



Accelerating India's ACC Component Manufacturing Ecosystem

October 2026



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22 September 2026

Foreword

Market Study Report on ACC Component Cost Disability

We are writing this foreword on 22 September 2026, the 10th World Energy Storage Day. Energy storage is now central to two of India's energy priorities: decarbonising the power grid and building sustainable mobility. India's progress on renewable energy over the past decade has been remarkable. In June 2025, non-fossil sources crossed half of the country's installed power capacity, five years ahead of the 2030 target in its Nationally Determined Contribution. As the share of solar and wind grows, storage is becoming the backbone that keeps the grid reliable. It is also a matter of national energy security, because batteries made in India, from materials processed in India, reduce dependence on imported fuels and on concentrated overseas supply chains.

India has put a substantial policy framework in place for cell manufacturing over the past five years. Cathode and anode materials, electrolytes, separators and battery-grade foils, however, make up the majority of the cost of a cell, and most of these materials are still imported. Building domestic capability in these components is the next step for both industrial competitiveness and energy security.

This report looks at each of these five components separately. For each one, it compares domestic manufacturing and capital costs with international benchmarks, maps manufacturing processes and raw material dependencies, and assesses the current level of localisation. The cost gaps appear to arise from different causes. In some cases it is raw material access, and in others it is conversion cost and capital intensity. This matters for policy, because support designed around one cause may not work for another. The figures will change as India's manufacturing base grows and international prices move, and we would be glad to support future updates.

The report is a good example of the stakeholder consultation work that we believe NETRA should be doing. It brings together cost data from component manufacturers, analysis led by Deloitte, and technical and commercial inputs from ARCI, CSIR-NCL and IIT Madras. We thank all of them, and in particular the companies that shared detailed cost information on a confidential basis, which is presented here only in aggregated form. We believe evidence of this kind will help policymakers develop policies that build a competitive component ecosystem and respond to what industry actually needs.

NETRA was set up to help clean energy technologies move from innovation to manufacturing and deployment at scale. We work through industry councils, including the Advanced Battery Council and the Manufacturing, Supply Chain and Circular Economy Council, and with members and partners across India, North America, Europe, East Asia and Australia. Our approach is to work alongside existing institutions rather than duplicate them, and to bring industry, researchers, investors and policymakers together on specific problems such as the one this report addresses.

Our membership includes companies that manufacture, or plan to manufacture, advanced chemistry cell (ACC) components in India, and these companies may benefit from any support framework that draws on this work. It also includes cell manufacturers, energy storage developers, fleet operators and industrial users of storage, whose interests are not always the same as those of component producers. Both perspectives have informed this foreword. We offer the report as an independent input for industry and policymakers, and we will continue to bring stakeholders together on these questions.



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INTERNATIONAL ADVANCED RESEARCH CENTRE FOR
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PREFACE

International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI), an autonomous R&D Centre of the Department of Science and Technology, was established with the mandate to develop unique, innovative, and commercially viable technologies in the field of advanced materials and processes required not only for the strategic sector but also for civilian applications, and to transfer these technologies to industries. The core focus areas of ARCI include advanced materials and batteries, ceramics, surface engineering, laser processing, solar & hydrogen energy materials, advanced powder metallurgy, and rare-earth materials & magnets.

ARCI has been actively engaged in the development of lithium-ion and sodium-ion battery technologies, including key Advanced Chemistry Cell (ACC) components such as LFP, LFMP, NVP, layered oxides for cathode materials, LTO, Si-C composite anode materials, cathode materials for Li-S batteries, solid electrolytes and demonstration of these materials at pilot-scale along with manufacture of cells and validation.

ARCI has developed expertise and established necessary capacity and competence not only in advanced battery materials but also in electrode processing, cell fabrication, testing and technology transfer. These capabilities, supported by its pilot-scale facilities, technology-development experience and interactions with Indian industry, position ARCI suitably to undertake a comprehensive assessment of the technological, manufacturing and cost aspects of ACC components.

The present study has been prepared based on the critical analysis and assessment of not only the inputs and comments received from relevant R&D institutions, industry stakeholders and other concerned organizations but also technical data available at ARCI. The contributions and observations provided by these institutions have been duly considered in the preparation of the report, and the participating institutions are broadly aligned with the technical assessment and recommendations presented herein.

The study is intended to provide a mechanism for assessing the feasibility of domestic manufacturing, technology routes, cost competitiveness, domestic value addition and the development of a robust indigenous ecosystem for ACC components in India.

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Place: Hyderabad

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September 23, 2026

Preface

India's shift towards clean mobility, integration of renewable energy, and development of energy storage brings Advanced Chemistry Cells (ACC) to the heart of the country's strategy for energy security, technological advancement, and industrial growth. Even though considerable progress is being made in building domestic capacity for cell manufacturing, the long-term competitiveness, resilience, and strategic independence of India's battery industry will depend not only on the number of cells produced but also on the depth and strength of the domestic ecosystem that supports it.

The battery industry, if it is to be competitive on a global scale, needs a high level of vertical integration, covering the entire process from the extraction and processing of critical minerals and precursor chemicals through to active materials, cell components, cell manufacturing, battery packs, applications, and end-of-life recycling. In this value chain, India has built considerable capabilities in downstream activities such as battery pack assembly, battery system integration, electric mobility applications, and associated engineering and manufacturing services. Nevertheless, important gaps remain in the upstream parts of the value chain, particularly in the domestic production of critical raw materials, battery-grade refined materials, precursor chemicals, and advanced cell components. Furthermore, the recycling sector, which is vital for closing the material loop and for enhancing long-term resource security, also needs considerable advances in technology and in manufacturing.

The report provides a thorough evaluation of the manufacturing landscape for the main components of Advanced Chemistry Cells, namely Cathode Active Materials, Anode Active Materials, Electrolytes, Separators, and Copper Foils. It looks at the manufacturing processes, the raw materials required, the process flows, the current domestic capabilities, the supply chain dependencies, the level of import exposure, and the possibilities for localization of these important components. By considering the battery value chain as a complete, integrated system rather than a series of separate manufacturing stages, the analysis reveals the interdependencies among upstream materials, component manufacturing, cell production, downstream applications, and recycling.

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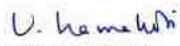
The technological, manufacturing, infrastructure, and supply-chain gaps that need to be dealt with if an integrated ecosystem is to be established are identified in this report, with special focus on the opportunities for domestic value addition in the upstream and midstream areas while taking into account the capabilities that India has already built up in the downstream field. The aim is to identify practical routes by which India can gradually strengthen its position across the entire battery value chain, covering raw materials and precursor chemicals, as well as components, cells, battery systems, and recycling.

IIT Madras contributes to India's national priorities of energy security, clean-energy transition and technological self-reliance through multidisciplinary research in battery science and technology. Its expertise spans lithium-ion, sodium-ion, zinc-ion, lithium-sulfur and redox-flow batteries, integrating fundamental electrochemistry, materials science and technology development. Research on advanced electrode materials, solid and polymer electrolytes, and functional separators aims to enhance battery performance, safety and cycling stability while advancing indigenous energy-storage solutions. IIT Madras Research Park complements these strengths through industry-linked engineering, prototyping, and commercialization, with capabilities in battery-pack design, battery-management systems, thermal management, and charging technologies for electric vehicles and stationary storage. Together, this materials-to-systems ecosystem connects scientific discovery with practical applications, supporting renewable-energy integration, electric mobility and the development of domestic capabilities across the battery value chain.

I truly value the work of the experts and those who have taken part in this in-depth technical evaluation. The analysis in this report provides useful insights into the opportunities and challenges of establishing a full-scale domestic ecosystem for ACC components. I am certain that this report will aid in decision-making and will support India's aim of creating a technologically capable, vertically integrated, globally competitive, and sustainable battery manufacturing ecosystem.

With warm regards,

Sincerely yours,


(V. Kamakoti)



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Foreword

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The transition towards clean energy and sustainable mobility has brought Advanced Chemistry Cell (ACC) technologies to the forefront of India's industrial and technological priorities. As the country strives to establish a robust domestic ACC manufacturing ecosystem under the vision of self-reliance and energy security, it is imperative to understand the economic and technological factors that influence the competitiveness of indigenous manufacturing across the ACC value chain.

This report, presents a comprehensive assessment of the cost disability associated with key ACC cell components. By systematically identifying the factors contributing to manufacturing costs and benchmarking them against global practices, the report provides an evidence-based foundation for policy interventions aimed at strengthening India's advanced battery manufacturing capabilities and enhancing the competitiveness of domestic industry.

CSIR-National Chemical Laboratory (CSIR-NCL), Pune, is pleased to have contributed technical inputs to this important national initiative. As a premier research institution with longstanding expertise in chemistry, materials science, electrochemistry, catalysis, and chemical process engineering, CSIR-NCL remains committed to supporting the development of indigenous technologies and providing scientific inputs that facilitate informed policy and industrial decision-making.

I am confident that the findings and recommendations presented in this report will serve as a valuable resource for policymakers, industry, researchers, and other stakeholders engaged in advancing India's ACC manufacturing sector. I congratulate all contributors for their dedicated efforts in bringing out this timely and impactful report and wish this endeavour every success in supporting the nation's clean energy and industrial growth objectives.

(Ashish Lele)

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Foreword

It is a privilege to introduce this report on “Accelerating India’s ACC Component Manufacturing Ecosystem”, a study commissioned by the Net Zero Energy Transition Association (NETRA) to assess the manufacturing landscape and competitiveness of Advanced Chemistry Cell (ACC) components in India. As India accelerates its transition towards electric mobility, energy storage, and advanced manufacturing, the development of a robust domestic ecosystem for critical battery materials and components will be as important as the establishment of cell manufacturing capacity itself. Strengthening capabilities across the component value chain is essential to enhancing domestic value addition, reducing import dependence, and improving the long-term resilience of the battery ecosystem.

In preparing this report, we had the opportunity to engage extensively with multiple stakeholders, including industry participants, manufacturers, technology providers, and research institutions. The stakeholder discussions have been instrumental in forming a holistic view of the challenges and opportunities that lie ahead and developing the forecasts and action items presented herein.

The report provides a detailed assessment of the global and Indian ACC component landscape, covering key battery components including Cathode Active Materials (CAM), Anode Active Materials (AAM), Electrolytes, Separators, and Current Collectors. It examines manufacturing processes, raw material requirements, supply-chain dependencies, localization opportunities, and the cost competitiveness of domestic manufacturing relative to global benchmarks. The analysis highlights both the opportunities and challenges across individual component segments, recognizing that each faces distinct constraints related to raw material access, technology maturity, economies of scale, and manufacturing capabilities.

We are grateful to all the stakeholders for their guidance and engagement throughout this study. Their support has been invaluable in ensuring that the report reflects both technical rigor and practical industry perspectives. We look forward to supporting the continued development of a competitive, resilient, and self-reliant ACC component manufacturing ecosystem in India.



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Abbreviations

AAM	Anode Active Material
ACC	Advanced Chemistry Cell
AI/ML	Artificial Intelligence/Machine Learning
AIS	Automotive Industry Standard
ALMM	Approved List of Models and Manufacturers
BESS	Battery Energy Storage Systems
BFSI	Banking, Financial Services and Insurance
BMS	Battery Management System
BU s	Billion Units
CAFE	Corporate Average Fuel Economy
CAM	Cathode Active Material
CAPEX	Capital Expenditure
CPC	Calcined Petroleum Coke
Cu	Copper
DISCOM	Distribution Company
DVA	Domestic Value Addition
EMS	Energy Management System
EPR	Extended Producer Responsibility
ESG	Environmental, Social, and Governance
ESO	Energy Storage Obligation
EV	Electric Vehicle
FDI	Foreign Direct Investment
FTAs	Free Trade Agreements
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWh	Gigawatt-hour
HSN	Harmonized System of Nomenclature
IESS	India Energy Security Scenarios
INR	Indian Rupee
IoT	Internet of Things
IT	Information Technology
JV	Joint Venture
Ktpa	kilotonnes per annum

kWh	Kilowatt-hour
LCO	Lithium Cobalt Oxide
LFP	Lithium Iron Phosphate
MGV	Medium Goods Vehicle
MoU	Memorandum of Understanding
MSMEs	Micro, Small and Medium Enterprises
TPA	tonnes per annum
MWh	Megawatt-hour
Na-ion	Sodium-ion
Na-S	Sodium-sulphur
NCA	Nickel Cobalt Aluminium
NCMM	National Critical Mineral Mission
NEP	National Electricity Plan
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PLI	Production-Linked Incentive
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PSD	Particle Size Distribution
QCOs	Quality Control Orders
R&D	Research and Development
RTC	Round-the-Clock
SEI	Solid Electrolyte Interphase
SPR	Strategic Petroleum Reserves
SSBs	Solid State Batteries
TCO	Total Cost of Ownership
TOD	Time-of-Day
TRL	Technology Readiness Level
TWh	Terawatt-hour
UPS	Uninterruptible Power Supply
VAT	Value Added Tax
VGF	Viability Gap Funding
VRE	Variable Renewable Energy



