new investments around the world at risk.

Figure 8. Announced LiB manufacturing capacity and expected demand in 2025



Source: BloombergNEF, 2024.

The most significant recent Chinese policy was an announcement in December 2023 of restrictions on the export of battery-grade graphite, a key mineral used in battery anodes, which has created vulnerabilities in several countries, including the United States (Tabeta & Kawate, 2023). An interviewed Indian cell manufacturer mentioned that the restrictions have had an impact on their operations since they now require additional approvals to source graphite from China for anodes, thereby creating delays. The manufacturer highlighted that companies require a constant, timely source of raw materials. Gigafactory operations cannot be temporarily ceased since impurities may enter the production process.

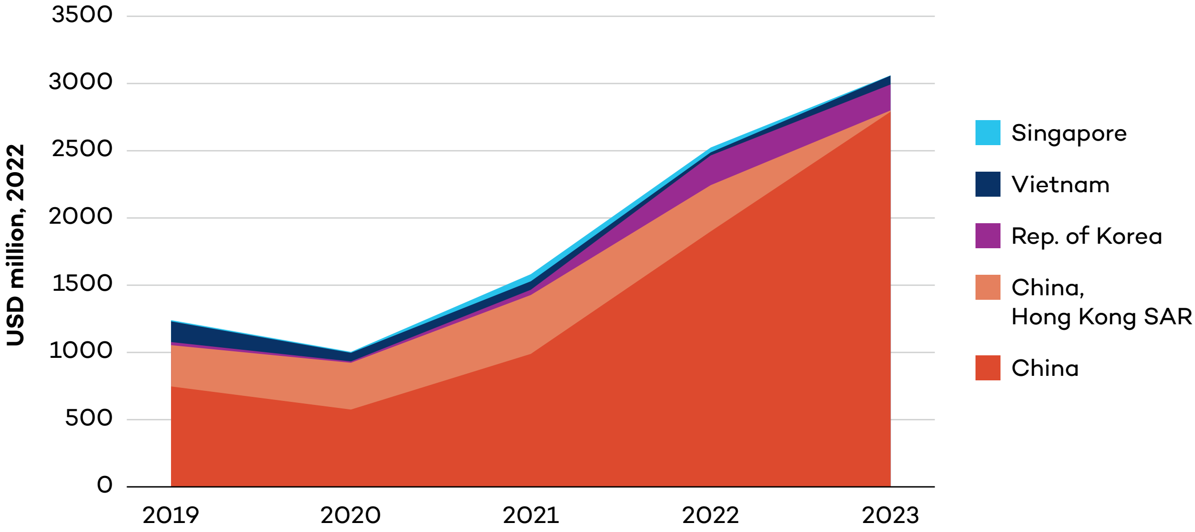
Aside from restrictions by China, the geographic concentration of critical minerals supply provides high levels of geopolitical and economic leverage to existing mineral-rich countries. Major upstream suppliers, such as Chile, the Democratic Republic of the Congo, and Indonesia, are using their market power to attempt to capture more value from production. This has resulted in policies that mandate increased state participation in the mining industry, such as Chile's new national lithium strategy to direct export bans and Indonesia's recent ban on the export of unprocessed nickel. In practice, these moves have resulted in increased sourcing and pricing uncertainty for importing countries, such as India. One way to mitigate these risks is to prioritize battery chemistries with a lower reliance on imported minerals, such as LFP batteries. Additionally, India can pursue more state-to-state collaborations with these countries by supporting KABIL in its sourcing efforts through broader investment and trade agreements.

The importance of localizing battery production and the risks of disruption are leading advanced economies to enact a range of new industrial policies. In the United States, for example, the most important policy is the IRA, a piece of legislation that focuses on a much broader build-out of the clean energy industry. Likewise, in Europe, the Critical Raw Materials Act has been paired with the Net Zero Industry Act and is a piece of the larger Green Deal Industrial Plan. India's early efforts to build its own battery supply chain will face the challenge of competing with industrial policies from other advanced economies in attracting investment from large OEMs and battery producers. However, it could also lead to new opportunities for India since industrialized economies will be on the lookout for partnerships with like-minded nations to overcome inherent cost disadvantages. Pursuing new trade and investment partnerships and strengthening existing bilateral agreements with these countries should be a key priority for India.

4.5 Trade and Supply Chain of Battery Components

The supply chain of battery (cell) components is poorly tracked, and available Harmonized System (HS) codes for tracking trade flows often include other components. This analysis is thus limited by the lack of sufficiently detailed publicly available trade data and is based on groupings of materials relevant to cathodes, anodes, separators, and electrolytes undertaken by the Critical Materials Monitor. The data for LiBs and battery cells is exclusively for LiBs but is not exclusively used in EVs.