Chapter 1. Context and strategic relevance

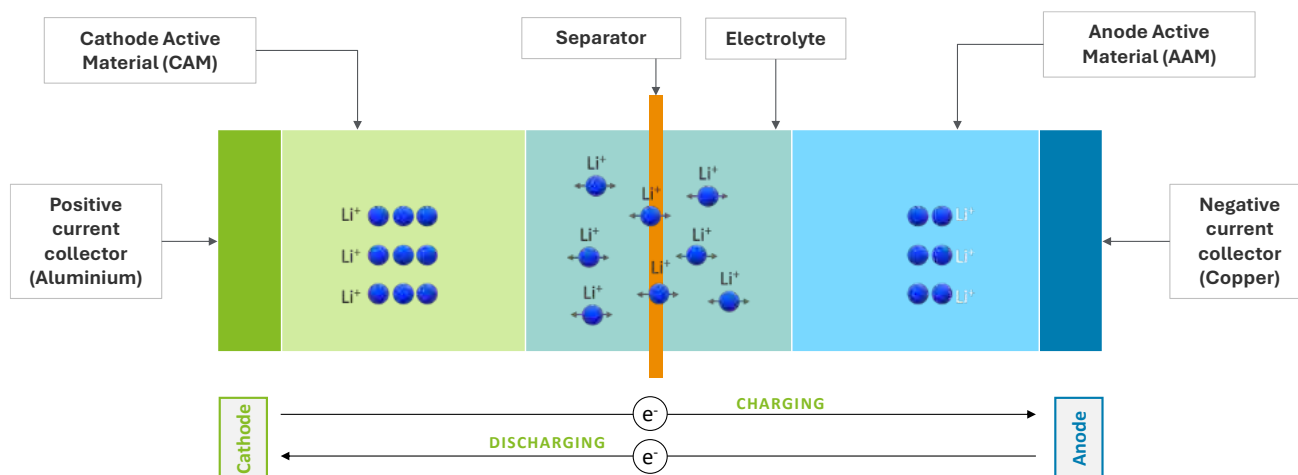
1.1. The role of ACC components

Globally, the demand for ACC (Advanced Chemistry Cell) batteries has been driven by a worldwide push towards clean technologies, in the form of EVs and renewable energy coupled BESS. ACC batteries are being increasingly used for EVs and grid-scale applications. Other applications include compact batteries for electronics and other handheld devices such as machine tools. The global demand from these applications reached 1,495 GWh in 2025 and is expected to continue growing at a CAGR of ~22% to reach more than 4 TWh in 2030.

An ACC consists of five key components: the cathode active material (CAM), anode active material (AAM), electrolyte, separator, and current collectors. These components account for a significant share of ACC manufacturing costs and have a direct impact on its performance and safety.

In a lithium-ion ACC, during charging and discharging, lithium ions move between the cathode and anode through the electrolyte, while electrons flow through the external circuit, storing and generating electrical power. Current collectors, typically aluminium for the cathode and copper for the anode, facilitate electron transport.

Figure 1: Key components of an advanced chemistry cell

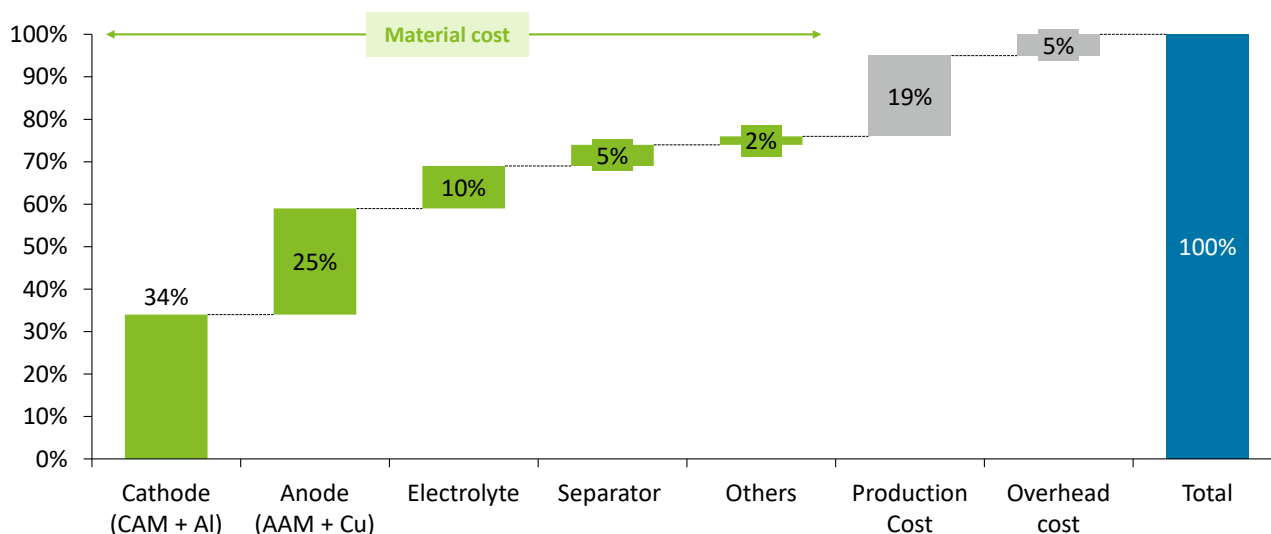


Key component	Details
1. Cathode	Positive electrode coating, consisting largely of CAM.
2. Anode	Negative anode coating, consisting largely of AAM graphite, synthetic or natural.
3. Electrolyte	Medium for lithium-ion migration, consisting of lithium salts, additives, and solvent.
4. Separator	Physical membrane that separates cathode and anode while allowing lithium ions to pass through, largely made of polymers.

Key component	Details
5. Copper and Aluminium battery foil	Coated by AAM or CAM to form electrodes, negative and positive current collectors, respectively.

ACC components account for approximately 76% of total cell manufacturing cost, with cathode (34% of cell cost) and anode (25% of cell cost) components alone representing the largest share of total material costs followed by electrolyte and separator. Cost breakdown of a lithium-ion ACC is provided in the figure below:

Figure 2: Cost breakdown of lithium-ion cell (%)

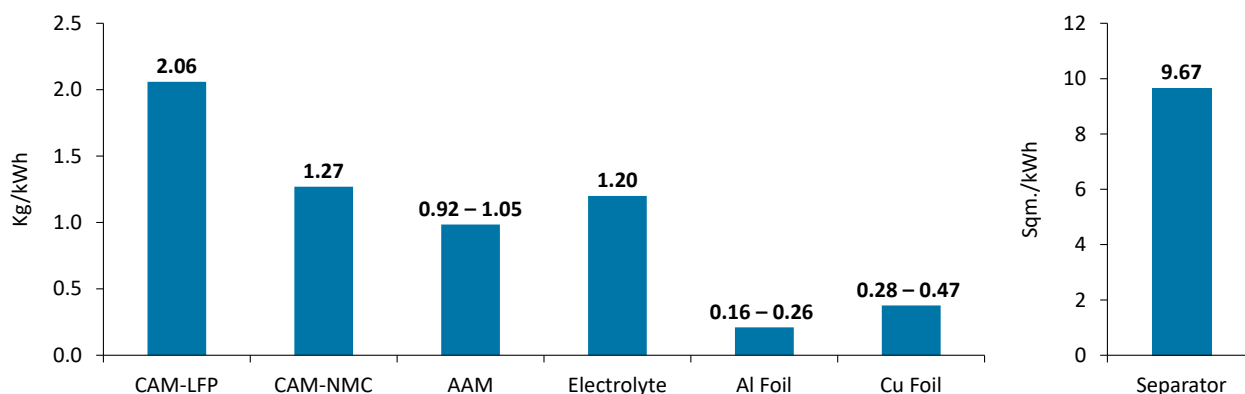


Source 1: Analyzing material and production costs for lithium-ion batteries using process-based cost modeling – CellEst 3.0 (Ruppert, Janik et al., 2025)

Given that active cell components (materials that directly participate in the chemical or electrochemical reactions to store and release energy) are the key cost drivers, establishing their domestic capabilities is critical to achieving cost competitiveness, supply chain security, and long-term value capture. Investments in local production of ACC components and cell manufacturing can significantly reduce dependence on imports while enhancing control over cost, quality, and technology development.

Quantity of cell components required per kWh of ACC capacity varies from chemistry to chemistry. Chemistries with higher energy densities, such as NMC, require less material than LFP. The quantity of each cell component required per kWh of ACC capacity is shown in the following figure:

Figure 3: Quantity of cell components required per kWh

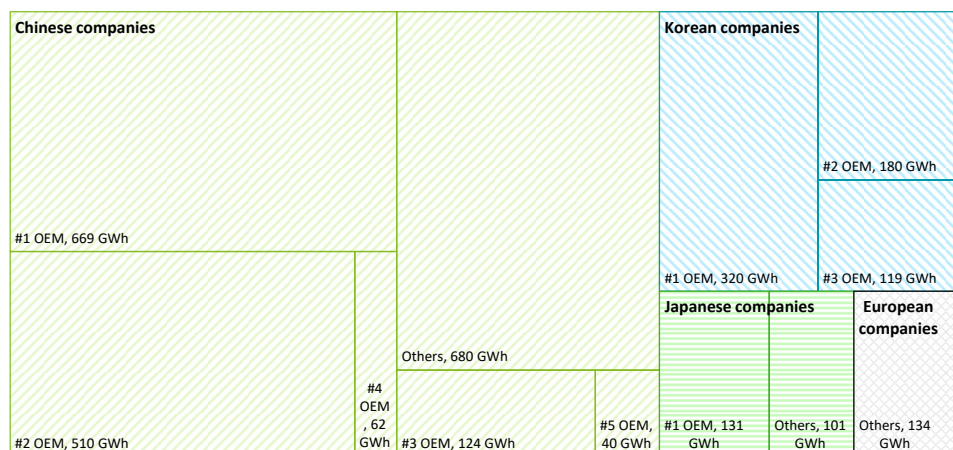


Source 2: Analyzing material and production costs for lithium-ion batteries using process-based cost modeling – CellEst 3.0 (Ruppert, Janik et al., 2025), NITI Aayog Mine to Market study (2023), SPJ – Science: Advanced Electrode Materials in Lithium Batteries: Retrospect and Prospect [SPJ – Science: Advanced Electrode Materials in Lithium Batteries: Retrospect and Prospect](#)

1.2. Global ACC component landscape

Driven by the rapid global adoption of electric vehicles (EVs) and the accelerating deployment of renewable energy, global battery cell manufacturing capacity has reached approximately 3 TWh in 2025.¹ Compared to the manufacturing capacity of approximately 3 TWh, the global demand was approximately 1.5 TWh.

Figure 4: Global battery cell manufacturing capacity (in GWh)



China alone represents ~68% of the total capacity followed by Korea (~20%) and Japan (~8%).

Source 1: IEA, analyst reports

As far as ACC component manufacturing is concerned, the global capacity is currently much higher than the anticipated demand. Table 1 below provides the global ACC component manufacturing capacity:

Table 1: Global capacity for each ACC Component (in 2025)

ACC component	CAM-LFP	CAM-NMC	AAM	Electrolyte ²	Copper foil ³	Separator
Unit	TPA	TPA	TPA	TPA	TPA	million sq. m
2025 capacity	5,487,000	2,690,000	5,743,700	2,381,400	2,780,000	41,694

Source 2: JP Morgan, June 2026 report, Nomura report, April 2025

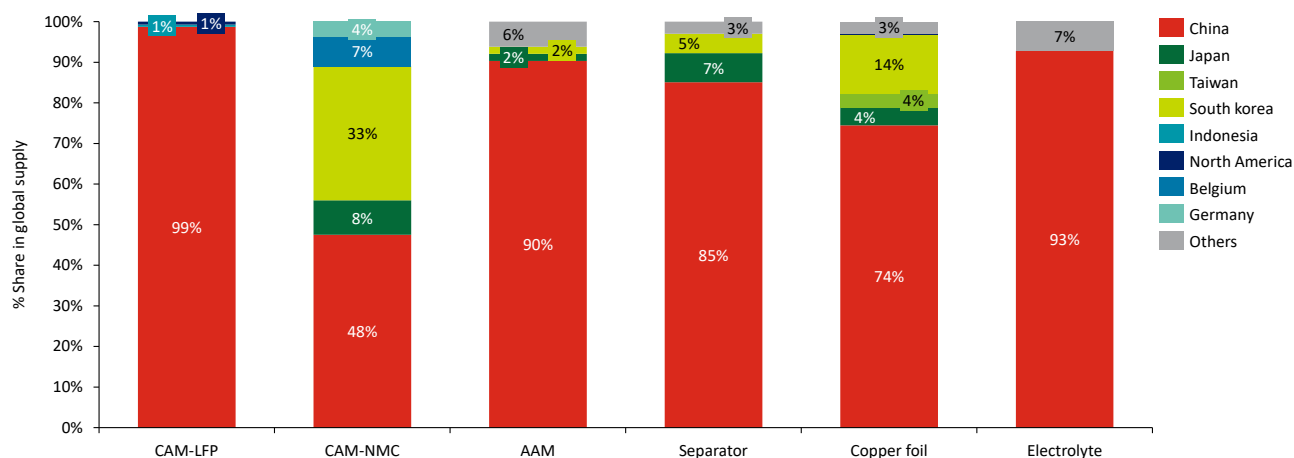
In terms of geographic distribution of the above capacity, China holds the largest share across CAM-LFP, CAM-NMC, AAM, separator, copper foil, and electrolyte, reflecting its established position within the global battery materials value chain. While countries such as South Korea, Japan, North America, and select European nations contribute to specific component segments, their shares remain relatively smaller in comparison.