Figure 9. India's lithium-ion battery and cell imports



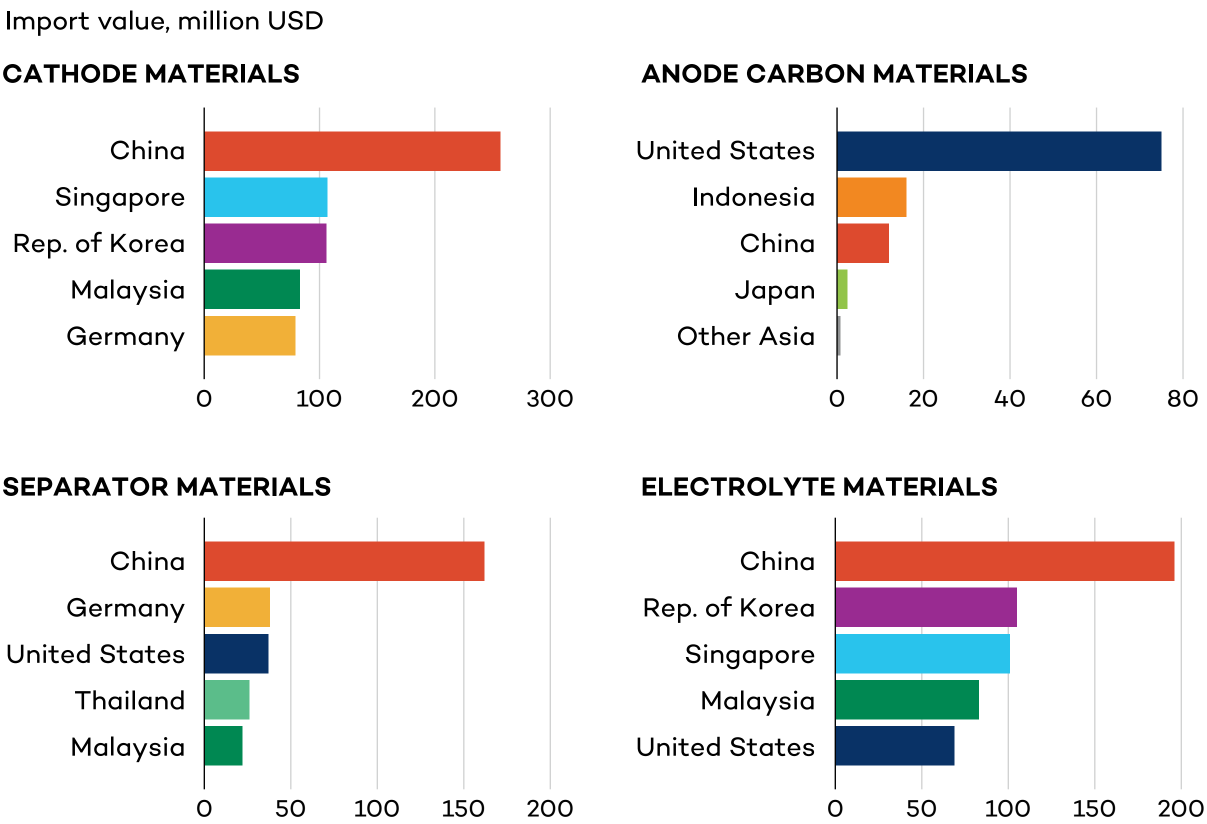
Source: UN Comtrade Database, 2024 (HS code, 850760).

With respect to Lithium-ion batteries and cells, India remains heavily reliant on China, with imports in 2023 totalling around USD 2.79 billion. The second source of imports is South Korea, with around USD 193 million in lithium-ion batteries and cells. Thus, in the short term, India is likely to remain reliant on China for lithium-ion cell imports, even if those cells are assembled into battery packs within India, until local cell production scales up in the country. A study by the Council on Energy, Environment and Water has found that India has started to increase its exports of fully assembled LiBs to key automotive hubs, such as Germany and Japan (Warrior et al., 2024). LiB exports increased from around USD 80 million in 2022 to USD 120 million in 2023, with potential room for further growth (Warrior et al., 2024).

With respect to battery components, the picture is not very different. For cathode, separator, and electrolyte materials, China is the number one source of Indian imports, far ahead of other countries (see Figure 10). This is different for anode materials, but graphite data likely does not represent anodes well, given that China controls 97% of synthetic graphite anode material production and 79% of natural graphite anode material production, followed by South Korea (13%) and Japan (8%) (Benchmark Source, 2023).

With respect to non-China trade partners, there are possibilities for increased engagement with existing partners, specifically South Korea, which is an important supplier of cathode and electrolyte materials to India. Another notable regional partner is Malaysia, where India has an existing Comprehensive Economic Cooperation Agreement (Ministry of Investment, Trade and Industry, n.d.). Similar to equipment and machinery, it is also advisable for India to deepen engagement with partners in the Minerals Security Partnership, such as Germany and the United States, since they also supply significant amounts of material to India (see Figure 10).

Figure 10. Top five sources of battery component imports to India, 2022



Source: Columbia University Center on Global Energy Policy, n.d.; UN Comtrade Database, 2024.

4.6 Localization Potential of Cell Components in India

Based on the analysis undertaken in this study and key parameters, we have developed a framework to assess the localization potential of EV battery cell components in India.

Table 3 provides a broad overview of the localization potential of different battery components based on the methodology highlighted below. This is mainly indicative and is designed to support prioritization by policy-makers. It is not intended to be an exhaustive or exclusive list. Based on this analysis, India should prioritize the localization of synthetic anodes, electrolytes, and cell casings and pouches, given existing domestic capabilities, cost competitiveness, and low intellectual property/tech reliance. At the same time, it should continue focusing on localizing cathodes, particularly LFP cathodes, since they constitute the largest value of a battery cell.

Table 3. Localization potential of cell components in India

Component	Dependence on imports	IP/tech reliance	Cost competitiveness	Existing local companies	Overall localization potential
Cathode	High	High	Low	Low	Medium
Anode	High	Low	High	Medium	High
Electrolytes	High	Low	Medium	Medium	High
Separators	High	High	Medium	Low	Medium
Cell casings and pouches	Medium	Low	High	Medium	High

Source: Authors.

Methodology:

Low: a) No. of existing domestic companies: 1–2; b) Capacity/Scale: less than 50 ktpa; c) Feedstock: very high reliance on imports.

Medium: a) Number of existing domestic companies: between 2 and 4; b) Capacity/scale: 50 to 100 ktpa; c) Feedstock: reasonable reliance on imports.

High: a) Number of existing domestic companies: more than 4; b) Capacity/scale: more than 100 ktpa; Feedstock: limited reliance on imports.

5.0 Machinery and Equipment

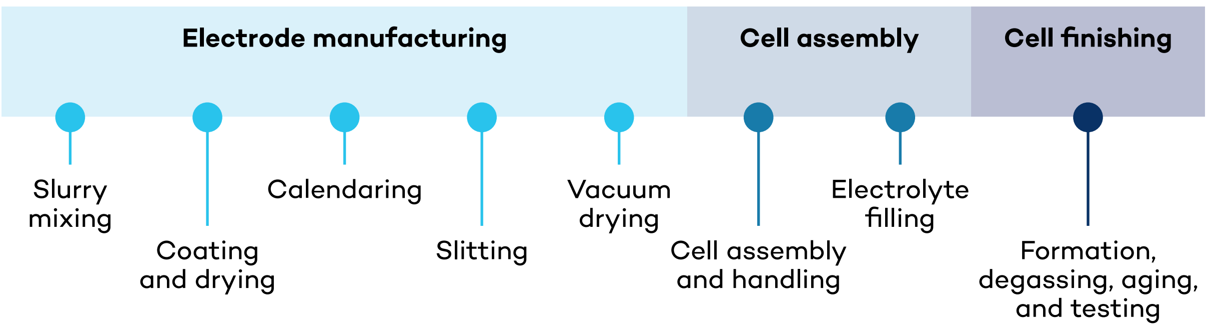
Companies and policy-makers are very focused on addressing raw material-related challenges in localizing battery cell production. However, companies can encounter other supply chain bottlenecks when building EV battery factories, particularly shortages of key equipment and machinery that are used in cell production. International experiences demonstrate that equipment and machinery shortages can be a real concern for companies in meeting their production and expansion targets.

Most famously, Tesla in 2018 had a shortage of battery manufacturing equipment at its Nevada Gigafactory, which meant it had to redesign some of its production lines as it lost out temporarily on vehicle output (Taylor & Sage, 2018). A McKinsey & Company analysis found that for battery-specific equipment, lead times of 1.5 years from ordering to commissioning are common because of the rapid growth in gigafactory construction, with some OEMs securing critical equipment 3 years in advance of commissioning (Breiter et al., 2022). Machinery and equipment constitute around 22.9% of the cost of LiB cells, making it essential to localize their production and vital to understanding supply chain challenges for equipment and machinery production in India (Gulia et al., 2022).

5.1 Definitions

Cell manufacturing differs slightly based on battery chemistry but generally involves several key steps. It begins with mixing active materials to form a slurry, which is then coated onto a collector foil and dried. After the electrodes are dried, they are compacted and cut before the cells are assembled, tested, and graded. Finally, these cells are put together into battery packs for battery EV manufacturers and stationary energy storage system providers (Porsche Consulting, 2024).

Figure 11. Cell manufacturing equipment across the EV value chain



Source: Breiter et al., 2022.

We have described some of the key equipment and machinery used for battery cell manufacturing and their functions in Table 4. It mainly covers key equipment used in cell manufacturing to identify the potential for localization.

Table 4. Key equipment used in cell manufacturing and its function

Equipment/machine	Function
Raw material feeding and mixer	This is an essential process to ensure the desired composition of the electrode slurry making. The raw material feeding machine feeds the raw material to the mixer, the function of which is to create a homogeneous mixture of input raw materials. This is considered one of the most critical parts of cell manufacturing, where any mishaps can lead to a failure of the batch output.
Coating machine and electrode drying oven	A uniform coating of slurry has to be applied to the current collectors in order to achieve the desired performance of the final cells produced. This is immediately followed by a long period in the drying oven to ensure that the slurry coated is completely devoid of any solvent by the time the electrode comes out of the oven.
Calendaring machine	The calendaring process is done to even out the thickness of the coating and increase the density of material loading on the current collectors. It works on the principle of two drum rolls applying pressure as the electrode moves between the drum rolls. It is a very sensitive operation and the pressure applied must be highly accurate to achieve a uniform thickness throughout the electrode roll.
Slitting machine	The electrode roll (mother coil) is slit into daughter coils as per the desired electrode design for the individual cell to be produced. During the slitting process, there are three considerations: (i) achieving the right dimensions, (ii) ensuring no residue from the slitting process comes on the electrode, and (iii) ensuring there is no burr formation on the edges of the electrode that can later damage the separator while assembling the cell and also lead to cell internal short circuit.
Electrolyte filling machine	This is a critical part of cell manufacturing—filling is done in the cell in the most controlled environment with a very low dew point temperature and very low relative humidity. The machine should also be able to fill the electrolyte liquid with accurate measurement.
Cell formation machine	This is the first electrical process applied to the cell wherein a small increasing power is applied to the cell to charge it for the first time. This process is also called cell activation. Machines used here can have only a charge function.
Electrode tab welding machine	The basic process of welding a homogeneous metal tab on the current collector.
Winding/Z-stacking machine	The winding process applies to cylindrical and prismatic cell types, and the Z-stacking process applies to pouch and prismatic cell types. These processes combine the electrodes and the separator(s) to form a jelly roll, which will go inside an individual cell.
Process machine for jelly roll insertion in cell case/can	As the cylindrical pouch and prismatic form factors are different, the machines to put their respective jelly rolls inside their case can/will be different. The processes are also different.