¹ IEA, analyst reports

² [Application Proof of Shida Shinghwa Advanced Material Group Co., Ltd.](#)

³ [Tianxia Gongchang Research China Electrolytic Copper Foil 2026: The 4.5µm Ultra-Thin and HVLP High-Frequency Dual-Track Breakthrough](#)

Figure 5: Global supply share by country across key ACC components (2025)



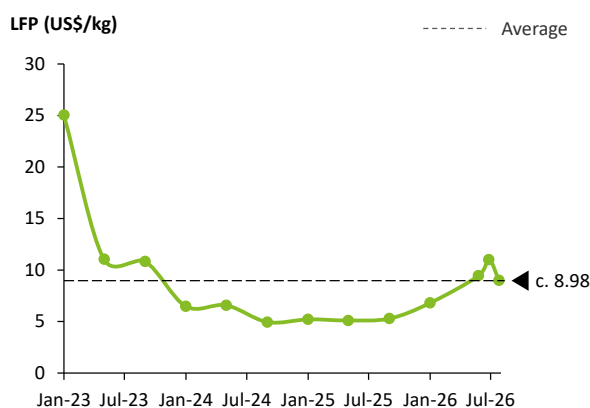
Source 3: JP Morgan, June 2026 report, Nomura report, April 2025

The concentration of component capacity in China makes it the primary anchor in the global ACC ecosystem. This strong presence across multiple stages of the battery materials supply chain underscores China's role as a key supplier of critical battery components and positions it as a significant participant in global battery manufacturing and trade.

Historical global price trends of ACC components

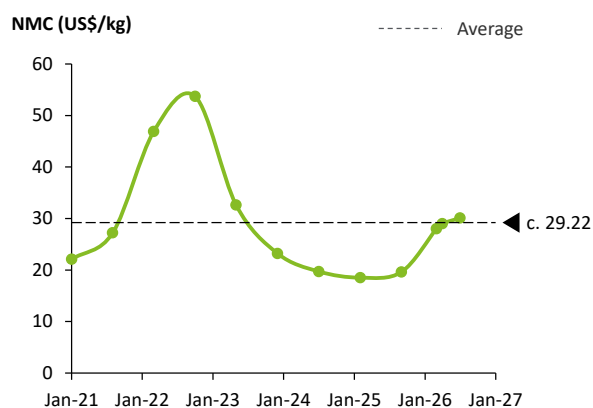
Prices of ACC components have followed varied trends over the years as each component is influenced by a different mix of factors. These include changes in raw material prices, periods of oversupply and capacity expansion, utilization, demand from EVs and energy storage, and shifts in competition.

Figure 6 Historical global LFP cathode material prices and trends, US\$/kg



Source 4 JP Morgan, ICSSino

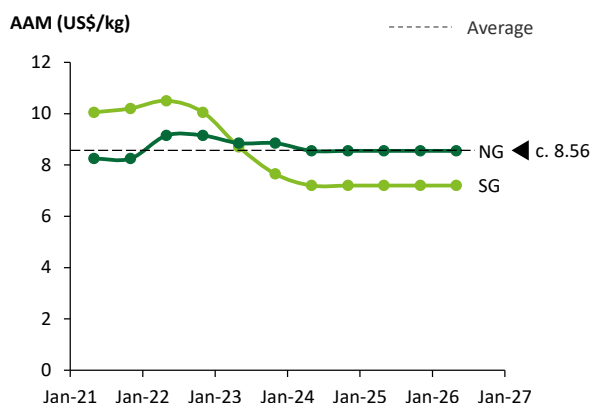
Figure 7 Historical global NMC cathode material prices and trends, US\$/kg



Source 5 JP Morgan, ICSSino

LFP prices have shown a variable trend historically. Decline of 2023 is due to global decline in lithium carbonate prices. Price increase from 2025 can be attributed to recovering lithium prices and stronger energy storage demand globally⁴.

Figure 8 Historical global anode material prices and trends, US\$/kg

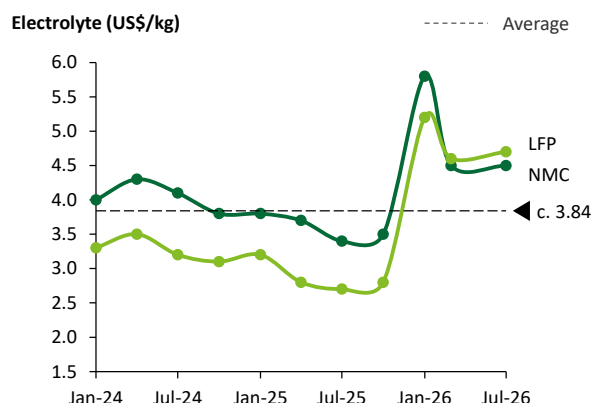


Note: Prices for high-end NG and SG; Source 6 JP Morgan, ICCSino

Historically, prices of high-end SG have been higher than high-end NG; however, post 2023, Chinese manufacturers switched their feedstock from costly needle coke to cheap petroleum coke^{6,7} – leading to decline in prices of high-end SG.

The rise in NMC prices post 2021 was on account of increase in battery metals prices such as lithium, nickel and cobalt due to growing demand. Prices fell post 2023 due to supply expansion and LFP rise. Price increase post 2025 follows LFP trend due to increase in critical mineral prices.⁵

Figure 9 Historical global electrolyte material prices and trends, US\$/kg



Source 7 JP Morgan, ICCSino

Consistent decline in electrolyte prices till 2025 is due to continuous capacity expansion and falling prices for lithium hexafluorophosphate (LiPF_6).⁸ Prices increased post 2025 due to increase in lithium carbonate and LiPF_6 prices and strong demand from energy storage.⁹

⁴ [\[SMM Mid-Year Market Analysis\] 2026 H1 LFP Cathode Material Market Review - Shanghai Metals Market \(SMM\)](#)

⁵ IEA Global Critical Minerals Outlook 2026

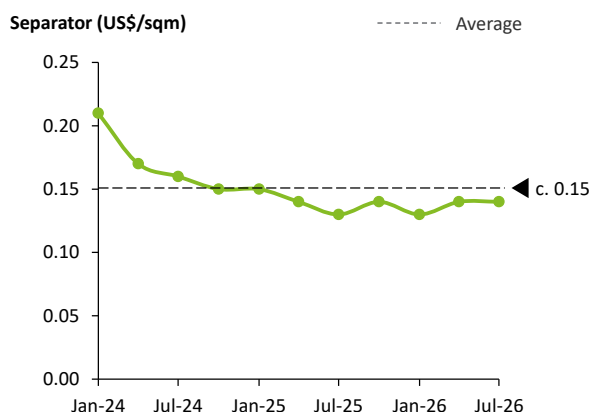
⁶ [Synthetic graphite anode prices fall 20% this year putting pressure on natural graphite](#)

⁷ [China's anode market tilts toward synthetic graphite amid supply shake-up - Fastmarkets](#)

⁸ [\[SMM Analysis\] 2024 Electrolyte Market Review - Shanghai Metals Market \(SMM\)](#)

⁹ [SunSirs: Lithium Hexafluorophosphate Prices Soar 280% Within Six Months](#)

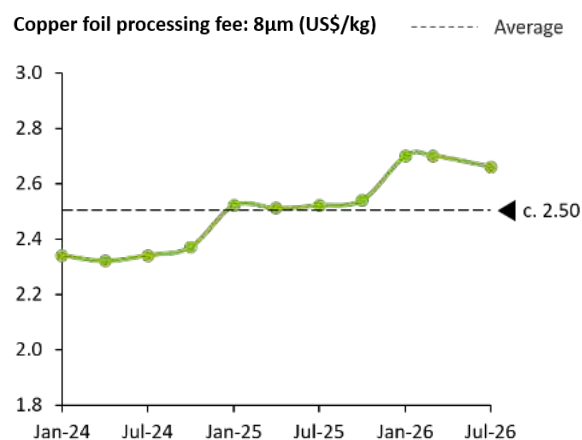
Figure 10 Historical global separator material prices and trends, US\$/sq. m



Source 8 JP Morgan, ICSSino

Separator prices declined from 2024 due to rapid capacity and shipment growth – leading to Chinese suppliers competing intensely on price. Modest recovery post 2025 is due to increased battery demand from stationary energy storage applications.¹⁰

Figure 11 Historical global copper foil processing prices and trends, US\$/kg

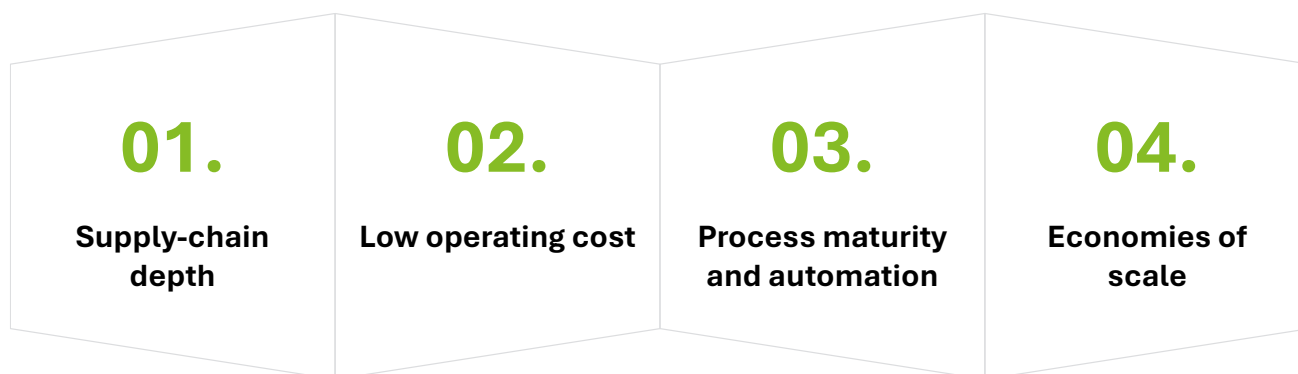


Source 9 JP Morgan, ICSSino

Lower copper foil processing prices in 2024 was due to overcapacity. Increase in prices post 2025 is due to higher utilization and stronger EV and energy-storage demand.¹¹

1.2.1. China's leadership in global ACC component manufacturing

China's leadership in the global ACC component manufacturing can be attributed to multiple structural benefits such as supply-chain depth, local component access, low operating cost due to matured industrial infrastructure, process maturity and automation, and economies of scale.



In the following sections, the advantages enjoyed by Chinese manufacturers are discussed.

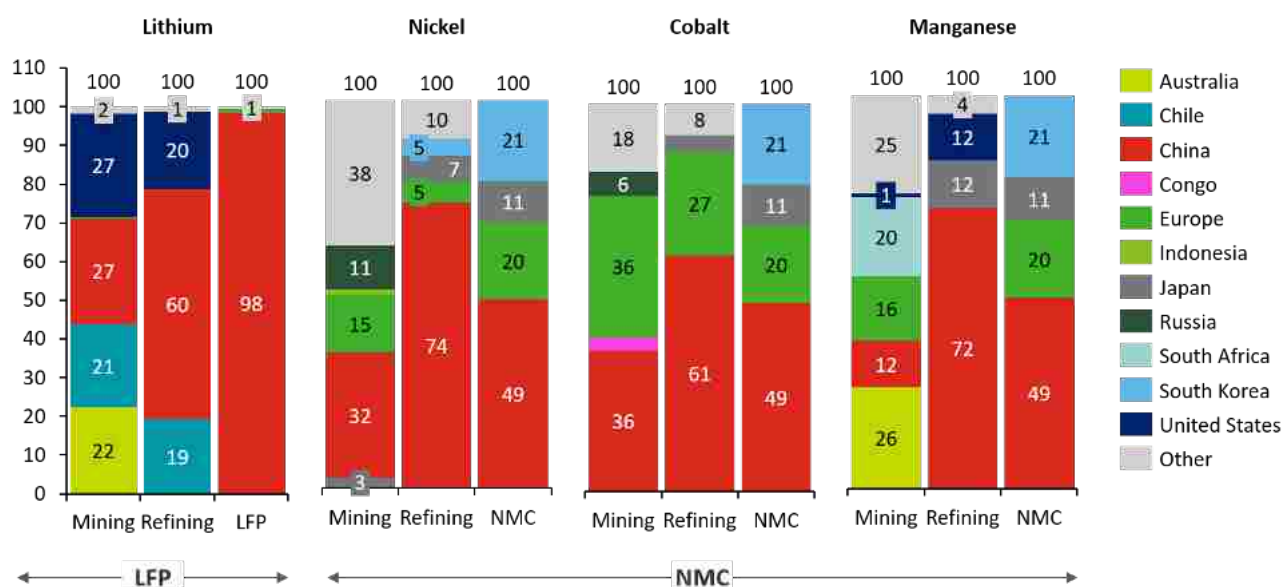
A. Supply-chain depth

While the presence of battery critical mineral ores is diversified across multiple geographies, Chinese firms enjoy a skewed share in the material value chain. The following graph illustrates the leadership of key countries in mining, refining and battery-grade material production.