Equipment/machine	Function
Vacuum oven drying	The cells are placed in a vacuum-based oven to remove any moisture before it goes into the process of electrolyte filling. Typically, the cells sit for a few hours.
Cell aging under observation	This process involves storing the cell in high-temperature rooms that are controlled in normal and high temperatures at different stages. They use temperature-controlled equipment.
Cell capacity grading	This machine is similar to the formation machine but also has a discharge function. The current rating may vary compared to the formation machine.
Cell DC internal resistance and AC internal resistance machines	These machines measure the internal resistance of the cell using DC current and AC current.
Cell open circuit voltage sorting machine	This process is used to study the open circuit voltage of the cell at various levels of observation. This result is also studied at a minimum of three decimal values.
Dry room dehumidifier	As a major part of dry room infrastructure, it is responsible for maintaining the humidity level in the dry room of the cell manufacturing unit.
Dry room wall panels	These panels are similar to those regularly used in the pharmaceutical industry and solar cell manufacturing.

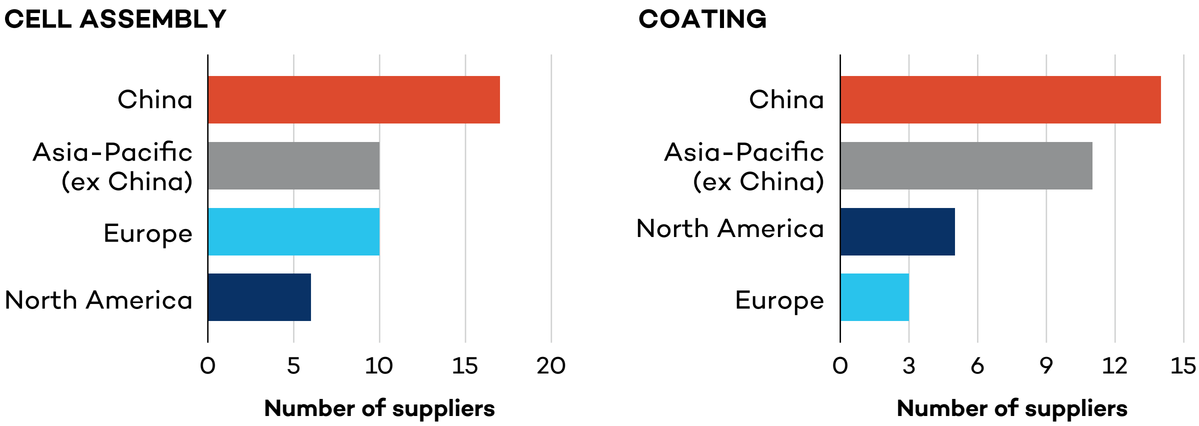
Source: Authors.

5.2 Global Production

Most EV battery cell equipment companies are in China, Japan, and South Korea. A study by Porsche Consulting estimates that Asia holds a 92% market share in battery manufacturing equipment, while Europe only has 8% of the global market share (Porsche Consulting, 2024). Despite Asia's dominance, a McKinsey & Company analysis found that most of these incumbent battery cell manufacturing and equipment suppliers are operating at more than 95% capacity, leaving little room to increase output (Fleischmann et al., 2022). The study mentions that "they may prioritize orders from established customers (mostly leading incumbent cell manufacturers) over those from new market entrants" (Fleischmann et al., 2022).

India battery cell manufacturing companies and EV OEMs that enter this sector may face bottlenecks in securing key equipment that could place their planned start of production at risk. Therefore, increased localization of battery cell equipment should be a key priority for the Indian government.

Figure 12. Key equipment suppliers by region



Source: Fleischmann et al., 2024.

5.3 Supply Chain Challenges

India currently relies on importing advanced battery manufacturing equipment and technology (See Section 4.4, Geopolitical Challenges). This import dependence restricts domestic innovation and limits the ability of companies to adapt to rapidly evolving technologies. An interviewed domestic battery producer emphasized the need for technology transfer and collaboration to accelerate innovation. Given the speed at which battery technologies are evolving, India risks falling behind in the global race to develop next-generation batteries without access to cutting-edge technology and equipment.

Another major concern is linked to battery and component performance in the extreme temperatures of the Indian subcontinent, which makes it essential to adapt technologies for their use in local conditions. In an interview, a local battery manufacturer acknowledged India's reliance on technologies from established players and highlighted the challenge of adapting technologies to the Indian environment and integrating them with new equipment.