¹⁰ [SMM Analysis] Separator Market 2026 Semi-Annual Review: Supply-Demand Pattern Tightens Marginally, Price Center Gradually Moves Up - Shanghai Metals Market (SMM)

¹¹ 2026 China Copper Foil Industry Half-Year Summary and Outlook [SMM Analysis] - Shanghai Metals Market (SMM)

Figure 12: Country-wise share in CAM value chain steps by ownership, %



Source: Science direct – China's hold on the lithium-ion battery supply chain: Prospects for competitive growth and sovereign control [Science direct - China's hold on the lithium-ion battery supply chain: Prospects for competitive growth and sovereign control](#)

As can be seen in the graph clearly, leading global suppliers of cathode materials have worked to establish ownership for critical assets at the mining and refining level. Such investments have ensured that these countries have a steady supply of battery-grade feedstock for cathode manufacturing. While mining may physically take place in other geographies- for example Congo, which mines nearly 70% of the world's cobalt, ownership of mining and refining assets remains with these leading players. Such vertical integration helps reduce upstream costs, provides cost-optimal supplier agreements and shields them from supply chain shocks. This also allows them to stockpile material well in advance of any anticipated shortages.

In graphite anodes as well, China holds nearly 96%¹² of refining capacity for mined graphite. Chinese graphite anode manufacturers hold the entire industry chain from natural graphite mining to artificial graphite manufacturing. Estimates suggest that this creates almost three-fold advantages in technology, cost control, and production scale. BTR in China leads the natural graphite sector with ~63% global market share, while Shanshan in China has led the artificial graphite sector for years. The top five firms here hold ~70% of the global market.

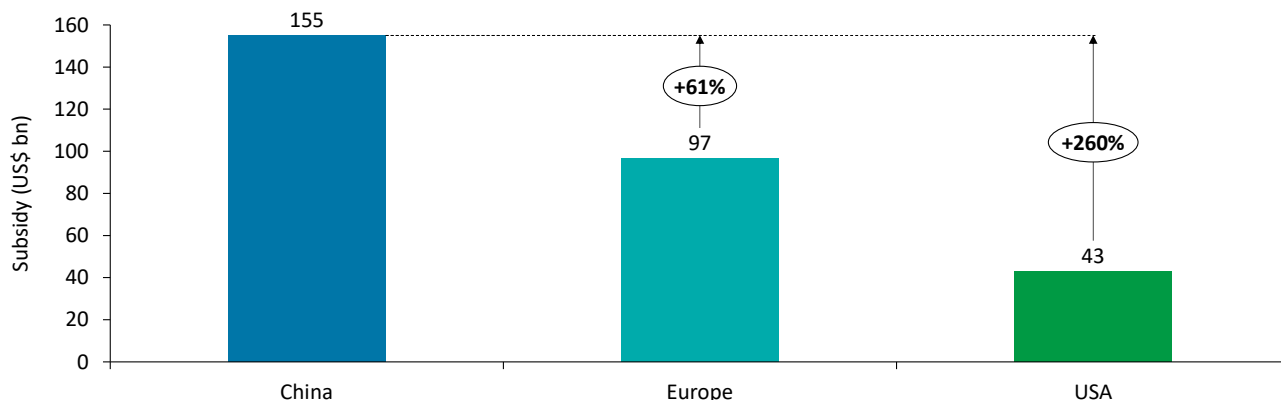
B. Low operating cost

1. Domestic manufacturing incentives

China's leadership in the EV and battery manufacturing ecosystem has been supported by a combination of large-scale manufacturing investments and sustained government support. Total subsidies for EV and battery manufacturing were approximately USD 155 billion from 2018 to 2024. In comparison, subsidies in Europe and the United States stood at USD 97 billion and USD 43 billion, respectively, in the observed period.

¹² IEA Critical Minerals Outlook 2025

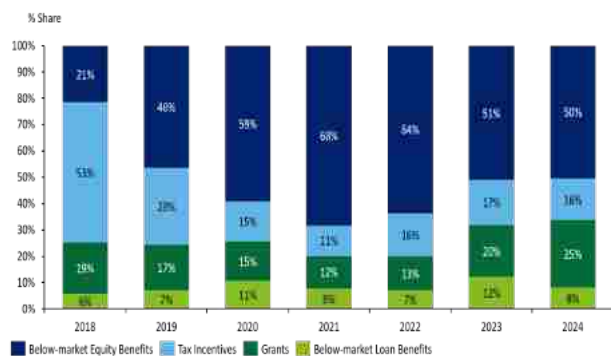
Figure 13: Total subsidy in EV and battery manufacturing by region, from FY 2018-2024



Source 10: Global Clean Investment Monitor, International Monetary Fund

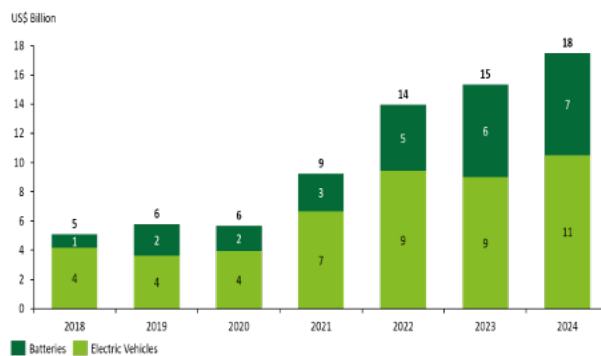
China's manufacturing support framework for the EV and battery sector has undergone a significant transformation since 2018. While tax incentives constituted the largest share of manufacturing subsidies in the early years, their relative importance declined steadily as the industry matured. In parallel, below-market equity support emerged as the key policy instrument, accounting for around half of manufacturing subsidies by 2024. This trend reflects China's increasing reliance on state-backed capital and government-supported investors to provide long-term financing, sustain production expansion, and support firms through periods of weak profitability and market consolidation. Grants and concessional lending continued to play a complementary role.

Figure 14: Annual share of Chinese manufacturing subsidies by subsidy instrument



Source 11: Global Clean Investment Monitor

Figure 15: Annual Chinese manufacturing subsidies by technology



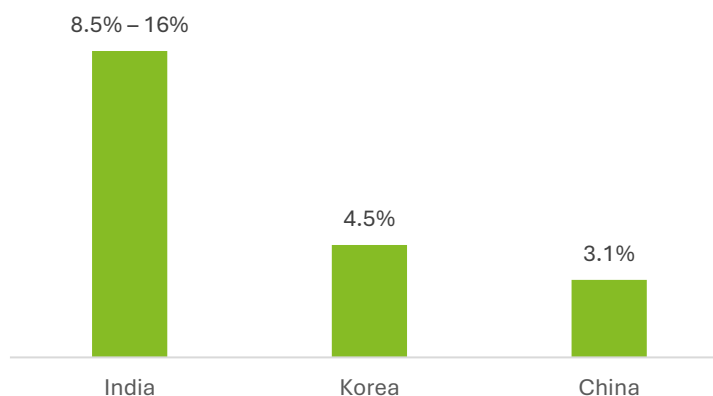
Source 12: Global Clean Investment Monitor

The combination of sustained investment and policy support has enabled Chinese manufacturers to optimize their operating costs. As a result, China has emerged as one of the most cost-competitive manufacturing hubs across the battery value chain.

2. Low financing cost

ACC component manufacturing is highly capital intensive and requires significant upfront investment in plant, machinery, technology acquisition, and working capital. Compared to leading manufacturing ecosystems, Indian manufacturers typically face higher borrowing costs and more limited access to long-tenor, policy-supported industrial financing. Industry consultations indicate that higher financing costs are a meaningful contributor to overall manufacturing disability across several ACC components, particularly in capital-intensive segments such as anode materials, electrolyte salts, and separators. In contrast, leading global manufacturers often benefit from lower-cost financing through state-backed financial institutions, preferential lending mechanisms, and mature financial ecosystems, enabling lower per-unit financing costs and faster capacity expansion. As a result, the cost of capital represents an important structural disadvantage for emerging domestic manufacturers during the initial years of operation and scale-up.

Figure 16 Interest rates in India, Korea, and China (in %)



Source 13 Chinese Govt disclosure loan prime rates, Xinhuanet (state-run press agency for the People's Republic of China), msmlloans.in (ranges validated through official websites of Scheduled banks)

Corporate lending rate in China is ~3.1%¹³, lending rates in Korea are approximately 4%-5%¹⁴, while Indian interest rates range from 8.5%-16%¹⁵, depending on the source of the loan (Public Sector Banks, Private Banks), borrowers' credit ratings and multiple other factors.

C. Process maturity and automation

1. Process mastery, automation, and scrappage rates

During initial plant output stabilization and the initial few years of operation, an elevated level of scrappage is expected across most ACC component manufacturing processes. Bringing down this scrappage rate to sustainable levels requires time and dedicated manpower.¹⁶ Companies operating outside of the above geographies face lower yields initially which primarily stem from lack of process standardization, process verification and tuning and lower levels of automation. This is also illustrated in the graph alongside which depicts that a new entrant desirous of venturing into the upstream manufacturing of battery value chain faces high scrap rates for first 5-6 years. Leading players in China, Korea, and Japan, by virtue of having sustained focus on R&D and innovation have reaped the benefit of being an early-entrant and command strong cost advantages over new/relatively less mature players.

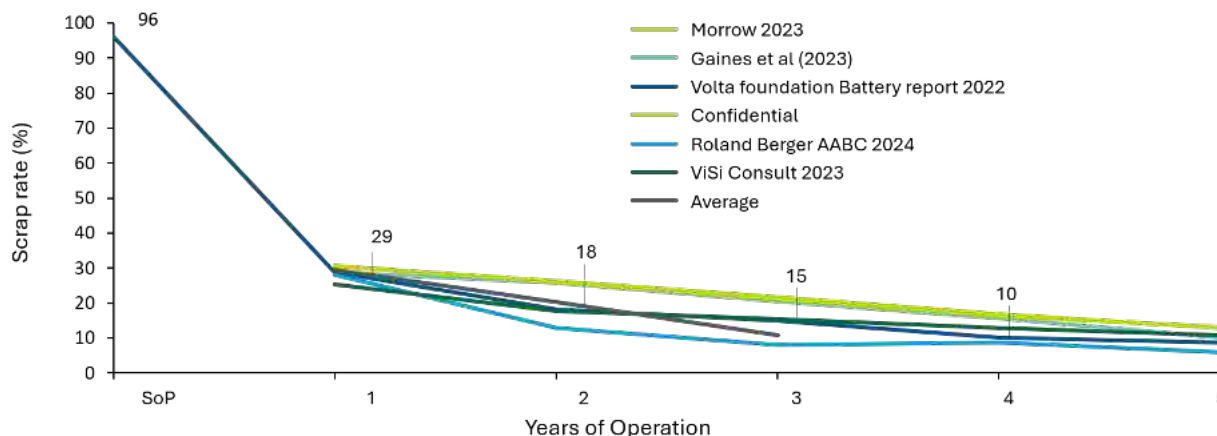
¹³ [Interest Rate – The State Council, The People's Republic of China](#)

¹⁴ [Korea Lending rates](#)

¹⁵ [Top banks for Project finance in India](#), validated by lending offerings of top banks SBI Bank, HDFC Bank, ICICI Bank, Tata Capital

¹⁶ Source: Fraunhofer DE

Figure 17: Scrap rates over years of operation



Source 14: [The ramp-up of a gigafactory in battery cell production](#)

For new entrants, lack of economies of scale, automation, digitalization, and process efficiency leads to lower yield and utilization rates resulting in higher costs per unit, affecting the overall profitability and economic viability. Leading players in China, Korea, and Japan have already progressed along the economic ramp-up curve so that costs such as depreciation of machinery and buildings are offset as quickly as possible. It is expected that such disparities will continue for Indian players since there are relatively less cell production capacities in India which can act as potential offtakers.

Critical parameters in the early years of upstream manufacturing are scrap rate and production utilization. An analysis by Fraunhofer suggests that optimizing these parameters can significantly influence the viability of a plant. If not optimized, the break-even date – which is the point where cumulative revenue equals cumulative costs – can be delayed. For Indian companies venturing into component and cell production, it is expected that they will face this issue in the initial years compared with global leaders who have already achieved an optimal balance of both. Figure alongside shows this conundrum for a 40 GWh NMC 811 integrated pouch cell production in EU. It shows that a conventional entrant in the upstream supply chain may take 7-8 years to achieve break-even vis-à-vis leading companies who can achieve the same in ~4.5 years.

A case study¹⁷ of cost-disability due to inherent efficient processes suggests that for an AAM and CAM production by a new player, factory-yield level, automation and legacy cell formats can lead to a cost disability of ~55-60%.

2. Technological know-how

Countries around the world have invested deeply in R&D and innovation which have enabled them to master the technology of component and cell production. Continued R&D and innovation have enabled them to reduce scrappage and improve automation in manufacturing. Moreover, the overall process of ACC component manufacturing is technically intensive and demands strict quality requirements. This is being addressed by digital tools and data-driven strategies to optimize process parameters and enhance manufacturing yields/efficiency and product quality. Sustained focus on R&D and innovation has enabled leading manufacturers to develop proprietary technologies, reduce their dependence on foreign technology providers, and minimize royalty and licensing costs. The resulting technological advantage has supported these leading enterprises and their countries as market leaders. In terms of innovation output, China leads globally in the number of patents granted in this sector, followed by Japan, South Korea, United States, and Europe. In contrast, India has comparatively limited patent activity, with fewer than 50 patents^{18,19} granted to Indian entities such as, institutes, government laboratories, private R&D

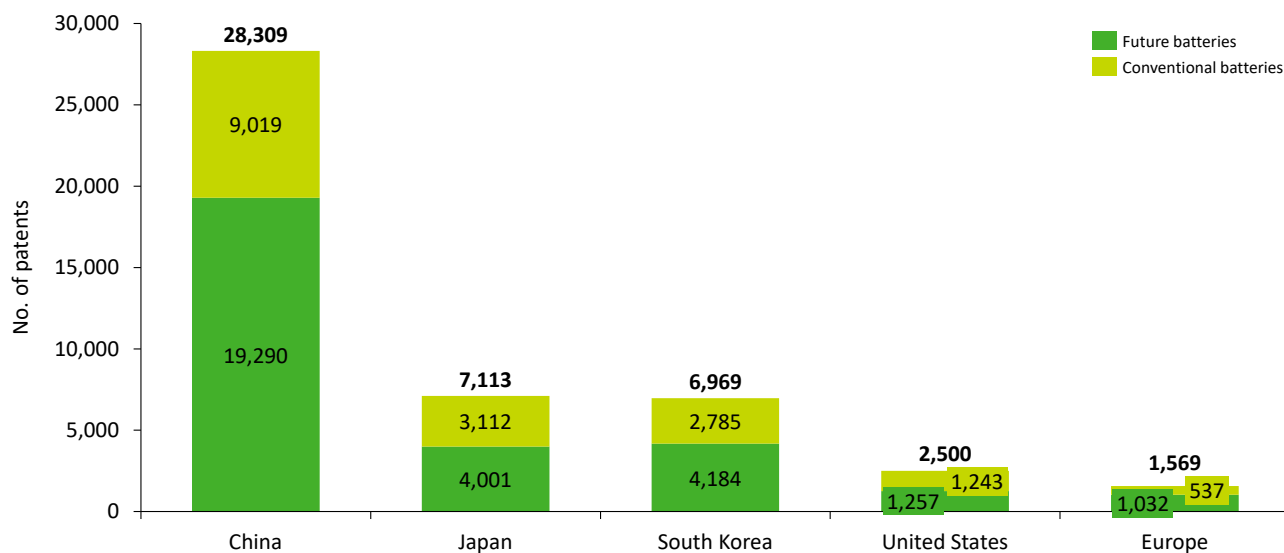
¹⁷ Volta report, CRU

¹⁸ <https://iprsearch.ipindia.gov.in/publicsearch>

¹⁹ <https://patents.google.com>

organizations, and industry players. However, the country's innovation ecosystem has been gaining momentum since 2020, reflecting a growing focus on indigenous battery technology development and manufacturing capabilities.

Figure 18: Number of patents across 1990-2024 globally



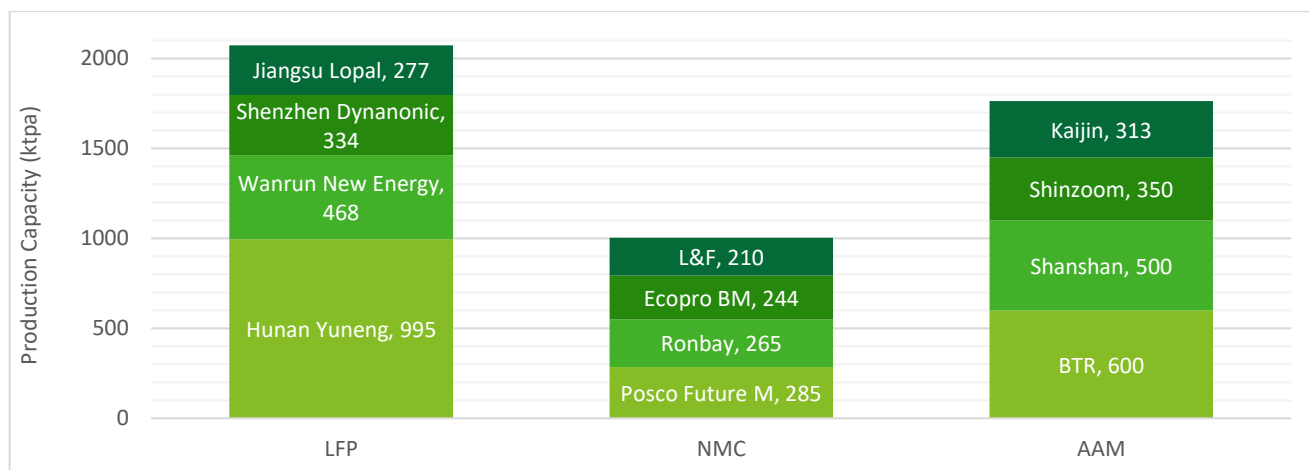
Note: Future batteries: Lithium-based high-energy technologies such as lithium solid-state batteries (Li-SSBs), lithium-sulfur batteries (Li-S batteries), and lithium-air batteries (Li-air batteries) and non-lithium-based low-cost technologies such as sodium-ion batteries (SIBs) and new metal-ion batteries (NMIBs); Conventional batteries: Prevailing LFP and NMC batteries

Source 15: Energy Environ. Sci. (2025) 18 (12): 6117–6130

D. Economies of scale

Leading ACC component manufacturers in China operate at much larger scales compared to their competitors in other global markets. This leads to lower cost of manufacturing per unit as they can leverage greater economies of scale.

Figure 19: Capacity of top four players in the LFP, NMC, and AAM space, ktpa



Source 16: Nomura, ICCSino

Such economies of scale are fueled by enormous downstream and local demand from EVs and grid-scale BESS which enables lower per unit capital expenditure, cheaper financing in the upstream segment (mining to component production) and reduces or lower risk to investors.

1.3. Conclusion

The global ACC component landscape is shaped by manufacturing scale, concentrated supply chains, and accumulated technological and process capabilities. As battery demand expands, cathode and anode active materials, electrolytes, separators, and battery foils will remain critical to cell cost, performance, safety, and reliability.

China's leadership in the ACC component value chain is not the result of a single cost advantage or policy incentive. It is the outcome of a deeply integrated manufacturing ecosystem that was built over several decades. The key factors benefitting Chinese ecosystem players are local access to refined minerals and battery components (dense supplier base), large domestic demand, mature manufacturing clusters, and significant cumulative production experience. This ecosystem allows manufacturers to source inputs locally, reduce logistics and inventory costs, ramp plants faster, improve yields and utilization, and spread capital costs over large production volumes. Government support including financing, industrial infrastructure, land and demand-side policies played an important role in accelerating this ecosystem, but the resulting advantage is due to scale, learning and supply-chain depth.

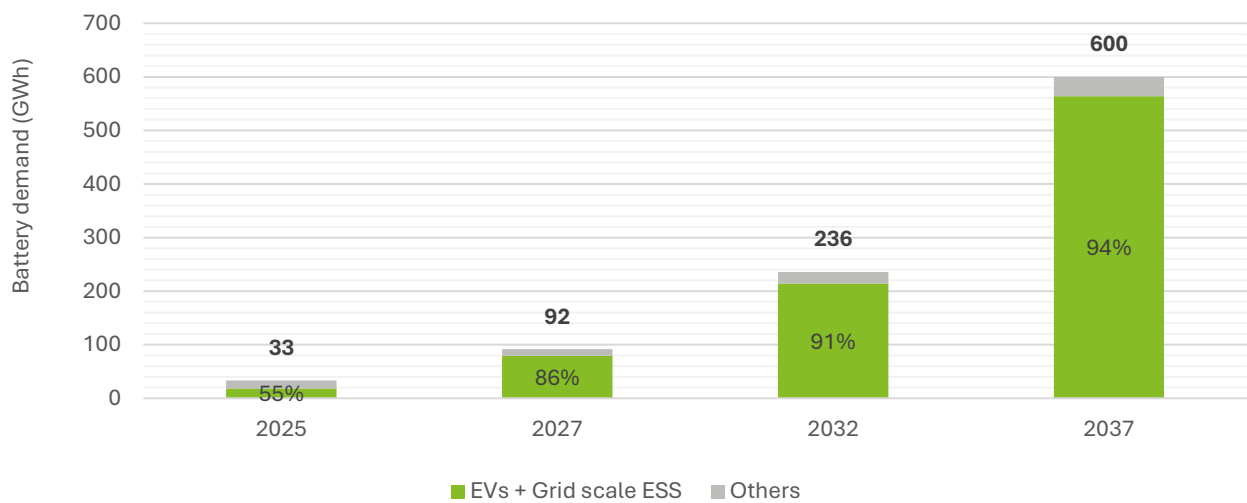
Chapter 2. India’s ACC component ecosystem overview

2.1. ACC components in India’s manufacturing ecosystem

India’s battery demand is poised for exponential growth, driven by the rapid adoption of electric vehicles, expansion of renewable energy capacity, increasing deployment of energy storage systems, and the growth of the electronics manufacturing sector. Battery demand is projected to increase from approximately 33 GWh in 2025 to nearly 600 GWh by 2037, underscoring the strategic importance of batteries in supporting India’s energy transition, industrial growth, and net-zero ambitions.

To meet this rapidly expanding demand in a secure and cost-competitive manner, India must move beyond cell manufacturing and develop a comprehensive Advanced Chemistry Cell (ACC) ecosystem. While significant investments have been announced in ACC cell production, critical upstream components such as cathode active materials, anode active materials, electrolytes, separators, and battery-grade copper foil continue to have limited domestic manufacturing capacity. This dependence on imports creates supply chain vulnerabilities and limits value addition within the country.

Figure 20: Projected battery demand till 2037, GWh



Source 17: HLC-VB_Aggregation of battery demand and long-term action plan_Mar26, MHI

Developing a robust domestic ACC ecosystem is therefore essential to strengthen supply chain resilience, enhance energy security, reduce import dependence, and improve the global competitiveness of India’s battery industry. An integrated ecosystem spanning materials, components, cells, packs, and recycling will be critical for supporting future battery demand and establishing India as a leading hub in the global battery value chain.

Existing manufacturing capacities for cathode active materials, anode active materials, and electrolytes are relatively small, while domestic production of separators and battery-grade copper foil remains largely absent. This reliance on imports exposes the industry to supply chain risks and constrains value addition within the country. The current manufacturing capacity across key ACC components, presented in the table below, highlights the significant opportunity and need for further ecosystem development.

Accelerating domestic ACC component manufacturing is essential to meet growing battery demand, strengthen supply-chain resilience, reduce import dependence, and improve India's competitiveness.

Table 2: Summary of current ACC component capacity in India

Components	Unit	Existing capacity
Cathode Active Material	<i>ktpa</i>	7.98
Anode Active Material	<i>ktpa</i>	0.80
Separator	<i>million sq. m.</i>	NA
Electrolytes	<i>ktpa</i>	8
Aluminium battery foil	<i>ktpa</i>	25
Copper battery foil	<i>ktpa</i>	NA

Source 18: Based on stakeholder input

*NA – No identified domestic manufacturing capacity

As battery demand continues to grow across electric mobility, energy storage, consumer electronics, and emerging industrial applications, providing impetus to localized upstream manufacturing will be crucial to reduce import dependence, enhance supply chain resilience, increase domestic value addition, and support India's long-term objective of becoming a globally competitive hub for Advanced Chemistry Cell manufacturing.

2.2. Capacity gap and demand for ACC components

The significant expansion of domestic ACC cell manufacturing capacity is expected to drive substantial demand for upstream battery materials and components. Although several investments have been announced across key component segments, the current manufacturing base remains relatively limited, particularly for components such as separators, battery-grade copper foil, cathode active materials, and anode active materials. As a result, a gap is likely to emerge between the demand generated by upcoming ACC cell manufacturing facilities and the availability of domestically produced battery components.

Bridging this gap will be critical for the development of an integrated and self-reliant battery manufacturing ecosystem in India. The availability of locally manufactured components not only supports domestic value addition but also reduces supply chain risks, lowers import dependence, and improves the competitiveness of domestic cell manufacturing. As battery manufacturing scales, the requirement for cathode materials, anode materials, electrolytes, separators, aluminium foil, and copper foil is expected to increase proportionately, creating substantial opportunities for investment across the ACC component value chain.

The projected demand for individual Advanced Chemistry Cell (ACC) components provides an important indication of the manufacturing capacities required to support India's planned battery cell production. As the country's ACC manufacturing capacity expands, demand for critical battery materials and components is expected to increase significantly across the entire value chain. Comparing existing and planned capacities with the anticipated component demand highlights the scale of capacity additions and upstream manufacturing investments needed to support the growth of India's battery ecosystem. The following figure and table present the estimated demand trajectory for key ACC components through 2037, illustrating the requirements necessary to enable the continued expansion of the domestic ACC manufacturing industry.