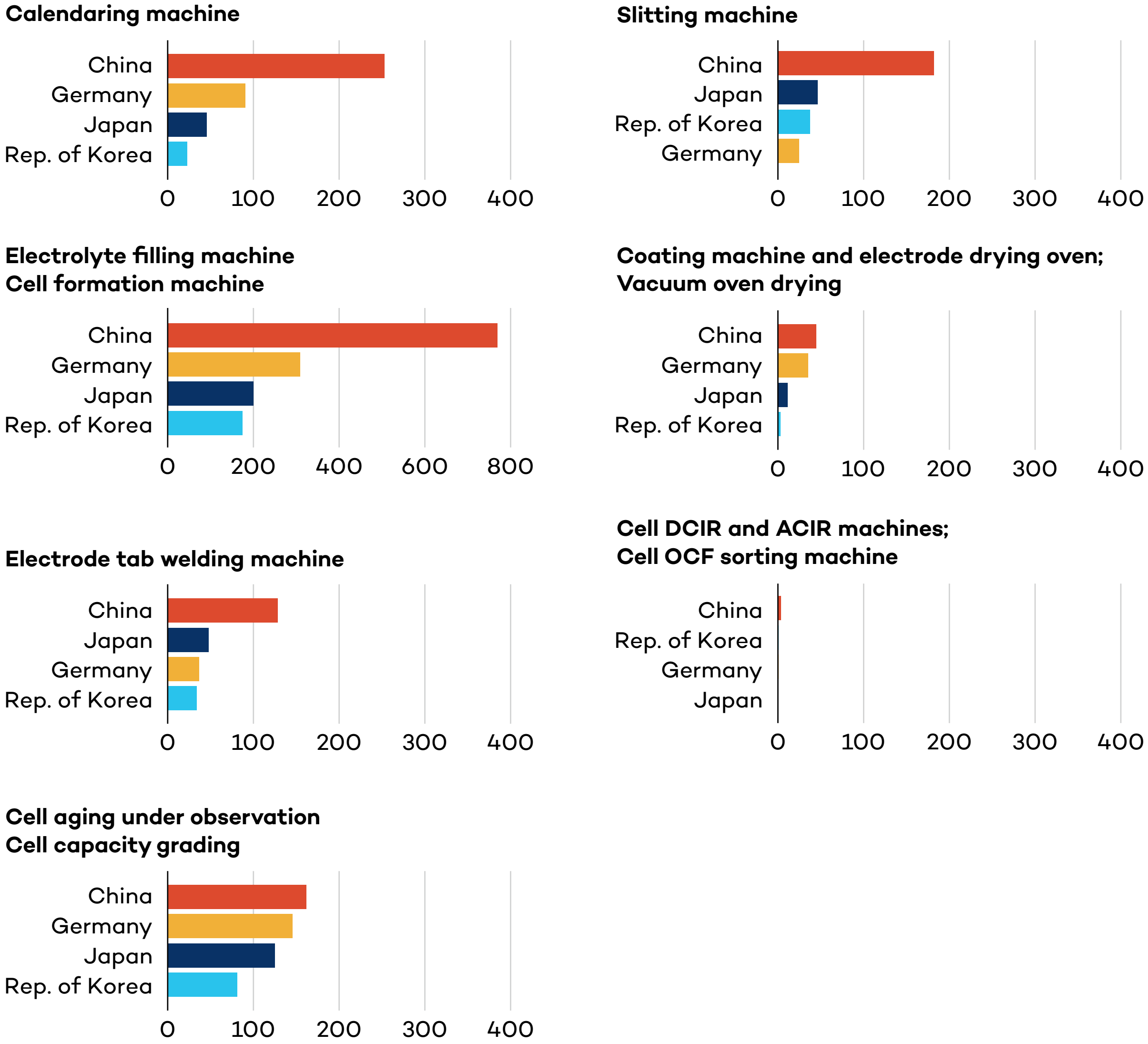
Aside from technologies, cell manufacturers highlighted the importance of ensuring high-quality standards for equipment and machinery that are used in cell manufacturing, which has made companies reliant on imports and vulnerable to price fluctuations and supply chain disruptions. An interviewed cell manufacturer stressed the importance of using high-quality equipment by cautioning that subpar equipment quality can significantly impact production efficiency and product safety. These challenges underscore the need for investments in domestic manufacturing of battery production equipment, strategic partnerships with established international players to access cutting-edge technologies, and setting up equipment testing centres to ensure local equipment companies can validate the quality of their equipment.

5.4 Trade Flows of Machinery and Equipment

Critical mineral processing and battery component manufacturing machinery and equipment are highly specialized, so trade flow data has limitations, in that it captures several types of machinery and equipment that are not used for those specific purposes. The HS codes used in this trade analysis are described in Annex A. This data can include other non-energy sectors as well, which poses significant limitations in interpreting it. Nonetheless, it does show several interesting results, such as:

1. India is highly reliant on a concentrated set of suppliers for key machinery and equipment used for mineral processing and battery component manufacturing. Specifically, the reliance on China for machinery and equipment is large. For all identified cell manufacturing machinery HS codes (except HS 903039), China is India's primary import partner. In total, imports from China amounted to USD 1.5 billion in 2022 alone.
2. India currently has trade partners in South Korea and Japan, among others, who already supply equipment. Both South Korea and Japan are free trade agreement (FTA) partners and have developed battery supply chain and equipment ecosystems. Both export significant amounts of machinery and equipment—for example, South Korea and Japan exported USD 353 million and USD 476 million, respectively, in relevant machinery and equipment to India in 2022.
3. India has potential partners that seek to diversify and strengthen supply chains in organizations such as the Minerals Security Partnership. It can also strengthen supply chain cooperation with key partners without an FTA, such as the United States and the EU. In the EU, Germany specifically has been a key trade partner for India, trading about USD 642 million in 2022 (details are highlighted in Figure 12).

Figure 13. Imports of key LiB machinery and equipment in India (trade value, USD million)



Source: UN Comtrade Database, 2024.