Table 3 Projected annual requirement for ACC components corresponding to projected battery demand (2032 and 2037)

Components	Unit	Projected annual requirement*	
		2032 236 GWh equivalent	2037 600 GWh equivalent
Cathode Active Material (NMC–LFP range)	ktpa	283-472	720-1,200
Anode Active Material	ktpa	236	600
Electrolytes	ktpa	283	720
Separator	Million sq. m.	2,360	6,000
Aluminium battery foil	ktpa	61	156
Copper battery foil	ktpa	118	300

*Considering 1 kWh of ACC requires 2kg of LFP CAM, 1.2kg of NMC CAM, 1kg of AAM, 1.2 kg of electrolyte, 10 sq.m. of separator, 0.26kg of aluminium battery foil and 0.50kg of copper battery foil.

Note: ACC component demand has been estimated by applying the material intensity requirement for each component (kg/kWh or m²/kWh) to the projected battery demand (GWh), assuming a constant battery chemistry and converting total battery demand into equivalent component requirements for each assessment year.

Overall, demand for all major ACC components is projected to grow at an annual rate of approximately 27% over the next decade, reflecting the rapid expansion of India's battery manufacturing sector. The sharp increase in requirements across active materials, separators, electrolyte, and metallic foils underscores the need for timely capacity additions, localization of supply chains, and strategic investments in component manufacturing to ensure a resilient and competitive domestic ACC ecosystem.

2.3. Key government initiatives on ACC components

The successful development of India's ACC manufacturing sector depends not only on cell production capacity but also on the localization of critical battery materials and components that underpin the value chain. Recognizing the importance of developing a globally competitive and self-reliant battery ecosystem, the Government of India has introduced a range of complementary policy measures beyond the ACC PLI Scheme. These include targeted incentive programs, trade and tariff interventions, support for domestic electronics and component manufacturing, and measures to facilitate access to critical equipment and technologies. Together, these initiatives aim to strengthen the domestic ACC component value chain, improve cost competitiveness, attract investments, and accelerate localization across the battery manufacturing ecosystem. The key initiatives undertaken by the Government of India to date are presented below.

A. Initiative 1: Electronics Component Manufacturing Scheme (ECMS) by MeitY

In April 2025, the Ministry of Electronics and Information Technology (MeitY) notified the Electronics Component Manufacturing Scheme (ECMS)²⁰, to promote domestic manufacturing of electronic components and sub-assemblies, strengthen local value addition, and reduce import dependence within the electronics supply chain.

The Scheme provides incentives for manufacturing several components of lithium-ion cells used in digital applications, including cathode materials, anode materials, electrolytes, separators, and copper foil. However,

²⁰ [ECMS Notification notified on 08.04.2025.pdf](#)

the current scope of the Scheme is limited to digital applications and does not cover components used for energy storage and mobility applications.

Table 4: Key Scheme Provisions for Li-ion Cells for Digital Applications under the Electronics Component Manufacturing Scheme (ECMS).

Applicable category	Target Segment-D (Supply chain ecosystem and Capital equipment)
Outlay	₹1,712 crore (Target Segment-D) ²¹
Category name	i. Supply chain of sub-assemblies (A) and bare components (B) and (C). ii. Capital goods used in electronics manufacturing including their sub-assemblies and components. <i>Note: Li-ion Cells for Digital Applications (excluding energy storage and mobility applications) is part of Bare components (B)</i>
Minimum investment	₹10 crore
Incentive	Capex incentive: 25%

Source 19: ECMS Notification (8th April, 2025), ECMS Guidelines (26th April, 2025)

The ECMS is a positive step towards building a domestic manufacturing ecosystem for advanced battery components, as the 25% CAPEX incentive can reduce the upfront investment burden and improve the economics of establishing component manufacturing capacity in India.

However, the Scheme is limited to only lithium-ion cells for digital applications and excludes energy storage and mobility applications. As shown in Figure 20, these two applications are expected to account for more than 90% of India's total battery demand by 2032 but are currently outside the scope of ECMS. This could risk India relying significantly on imported ACC components for batteries serving mobility and energy storage applications as they represent the majority of domestic battery demand.

There is a need to provide exclusive support to lithium-ion cell components used in mobility and energy storage applications, considering their dominance in domestic demand, to facilitate manufacturers while building a more complete domestic battery supply chain in India and reduce dependence on imported components.

B. Initiative 2: Basic Customs Duty (BCD) Waivers on Lithium-ion Cells, Components, Sub-parts, Inputs, and Raw Materials to Support Domestic Battery Manufacturing

The Government of India has created a two-part Basic Customs Duty (BCD) exemption framework to support domestic ACC manufacturing. One set of exemptions covers key raw materials used in lithium-ion cells, such as cathodes, anodes, electrolytes, separators, binders, and additives.²² The identified customs-duty measures relating to lithium-ion cell manufacturing show a broad trend of continued and expanded support. The policy evolved from an initial duty reduction, to adding more eligible items, extending support from electric vehicle batteries to battery energy storage systems and finally streamlining implementation through a CBIC notification²³.

²¹ [ECMS Guidelines](#)

²² [Ministry of Finance - D.O.F. No. 334/3/2026-TRU](#)

²³ [CBIC Notification No. 27/2026](#)

This consistent expansion indicates a long-term commitment to building a domestic cell manufacturing industry, rather than providing a temporary budget incentive.

Table 5: Cell component and Raw material exemptions

Cell Component and Raw Material Exemptions
The exemption framework covers specified parts, sub-parts, inputs and raw materials imported for use in the manufacture of lithium-ion cells, subject to the descriptions, tariff classifications and applicable end-use conditions prescribed in the relevant customs notification. The applicable exemption has been continued up to 31 March 2028. This shows that the Government of India wants to encourage domestic cell manufacturing, not just battery pack assembly, by making local cell production more cost-effective and competitive.

Source 20: India Budget | 2026-27

While the BCD exemption supports the development of domestic manufacturing capabilities and the associated supply chain, such support may need to continue until a competitive domestic component manufacturing ecosystem is established. As the industry scales up, the Government may consider introducing calibrated trade-remedial measures to safeguard emerging domestic manufacturers against dumping and other unfair or predatory trade practices by overseas suppliers.

C. Initiative 3: Basic Customs Duty (BCD) Waivers on Equipment and Machinery to Support Domestic Battery Manufacturing

In addition to supporting the import of critical raw materials and cell components, the Government has also provided customs duty exemptions on key machinery and equipment required for lithium-ion cell manufacturing, thereby facilitating the establishment and expansion of domestic manufacturing capacity.

Table 6: Equipment and machinery exemptions

Equipment and Machinery Exemptions
Budget 2026-27 extension: As part of the 2026 customs-duty measures, the Government continued support for importing specified capital goods used in lithium-ion cell manufacturing and expanded its application to cells manufactured for Battery Energy Storage Systems (BESS). Notification No. 01/2026-Customs dated 1 February 2026 amended S. No. 69A of Notification No. 25/2002-Customs to extend the existing exemption, earlier applicable to machinery used for manufacturing lithium-ion cells for electrically operated vehicles, to machinery used for manufacturing cells for BESS, with effect from 2 February 2026.
Subsequently, Notification No. 27/2026-Customs dated 8 July 2026 consolidated the earlier S. Nos. 69 and 69A into a revised S. No. 69 covering 85 listed categories of machinery and equipment used across major stages of lithium-ion cell manufacturing, including material preparation, coating, compression, winding, electrolyte filling, sealing, welding, formation, testing, inspection, cleaning, recovery, treatment and packaging.

Equipment and Machinery Exemptions

CBIC Notification No. 27/2026-Customs²⁴ (8 July 2026): CBIC Notification No. 27/2026-Customs dated 8 July 2026 subsequently consolidated and revised the machinery exemption by substituting the earlier S. Nos. 69 and 69A of Notification No. 25/2002-Customs with a single S. No. 69 covering 85 listed categories of machinery and equipment used in lithium-ion cell manufacturing. The revised framework now covers 85 categories of machinery and equipment used, covering major stages of the lithium-ion cell manufacturing process. These include equipment for coating, compression, winding, filling, sealing, welding, testing, formation, cleaning, material recovery, treatment, inspection, and packaging, ensuring comprehensive customs duty relief for cell manufacturing operations.

While the initial BCD exemption on imported capital equipment constitutes an important policy intervention for accelerating the establishment of domestic cell manufacturing capacity, the industry should utilise this policy window to pursue technology transfer, progressively indigenise equipment manufacturing, and develop domestic capabilities for producing selected machinery. As these capabilities mature, the Government may consider introducing a calibrated duty structure for equipment that can be competitively manufactured in India, while retaining exemptions for specialised machinery and equipment for which adequate domestic manufacturing capacity is not available.

Source 21: India Budget | 2026-27, GOVERNMENT OF INDIA, MINISTRY OF FINANCE (Department of Revenue), Notification No. 27/2026-Customs, 8th July, 2026, Government Expands Duty-Free Equipment List for Lithium-Ion Battery Manufacturers

Together, these exemptions lower both operating and capital costs for manufacturers, enhancing the commercial viability of domestic ACC cell production and supporting the development of an integrated battery manufacturing ecosystem in India.

²⁴ [CBIC Notification No. 27/2026](#)

Table 7: Policy trend from 2023 to 2026

Policy trend (2023-2026)		
Taken together, the Government of India's customs duty measures for ACC manufacturing show a clear and consistent trend of increasing support. With each budget cycle, the government has either expanded the range of eligible items, extended the duration of benefits, or broadened their applicability to more use cases. Importantly, none of these exemptions have been withdrawn, indicating a sustained commitment to promoting domestic ACC manufacturing.		
Budget Year	Nature of Move	Key Change
2023	Rate cut and foundational exemption	BCD on lithium-ion cells for EV batteries has been reduced (21% → 13%), capital goods/machinery for Li-ion cell manufacture exempted for the first time.
2025	List broadening	35 additional capital goods added for EV battery manufacturing, 28 additional capital goods added for mobile phone battery manufacturing, BCD exemption extended to cobalt powder and other critical raw materials.
2026 (Budget, Feb)	Scope expansion	Capital goods exemption extended to 31.03.2028, scope widened from EV/mobile cells to Battery Energy Storage Systems.
2026 (CBIC Notification, July) ²⁵	Combining multiple provisions into a single framework	Notification No. 27/2026-Customs consolidated S. Nos. 69 and 69A into a single entry covering 85 categories of capital goods spanning material preparation through final packaging, thereby providing a more consolidated and detailed framework for identifying eligible machinery.

Source 25: Union Budget 2023, BASIC CUSTOMS DUTY RATES ON GOODS | Budget 2023, Union Budget 2025, SUMMARY OF UNION BUDGET 2025-26 | Gol, India Budget | 2026-27, GOVERNMENT OF INDIA, MINISTRY OF FINANCE (Department of Revenue), Notification No. 27/2026-Customs, 8th July, 2026 Union Budget 2023 BASIC CUSTOMS DUTY RATES ON GOODS | Budget 2023 Union Budget 2025 SUMMARY OF UNION BUDGET 2025-26 | Gol India Budget | 2026-27 GOVERNMENT OF INDIA, MINISTRY OF FINANCE (Department of Revenue), Notification No. 27/2026-Customs, 8th July, 2026

The Government of India's continued extension of Basic Customs Duty (BCD) exemptions on lithium-ion cell raw materials, components, sub-parts, inputs, and manufacturing equipment reflects a targeted policy approach to accelerate domestic ACC manufacturing. By reducing both input costs and capital expenditure requirements, these measures enhance the competitiveness of local manufacturers, facilitate capacity creation, encourage investments across the battery value chain, and support the long-term objective of establishing a self-reliant and globally competitive battery manufacturing ecosystem in India.

²⁵ [CBIC Notification No. 27/2026](#)

Collectively, these initiatives demonstrate the Government of India's commitment to developing a comprehensive and self-reliant ACC component manufacturing ecosystem – leading to high domestic value addition and enhanced supply chain resilience.

2.4. ACC component-wise market assessment

The manufacturing of Advanced Chemistry Cell (ACC) components requires significant capital investment, advanced process technologies, and access to high-quality raw materials. The overall manufacturing economics is influenced by the scale of production, technology maturity, process configuration, localization of raw materials, financing costs, and operational efficiencies.

A benchmarking exercise has been undertaken across multiple domestic and international manufacturers for each component category. The assessment evaluates both capital expenditure (CAPEX) and manufacturing costs based on representative commercial-scale facilities. The analysis also compares manufacturing costs in India with those in leading countries to identify the existing cost disability and the major factors contributing to the competitiveness gap.

The components are assessed on the following parameters, the data of which is sourced from various players:

- 1) Installed capacities
- 2) Average capital expenditure per ktpa/ million sq. m
- 3) Minimum scale of production capacity required to achieve financial viability
- 4) Key challenges for each component

A. Cathode Active Material (CAM)

Cathode Active Material (CAM) is a critical component of lithium-ion batteries that largely determines energy density, capacity, voltage, and overall battery performance. This assessment evaluates the existing domestic production capacity, planned manufacturing investments, and the minimum scale required for commercially viable CAM production. Drawing upon inputs from industry participants and market assessments, the analysis examines the readiness of the domestic supply ecosystem to support the growing requirements of India's Advanced Chemistry Cell (ACC) industry.

Production capacities and CAPEX requirement

Current Cathode Active Material (CAM) manufacturing capacities reflect a clear preference toward LFP technology. Current CAM-LFP manufacturing capacity is 7,775 TPA, while CAM-NMC capacity is 200 TPA.

Table 8: Existing manufacturing capacity of CAM

Technology	Current manufacturing capacity (TPA)
CAM-LFP	7,775
CAM-NMC	200

Source 22: As per input from industry players

In addition, the following table highlights the average CAPEX required for establishing a CAM LFP manufacturing plant in India.

Table 9: Capex breakdown for Cathode Active Material (LFP) and NMC (in ₹ crore/ ktpa)

Cost head	CAM (₹ crore/ ktpa)
Plant and machinery	24
Land and site development	8
Technology, acquisition cost	3
Soft costs	5
Others	6
Total (in ₹ cr/ ktpa)	46

Source 23: As per input from industry players

The CAPEX requirement for Cathode Active Material manufacturing plant is ₹46 crore/ktpa, with plant and machinery (₹24 crore/ktpa) being the largest investment component. Capex requirements can vary across projects depending on technology acquisition, infrastructure requirements, and plant configuration.

For Cathode Active Materials (CAM), stakeholders indicated a minimum viable capacity ranging from 20,000-60,000 TPA.

Table 10: Minimum viable capacity and average CAPEX required for CAM (TPA)

Technology	Min. viable capacity (TPA)	Average CAPEX (in ₹ crore/ ktpa)
CAM	20,000-60,000	46

Source 24: As per input from industry players

Key challenges related to CAM manufacturing:

Some of the key challenges related to CAM manufacturing are mentioned below:

- Domestic availability of battery-grade phosphate materials is limited. Although ferric/ferrous phosphate is produced in India, industry consultations indicate that only about 20% of the requirement can currently be met domestically due to the lack of battery-grade quality material.
- Jet mills and spray dryers, which are important equipment used in CAM processing, are mostly imported. This limits local technology development and increases project costs.
- Jet milling is a major process bottleneck, with cycle times of approximately 20 hours per batch, impacting manufacturing throughput and operational efficiency.
- CAM production requires extremely tight particle-size control at sub-micron levels, making process stability, quality assurance, and yield optimization key challenges for domestic manufacturers.
- Particle engineering plays a critical role in product performance, with material particle sizes typically in the range of 10-12 microns prior to thermal processing, followed by further modification through calcination and final milling stages to achieve battery-grade specifications.

The assessment indicates that India's CAM ecosystem is primarily focused on LFP technology, supported by manufacturing processes that are largely aligned with global industry practices. However, the sector continues to

face challenges related to high import dependence for critical raw materials and equipment, limited availability of battery-grade intermediates, and the need for advanced process control to achieve the stringent quality standards required for battery applications. These factors underscore the importance of strengthening domestic capabilities across materials, technology, and manufacturing to support the rapid growth of India's ACC industry.

B. Anode Active Material (AAM)

Anode Active Material (AAM) is a key component of lithium-ion batteries that influences charging performance, cycle life, efficiency, and battery durability. This assessment evaluates the existing domestic production capacity, planned manufacturing investments, and the minimum scale required for commercially viable AAM production. Drawing upon inputs from industry participants and market assessments, the analysis assesses the preparedness of the domestic supply base to meet the evolving demand of India's Advanced Chemistry Cell (ACC) industry.

Production capacities and CAPEX requirement

The anode active material (AAM) manufacturing sector is expected to witness capacity additions across both Natural Graphite (NG) and Synthetic Graphite (SG) technologies. While there is currently no reported manufacturing capacity for NG, the existing manufacturing capacity for SG is 800 TPA.

Table 9: Existing manufacturing capacity of AAM-NG and SG

Technology	Current manufacturing capacity (TPA)
AAM-NG	Nil
AAM-SG	800

Source 25: As per input from industry players

The average CAPEX investment required for an AAM manufacturing plant is ₹129 crore/ktpa, with plant and machinery costing ₹76 crore/ktpa, making it the largest investment component. Land and site development and soft costs also contribute significantly to the overall project cost.

Table 10: Capex breakdown for Anode Active Material (in ₹ crore/ ktpa)

Cost head	AAM (₹ crore/ ktpa)
Plant and machinery	76
Land and site development	22
Technology, acquisition cost	0.3
Soft costs	13
Others	17
Total (in ₹ cr/ ktpa)	129

Source 26: As per input from industry players

As per industry estimates, the minimum viable capacity is highlighted below. This points to the fact that there would be a need for suitable incentives in the initial years till Indian players achieve such levels of capacity utilization.

Table 13: Minimum viable capacity, average CAPEX required for AAM (TPA)

Technology	Min. viable capacity (TPA)	Average CAPEX (in ₹ crore/ ktpa)
AAM	10,000-30,000	129

Source 27: As per input from industry players

Key challenges related to AAM manufacturing:

Some of the key challenges related to AAM manufacturing are mentioned below:

- Natural graphite processing suffers from low material conversion efficiency, with reported requirement of approximately 2.1 tonnes of graphite flakes to produce 1 tonne of battery-grade anode material. This increases raw material consumption and production costs.
- Synthetic graphite production requires significant quantities of specialised raw material inputs. On average, producing 1 tonne of anode material requires around 1.28 tonnes of mesophase coke and 0.24 tonnes of coal tar pitch. Ensuring the consistent availability of these feedstocks at the required quality and competitive cost presents a significant challenge, as any supply constraint or quality variation may adversely affect production continuity, yields, and manufacturing costs.
- Feedstock quality remains a critical challenge. For natural graphite anodes, graphite flakes require more than 94% carbon content before further purification and processing, limiting the pool of suitable raw material sources.
- Particle engineering capabilities are critical for battery-grade production. Spheroidized graphite particles are typically maintained in the 30-50-micron range, requiring advanced shaping and process control technologies.
- Raw material characteristics can significantly impact production yields. Petroleum-based coke feedstocks may contain 10-12% moisture content, contributing to lower yields of approximately 65-70% in some synthetic graphite production routes.

The assessment indicates that India's AAM ecosystem is developing across both synthetic and natural graphite technologies, with manufacturing processes broadly aligned with global industry practices. However, the sector remains dependent on imported feedstocks and critical graphitization technologies, while battery-grade material quality and purification continue to be key technical challenges. As domestic ACC manufacturing scales up, strengthening indigenous capabilities across graphite processing, feedstock supply, and advanced anode manufacturing technologies will be essential for building a competitive and self-reliant battery materials ecosystem.

C. Electrolyte

Electrolytes are essential components of lithium-ion batteries that enable the movement of lithium ions between the cathode and anode, directly influencing battery performance, safety, efficiency, and cycle life. This assessment evaluates the existing domestic production capacity, planned manufacturing investments, and the minimum scale required for commercially viable production. Drawing upon inputs from industry participants and market assessments, the analysis examines the readiness of the domestic supply ecosystem to support the growing requirements of India's Advanced Chemistry Cell (ACC) industry.

Production capacities and CAPEX requirement

The electrolyte materials segment is expected to witness capacity expansion for electrolyte manufacturing. Existing electrolyte manufacturing capacity is 8,000 TPA.

Table 11: Existing manufacturing capacity of Electrolyte

Technology	Current manufacturing capacity (TPA)
Electrolyte	8,000

Source 28: As per input from industry players

Industry interactions indicate a growing interest in establishing and expanding electrolyte manufacturing capabilities within the country. Information collected from participating companies has been used to assess the capital investment needed for setting up and scaling production facilities. Based on the proposed manufacturing plans, the CAPEX intensity has been estimated on a per ktpa basis.

The average CAPEX investment required for an electrolyte manufacturing plant is ₹67 crore/ktpa, with plant and machinery and soft costs contributing ₹19 crore/ktpa each, making them the largest investment components. Land and site development also represent a significant cost at ₹18 crore/ktpa, while technology acquisition costs account for ₹8 crore/ktpa of the total project investment.

Table 15: Capex breakdown for Electrolyte (in ₹ crore/ ktpa)

Cost head	Electrolyte (₹ crore/ ktpa)
Plant and machinery	19
Land and site development	18
Technology, acquisition cost	8
Soft costs	19
Others	3
Total (in ₹ cr/ ktpa)	67

Source 29: As per input from industry players

As part of the assessment, the cost economics of electrolyte manufacturing were also examined to understand the competitiveness of domestic production. The findings suggest that Indian manufacturers currently incur higher production costs relative to international benchmarks, particularly those in China. This difference is influenced by factors such as dependence on imported specialty chemicals, higher procurement and transportation costs, limited backward integration, and the absence of large-scale domestic manufacturing infrastructure.

Achieving commercial viability in electrolyte manufacturing requires the establishment of minimum economic production capacities that enable efficient utilization of production assets, optimization of raw material sourcing, and competitive unit production costs. Because these materials are highly sensitive to purity, quality control, and process efficiency, sub-scale operations often face significant cost disadvantages. Consequently, the estimated CAPEX requirements provide an indication of the investment needed to establish minimum viable production capacities for electrolyte formulation, enabling manufacturers to achieve operational efficiency, meet battery-grade quality specifications, and compete effectively in the growing lithium-ion battery value chain.

Table 16: Minimum viable capacity, average CAPEX required for Electrolyte

Technology	Min. viable capacity (TPA)	Average CAPEX (in ₹ crore/ ktpa)
Electrolyte	12,000-32,000	67

Source 30: As per input from industry players

For manufacturing of 32,000 TPA for electrolyte, 10,000 TPA for LiPF_6 would be required. Establishing facilities at these scales is estimated to require an average capital investment of approximately ₹67 crore/ ktpa, providing an indication of the investment needed to develop economically viable domestic manufacturing capabilities in the electrolyte value chain.

Key challenges related to electrolyte manufacturing:

Some of the key challenges related to electrolyte manufacturing are mentioned below:

- Electrolyte salts represent one of the most critical components of the electrolyte value chain, contributing approximately 30% of electrolyte cost while accounting for only around 12% of the volume, highlighting the strategic importance of domestic salt manufacturing capabilities.
- electrolyte manufacturing is highly moisture-sensitive, requiring stringent environmental controls, specialized equipment, and high-purity processing conditions to maintain product quality and performance.
- The limited shelf life and high sensitivity of LiPF_6 present significant logistics challenges, requiring specialized storage, handling, and transportation infrastructure.

The assessment indicates that while India has developed capabilities in electrolyte formulation and blending, the ecosystem continues to rely heavily on imported lithium- and fluorine-based inputs. The highly sensitive nature of electrolyte salt production, coupled with dependence on critical raw materials and specialized chemical processes, underscores the need to strengthen domestic upstream capabilities to support the anticipated growth in ACC cell manufacturing and improve supply-chain resilience.

D. Separator

The separator is a critical safety component in lithium-ion batteries that physically separates the cathode and anode while allowing the movement of lithium ions, ensuring safe and efficient battery operation. This assessment evaluates the existing domestic production capacity, planned manufacturing investments, and the minimum scale required for commercially viable separator production. Drawing upon inputs from industry participants and market assessments, the analysis examines the readiness of the domestic supply ecosystem to support the growing requirements of India's Advanced Chemistry Cell (ACC) industry.

Production capacities and CAPEX requirement

Table 12: Existing manufacturing capacity of Separator

Technology	Current manufacturing capacity (million sq. m)
Separator	Nil

Source 31: As per input from industry players

Feedback received from industry participants indicates a strong interest in developing domestic separator manufacturing capabilities to support the growing ACC value chain. Based on the proposed manufacturing plans, CAPEX intensity has been estimated on a per million square meters (million sq. m) basis. The following table summarizes the investment requirements for separator production in India.

Table 18: Capex breakdown for Separator (in ₹ crore /million sq. m)

Cost head	Separator (₹ crore/ million sq. m)
Plant and machinery	4.33
Land and site development	0.58
Technology, acquisition cost	0.09
Soft costs	-
Others	-
Total (in ₹ cr/ million sq. m)	5

Source 32: As per input from industry players

The average CAPEX investment required for a separator manufacturing plant is ₹5 crore/million sq. m, with plant and machinery costing ₹4.33 crore/million sq. m, making it the largest investment component. Land and site development (₹0.58 crore/million sq. m) and technology acquisition costs (₹0.09 crore/million sq. m) constitute the remaining investment requirements for the project. The estimates provide an indication of the capital investment required for establishing domestic separator manufacturing capacity.

As investments in manufacturing infrastructure increase and production scales improve, cost efficiencies are expected to be realized, strengthening the competitiveness of domestic separator production.

Table 19: Minimum viable capacity, average CAPEX required for Separator

Technology	Min. viable capacity (million sq. m)	Average CAPEX required (in ₹ crore/million sq. m)
Separator	120	5

Source 33: As per input from industry players

To achieve commercial viability in separator manufacturing, a minimum production capacity of 120 million sq. m is required. Establishing manufacturing facilities at this scale is estimated to require an average capital investment of approximately ₹5 crore/million sq. m, providing an indication of the investment needed to develop economically viable separator production capacity.