While Korea, Japan, and Germany individually do not come anywhere near China as key exporters of equipment and machinery, there is room for India to diversify machinery and equipment supplier countries. However, the cost implications of diversification will need to be considered in relation to the global competitiveness of domestic material, component, and battery cell manufacturing companies.

5.5 Localization Potential

Based on consultations with industry experts, we have highlighted the potential for the localization of key equipment and machinery used in battery cell production in India in Table 5 and detailed reasons in Appendix B of the report.

Table 5. Localization potential of equipment and machinery used in cell manufacturing in India

Equipment	Localization potential (high/medium/low)
Raw material feeding and mixer	Medium
Coating machine and electrode drying oven	Medium
Calendaring machine	Medium
Slitting machine	Low
Electrolyte filling machine	Low
Cell formation machine	Low
Electrode tab welding machine	Medium
Winding/Z-stacking machine	Low
Process machine for jelly roll insertion in cell case/can	Medium
Vacuum oven drying	High
Cell aging under observation	High
Cell capacity grading	Low
Cell DC internal resistance and AC internal resistance machines	Low
Cell open circuit voltage sorting machine	Low
Dry room dehumidifier	High
Dry room wall panels	High

Source: Authors.

6.0 Policy Recommendations

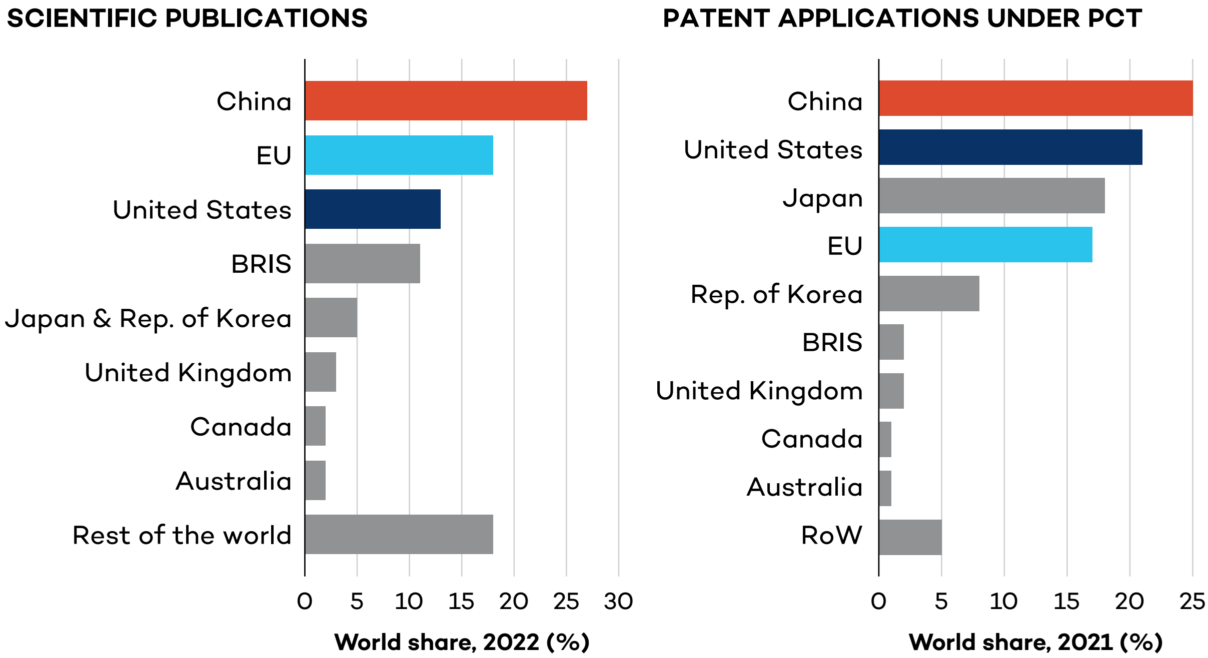
The national government's PLI-ACC scheme, state government policies and incentives, and demand-side deployment incentives have helped kick-start the growth of India's EV battery ecosystem. Accelerated investments and supportive regulations are crucial for India to become a competitive player in the rapidly evolving automotive supply chain and EV battery technology landscape. We have identified six strategic areas to improve investment attractiveness and unlock India's potential in battery supply chains.

6.1 Key Recommendations to Bolster India's Cell Manufacturing Landscape

1. Develop a supply chain ecosystem supporting innovation and material testing

Innovation is key to building competitiveness in advanced clean energy technologies. India lags behind those in China and advanced economies in both the share of scientific publications and the share of patents filed, as highlighted in Figure 14.

Figure 14. Global share of scientific publications and patent applications by country/region



Source: European Commission, 2024.
Notes: BRIS refers to Brazil, India, Russia, and South Africa; PCT refers to the Patent Cooperation Treaty.

It is essential for India to accelerate the innovation ecosystem through effective public investment and incentivize more private R&D spending. It can do so by

- establishing collaborative research platforms between government agencies, the private sector, and academia to coordinate R&D across the battery supply chain;
- increasing public funding for R&D dedicated to next-generation battery technologies, such as sodium-ion and solid-state batteries, advanced cell design, and technologies to facilitate their commercialization;
- establishing prototype cell fabrication and testing centres by partnering with international best-in-class institutions, which could support innovations from laboratories until commercialization;
- developing centres of excellence at academic institutes and government laboratories on battery cells that focus on technology innovation and shorten the product commercialization cycle; and
- accelerating technological advancements through university-led innovation challenges.

2. Upskill the labour force on battery cells, components, and recycling technologies

A lack of skilled workforce has emerged as one of the key constraints for companies investing in battery cell and component manufacturing. Overcoming this challenge will require greater collaboration among government, industry, and academia to develop dedicated courses and skilling programs on battery technologies and cell manufacturing. A few specific measures to address this gap include

- facilitating collaborations between Indian universities and colleges with global technology innovation centres (e.g., Fraunhofer, RWTH Aachen, Argonne National Laboratory, etc.) to train the workforce on battery cell technologies;
- developing an academic curriculum for undergraduate and graduate students that is aimed at specific segments of the battery supply chain—from upstream to downstream;
- developing centres of excellence in Indian technical universities that facilitate collaboration between industry and academia on skilling programs;
- rolling out targeted skill-development programs that are aligned with the specific needs of EV cell manufacturing companies through training institutes; and
- launching apprenticeship programs in collaboration with EV cell manufacturing companies.

3. Secure raw materials through domestic and international sources

India's reliance on imported raw materials makes cost competitiveness a challenge for Indian companies vis-à-vis international competitors. China's recent export restrictions on battery-grade graphite also underscores the need for diversification to mitigate trade risks. The government has taken several positive steps, such as streamlining regulations for domestic exploration, signing MoUs with mineral-rich countries, and creating a state-owned company, KABIL, to source minerals from overseas. A few specific measures to address this gap include

- streamlining the permitting and approval processes for domestic mining and processing plants while upholding high ESG standards;

- negotiating FTAs with potential consumer markets for Indian cell and precursor material manufacturers, such as a critical minerals agreement with the United States;
- providing incentives, such as a PLI scheme, which can help kick-start investments in the mineral refining segment; for example, the United States has provided a 10% production tax credit for its upstream and midstream sectors in the IRA;
- increasing collaboration with mineral-rich countries, such as in Africa and Latin America, through trilateral partnerships to unlock greater finance in mineral exploration and processing; and
- strategically stockpiling battery minerals during the ongoing low-price environment to further support India's efforts to secure its supply chain.

4. Leverage trade policies to benefit from external competitiveness

India is currently highly dependent on a few countries for the import of battery cells, components, and key equipment used in cell manufacturing. It is essential that India's trade policies focus on diversification and support the development of its nascent battery industry. India could undertake the following steps to achieve this:

- Negotiating FTAs with countries possessing critical mineral reserves or established battery technology expertise can secure reliable access to raw materials and advanced equipment at competitive prices.
- A carefully considered tariff policy on key materials, battery components, and cell manufacturing equipment that have the potential for localization until domestic companies achieve economies of scale and cost competitiveness. Existing tariffs should include sunset clauses to ensure companies focus on achieving export competitiveness.
- A push for technology transfer and licensing partnerships with established global battery technology players to support the build-out of battery gigafactories and EV manufacturing units and expedite domestic R&D efforts. For example, Chinese battery maker SVolt and Exide Industries have agreed on a multi-year technological partnership to develop LiBs for EVs in India.

5. Provide supply-side incentives to attract manufacturing investment

Given the intense global competition to attract investment from international OEMs and major battery producers in the battery supply chain to attract investment, India needs to provide a stable business environment. Interviewed local companies have mentioned that aside from the national PLI schemes (i.e., PLI-ACC and PLI-auto components), several state governments offer attractive subsidies, including tax exemptions, power and transport subsidies, and, in some cases, direct capital subsidies of around 20%, which make India competitive as a global investment destination. However, it is equally important to build awareness of these incentives among international investors and ensure that investment is flowing across the supply chain to cell components, equipment, and recycling segments. India can pursue this through the following steps:

- Incentives can be offered to companies investing in R&D related to EV battery technology to stimulate private sector participation and accelerate innovation.

- The localization of the EV cell supply chain can be encouraged through the use of a dedicated PLI scheme for raw material chemical processing—including cathode materials, anode materials, and battery components—that can help reduce dependency on imports and enhance the resilience of the overall ecosystem.
- Incentivize a circular economy ecosystem by enabling the recycling of scrap waste and end-of-life batteries to feed back into the battery value chain. For example, recycling battery waste would produce black mass (as a precursor), which could be effectively utilized to produce either critical minerals or CAM, feeding back to the system and reducing reliance on imports.
- India should consider adopting a battery passport initiative to bolster its recycling industry. The battery passport initiative is designed to store relevant data throughout the battery life cycle and is being rolled out by the EU in 2027.

6. Accelerate the growth of EV deployment through demand-side incentives and zero-emission vehicle mandates

Battery manufacturing in India is closely tied to India's EV deployment policies, since companies are often looking for a strong anchor market to locate their production. Although India has made progress in deploying e2w, e3w, and electric buses, it is still lagging behind leading jurisdictions in overall EV sales. The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME) scheme provided demand incentives for increasing the uptake of EVs in the country and ran from 2015 to 2024 in two phases. The national government has recently launched the PM E-DRIVE Scheme, with an outlay of INR 10,900 crore to provide incentives for electric two-wheelers, three-wheelers, commercial vehicles, and buses (PIB, 2024b). India can take some additional steps to bolster deployment, such as

- providing fiscal and non-fiscal instruments, as well as incentives for EV adoption in public transportation fleets, to create a sustainable market for EV batteries;
- providing access to priority sector lending for EVs under the Reserve Bank of India, which could unlock access to low-cost capital for EV battery manufacturing;
- strengthening Corporate Average Fuel Economy (CAFE) norms to encourage vehicle OEMs to increase the number of EV models in the market. The Bureau of Energy Efficiency, a government regulator, proposes carbon emission targets of 91.7 gm CO_2/km for CAFE-III from 2027 to 2030, and 70 gm CO_2/km for CAFE-IV from 2030 to 2032 (Mukherjee, 2024). These proposals would incentivize manufacturers to produce more EVs to avail of higher fuel efficiency credits;
- setting specific targets for fleet electrification to provide long-term demand signals to the industry; and
- lowering or exempting EVs from local taxes, including the Goods & Services Tax, could help unlock demand by lowering prices for end consumers.

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Appendix A. HS Codes and Descriptions for Key Battery Manufacturing Equipment

The supply chain of necessary machinery and equipment used in cell manufacturing is complex and poorly tracked. We have identified 10 trade flows of machinery and equipment that appear to capture the requirements for the mineral processing and battery supply chain as best as possible, as mentioned in this analysis. Note that these trade flows also include machinery and equipment used outside of battery industries.

Table A1. HS codes and descriptions for key battery manufacturing equipment

HS code	HS portal description	Target description
8455	Metal-rolling mills and the rolls used for them, as well as parts of these machines. It is part of Chapter 84, which covers machinery, mechanical appliances, electrical equipment, and parts	Calendaring machine
8462	Machine tools (including presses) for working metal by forging, hammering or die-stamping; machine tools (including presses) for working metal by bending, folding, straightening, flattening, shearing, punching or notching; presses for working metal	Slitting machine
8479	Machines and mechanical appliances having individual functions, not specified or included elsewhere in this chapter; parts thereof.	Electrolyte filling machine; cell formation machine
847981	Machines and mechanical appliances that treat metal, including electric wire coil-winders	Winding/Z-stacking machine
847982	Mixing, kneading, crushing, grinding, screening, sifting, homogenizing, emulsifying, or stirring machines	Raw material feeding and mixer
847989	Machines and mechanical appliances with individual functions that are not specified or included elsewhere in chapter 84 [of the HS]	Process machine for jelly roll insertion in cell case /can; dry room dehumidifier and dry room wall panels
8514	Industrial or laboratory electric (including induction or dielectric) furnaces and ovens (including those functioning by induction or dielectric loss); other industrial or laboratory equipment for the heat treatment of materials by induction or dielectric	Coating machine and electrode drying oven; vacuum oven drying
8515	Machines and apparatus that use electricity, lasers, or other light or photon beams for soldering, brazing, or welding; includes machines for hot spraying metals or sintered metal carbides	Electrode tab welding machine

HS code	HS portal description	Target description
903039	Instruments and apparatus for measuring or checking voltage, current, resistance or power, without a recording device (excluding multimeters), others	Cell DC internal resistance and AC internal resistance machines; cell sorting machine
903180	Measuring or checking instruments, appliances and machines, others	Cell aging under observation; cell capacity grading

Source: UN Comtrade Database, 2024.

Appendix B. Localization Potential of Cell Manufacturing Machinery and Equipment

The localization potential of battery cell manufacturing machinery and equipment, as well as their reasons, are entirely based on inputs from industry stakeholders.

Table B1. The localization potential for cell manufacturing machinery and equipment

Equipment	Localization potential (high/medium/low)	Reasons
Raw material feeding and mixer	Medium	There are other industries, like the pharmaceutical and food industries, that follow the same level of criticality. There is no special challenge in localizing this equipment in India.
Coating machine and electrode drying oven	Medium	It is possible to localize it, but the key component, the slot die, will likely need to be imported in the early stages of localization.
Calendaring machine	Medium	Careful attention is needed due to the sensitive nature of the electrodes.
Slitting machine	Low	There is a need to use high-precision and quality slitting tools, which might require imported blades.
Electrolyte filling machine	Low	A high level of equipment fine-tuning is needed, since improper fine-tuning can lead to electrolyte over-filling or under-filling, which will further lead to issues while closing the cell (cylindrical) and under-performance, respectively.
Cell formation machine	Low	Close attention to accuracy is required to activate the cell well. This machine is generally imported but can be localized with imported components.
Electrode tab welding machine	Medium	It is a fairly simple process, but the accuracy of the tab placement is crucial.
Winding/Z-stacking machine	Low	It can be challenging because the alignment of the electrodes and the separator must be highly accurate at a high pace.
Process machine for jelly roll insertion in cell case/can	Medium	Careful attention must be given to the handling of the jelly roll when inserting it into its respective case/can.

Equipment	Localization potential (high/medium/low)	Reasons
Vacuum oven drying	High	It is critical that the equipment be able to maintain consistent temperature and vacuum pressure.
Cell aging under observation	High	India is self-sufficient in making temperature-controlled equipment, so there is high potential.
Cell capacity grading	Low	High attention to accuracy is required. It can be localized with imported components.
Cell DC internal resistance and AC internal resistance machines	Low	This is very challenging to localize due to the need for high accuracy. However, some localization can be done by using imported critical components.
Cell open circuit voltage sorting machine	Low	This is very challenging to localize due to the need for high accuracy. However, some amount of localization can be done by using imported critical components.
Dry room dehumidifier	High	India's Bryair is a global leader in dehumidifier and desiccant rotor (a critical component of dehumidifier) manufacturing.
Dry room wall panels	High	A homegrown Indian company, Iclean, produces clean room/dry room panels that are preferred across the pharmaceutical and battery industries.

Source: Authors.

Published by the International Institute for Sustainable Development

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