Key challenges related to separator manufacturing:

Some of the key challenges related to separator manufacturing are mentioned below:

- Wet-process, Thermally Induced Phase Separation (TIPS) separator production uses 20-30% Ultra-high molecular weight polyethylene (UHMWPE) loading and specialized extrusion, stretching, and extraction equipment supplied by a limited number of global technology providers, creating high CAPEX and technology barriers.

- ii. Battery-separator-grade UHMWPE is fully imported, with no established domestic production in India, making feedstock availability a key constraint for local separator manufacturing.
- iii. Commercial lithium-ion separators require stringent quality control, including 9-25-micron thickness and tight specifications for porosity, air permeability, and thermal stability, posing a significant technical challenge for domestic manufacturers.
- iv. Separator materials are highly moisture-sensitive and require vacuum/moisture-barrier packaging and temperature-controlled storage to maintain performance and quality throughout handling and transportation.

The assessment indicates that India's separator ecosystem remains pre-commercial for lithium-ion applications, with domestic manufacturing experience currently built around lead-acid separators rather than the wet-process, ceramic-coated membranes ACC cells require. Both the base polymer feedstock (UHMWPE) and the ceramic-coating materials (boehmite/alumina) are almost entirely import-dependent, despite India's domestic bauxite base. Wet-process/biaxial-stretching technology and precision ceramic-coating capability are the primary capability gaps that need to be closed to localize production. The moisture sensitivity of the finished product adds further logistics, packaging, and inventory-management complexity across the value chain.

E. Aluminium Foil

Aluminium foil plays a critical role in the manufacturing and performance of batteries, particularly as the cathode current collector in Li-ion Cells. As an essential component, it contributes to the structural integrity, electrical conductivity, and overall efficiency of various battery types. From lithium-ion to lead-acid batteries, aluminium foil is utilized for its unique properties and versatility in meeting the specific demands of different battery chemistries. The choice of aluminium foil type depends on factors such as the specific battery chemistry, electrode materials, manufacturing process, and desired performance characteristics. Different battery technologies, such as lithium-ion, lead-acid, nickel-based, or other emerging battery systems, may have specific requirements for the type of aluminium foil used. Drawing upon inputs from industry participants and market assessments, the analysis examines the readiness of the domestic supply ecosystem to support the growing requirements of India's Advanced Chemistry Cell (ACC) industry.

Production capacities and CAPEX requirement

Based on industry inputs, the current aluminium foil manufacturing capacity in India is 25 ktpa. Based on industry benchmarks, the average capital investment required to establish aluminium foil production capacity is estimated at ₹32 crore per ktpa.

Table 20: Existing manufacturing capacity of aluminium foil

Technology	Current manufacturing capacity (ktpa)
Aluminium foil	25

Source 34: [Hindalco to set up battery foil manufacturing facility in Odisha to tap EV-market](#)

Table 13: Capex required for Aluminium foil (₹ crore/ktpa)

Cost head	Aluminium Foil (₹ crore/ ktpa)
Overall CAPEX	32
Total (in ₹ cr/ ktpa)	32

Source 35: [Hindalco to set up battery foil manufacturing facility in Odisha to tap EV-market](#)

Accordingly, any planned capacity expansion would require substantial capital expenditure, with investment levels scaling in line with the targeted increase in production capacity. This highlights the capital-intensive nature of aluminium foil manufacturing and underscores the importance of efficient capacity utilization and phased expansion planning.

Key challenges related to aluminium foil manufacturing:

Some of the key challenges related to aluminium foil manufacturing are mentioned below:

- i. Production of battery-grade foil requires ultra-thin gauges of 10-15 microns along with stringent thickness and surface-quality control, relying on imported rolling mills, control systems, and slitting equipment.
- ii. While India has a strong domestic aluminium value chain with access to bauxite, alumina, and primary aluminium, challenges persist in downstream precision rolling, alloying, and surface-treatment capabilities required for battery-grade foil production.

India possesses a strong domestic upstream aluminium ecosystem and has rapidly established dedicated battery-grade aluminium foil manufacturing capacity. With the commissioning of the planned 25,000 tonnes²⁶ battery foil facility and the availability of additional domestic aluminium processing capabilities, the projected 2030 demand of approximately 40,000 tonnes is considered achievable through existing capacity.

Consequently, unlike other ACC raw materials and components that continue to face cost disability due to import dependence, scale limitations, or technology gaps, aluminium foil is not expected to be a binding constraint from a cost or supply perspective. Therefore, aluminium foil is excluded from further cost disability analysis and is not considered a priority intervention area within the scope of this report. However, continued investment in battery-grade processing capabilities will be necessary to ensure that domestic production meets the required quality specifications and scales in line with future demand.

F. Copper Foil

Copper foil is a critical input in the manufacturing of Advanced Chemistry Cell (ACC) batteries, particularly lithium-ion batteries, where it is primarily used as the current collector for the anode. Owing to its excellent electrical conductivity, mechanical strength, and corrosion resistance, copper foil plays a vital role in ensuring efficient electron flow, battery performance, and cycle life. As India scales up domestic ACC manufacturing capacity, the availability of high-quality battery-grade copper foil will be essential for strengthening the local supply chain and reducing import dependence.

The choice of copper foil depends on battery chemistry, cell design, electrode specifications, and manufacturing processes. Battery manufacturers typically require ultra-thin, high-purity copper foil with stringent quality parameters relating to thickness uniformity, surface treatment, tensile strength, and conductivity. Different battery technologies, including lithium-ion, sodium-ion, and next-generation battery systems, may require varying specifications of copper foil to meet performance and safety requirements. Based on consultations with industry stakeholders and market assessments, the analysis evaluates the preparedness of the domestic copper foil industry to meet the projected demand from India's rapidly expanding ACC ecosystem.

Table 22: Existing manufacturing capacity of copper foil

Technology	Current manufacturing capacity (ktpa)
Copper foil	Nil

²⁶ [Hindalco to invest INR 800 Crore for 25,000-ton battery foil plant in Odisha | EV Reporter News](#)

Source 36: As per input from industry players

Based on industry inputs, the average capital investment required to establish copper foil manufacturing capacity is estimated at approximately ₹186 crore per ktpa. A significant proportion of the investment is directed towards plant and machinery, which accounts for around ₹28.3 crore per ktpa, while land and site development requirements including plant building and civil works contribute approximately ₹121 crore per ktpa. Additional investments are required towards technology acquisition, soft costs, and other supporting infrastructure, estimated at ₹5 crore, ₹27 crore, and ₹5 crore per ktpa, respectively.

Table 14: Capex required for copper foil (₹ crore/ ktpa)

Cost head	copper foil (₹ crore/ ktpa)
Plant and machinery	28.3
Land and site development	121
Technology, acquisition cost	5
Soft costs	27
Others	5
Total (in ₹ cr/ ktpa)	186

Source 37: As per input from industry players

Table 24: Minimum Viable Capacity, Average CAPEX required for copper foil

Technology	Min. viable capacity (ktpa)	Average CAPEX required (in ₹ crore/ktpa)
Copper foil	3.5	186

Source 38: As per input from industry players

Industry consultations indicate that a minimum viable manufacturing capacity of approximately 3.5 ktpa is required for a copper foil production facility to achieve operational efficiency and commercial competitiveness. As demand for ACC batteries increases, investments in domestic copper foil manufacturing capacity will be critical to ensuring supply chain resilience, reducing import dependence, and supporting the localization of India's battery value chain.

Key challenges related to copper foil manufacturing:

Some of the key challenges related to copper foil manufacturing are mentioned below:

- Manufacturing requires ultra-thin copper foil production capabilities, with industry inputs indicating standard foil thicknesses in the range of ~4.5 to 8 microns, necessitating advanced precision manufacturing processes.
- A critical dependency exists on imported titanium drums, with manufacturers indicating reliance on ~1.5 metre titanium drums used in electrodeposition processes. The absence of domestic manufacturing capabilities for such equipment increases costs and import dependence.

The assessment indicates that battery-grade copper foil manufacturing requires advanced technology, precision engineering, and stringent quality control processes. While key copper inputs are available domestically,

dependencies on imported copper concentrates, specialized equipment, and technology know-how continue to limit ecosystem maturity.

2.5. Summary of ACC components

The table summarizes the current manufacturing capacities of key ACC battery components in India. It highlights the significant capacity expansion being undertaken across cathode materials, anode materials, electrolytes, and separators to support the growth of domestic ACC cell manufacturing and reduce dependence on imported battery materials.

Table 25: Summary of current ACC component capacity details and investment requirements (in crore)

Technology	Unit	Existing capacity (unit)	Average CAPEX (₹ crore /unit)	Min. viable capacity (unit)
CAM	ktpa	7.98	46	20-60
AAM	ktpa	0.80	129	10-30
Electrolyte	ktpa	8	67	12-32
Separator	million sq. m	NA	5	120
Copper Foil	ktpa	NA	186	3.5
Aluminium Foil	ktpa	25	32	-

Source 43: As per input from industry players; note: the above-mentioned figures are considered on an average basis and can be used across all types of ACCs.

*NA – No identified domestic manufacturing capacity

While Indian players have substantial plans to increase their production capacity, it can be observed that the existing capacity in most cases falls short of the minimum capacity required for a viable business. Provision of financial incentives can help these players offset the disabilities and thereby enable them to further invest in capacity expansion.

Overall, the planned expansion of ACC component manufacturing represents a crucial step toward reducing import dependence, increasing domestic value addition, strengthening supply-chain resilience, and establishing a globally competitive battery ecosystem in India.

Testing infrastructure for ACC components in India

India has established capabilities for battery R&D, electrochemical characterization and cell-level testing, supported by IITs, CSIR laboratories, ARCI, and emerging private testing facilities. However, dedicated, independent and standardized testing infrastructure for individual ACC components particularly battery separators and electrolytes, remains limited. Existing capabilities are distributed across institutions and are not uniformly configured or accredited for end-to-end component qualification. Manufacturers often need to combine multiple laboratories for chemical, physical, and electrochemical qualification, which increases sample movement, coordination requirements, testing costs, and qualification timelines, while limiting access to independent third-party validation through a coordinated testing framework.

Table 26: Status of testing infrastructure for ACC components

ACC component	Status	Testing agencies/ Institutes
Cathode Active Material (LFP)/NMC	Existing facilities support development, material characterization, and electrochemical evaluation of lithium-ion battery cathode materials, including LFP and NMC, with cell-level validation capabilities.	• ARCI²⁷ • C-MET²⁸ • CAMB-Swagelok Cell²⁹
Anode Active Material-Graphite	Existing facilities support development of lithium-ion battery anode materials and their fabrication/ electrochemical evaluation, including graphite-based anodes, with cell-level testing capabilities.	• C-MET^{30,31} • CAMB-Swagelok Cell³²
Separator	Existing laboratory capabilities support the development and testing of Li-ion battery separators, including separator fabrication and evaluation of thermal stability.	• IIT-Madras³³ • CSIR³⁴ • IIT Bombay³⁵
Electrolyte	Existing laboratory capabilities support electrolyte material evaluation and electrochemical characterization, including assessment of electrolyte properties and their impact on battery performance.	• IIT Madras³⁶
Copper Foil	Battery-grade foil testing capabilities are emerging alongside domestic foil manufacturing, while institute qualification infrastructure remains limited.	No dedicated testing facility available

India has a growing battery testing and characterization ecosystem, with institutions such as ARCI, CSIR, IIT Madras, IIT Bombay, and C-MET providing capabilities across battery-material characterization and cell-level testing. Consequently, manufacturers may need to utilize multiple specialized laboratories for chemical, physical, electrochemical, and application-specific qualifications. In addition to the fragmented availability of testing capabilities, key gaps include access to specialized testing equipment and software, trained personnel capable of high-precision sample preparation and measurement, and the periodic augmentation of test methods and equipment to address emerging chemistries, cell formats and evolving national and international standards. Further, the availability of independent and accredited third-party facilities offering an integrated pathway from component characterization to representative cell-level validation remains limited.

Key challenges in developing India's ACC component manufacturing ecosystem

²⁷ [Technology Incubator | इंटरनेशनल एडवांस्ड रिसर्च सेंटर फॉर पाउडर मेटलर्जी एंड न्यू मैटेरियल्स](#)

²⁸ [Materials Renewable Energy | CENTRE FOR MATERIALS FOR ELECTRONICS TECHNOLOGY \(C-MET\)](#)

²⁹ [Swagelok cell | International Advanced Research Centre for Powder Metallurgy and New Materials](#)

³⁰ [Materials Renewable Energy | CENTRE FOR MATERIALS FOR ELECTRONICS TECHNOLOGY \(C-MET\)](#)

³¹ [Cover](#), CMET Annual report

³² [Swagelok cell | International Advanced Research Centre for Powder Metallurgy and New Materials](#)

³³ [The paper partition for batteries | Indian Institute of Technology Madras - IITM Shastra](#)

³⁴ [Energy Materials & Devices | CSIR-Central Glass & Ceramic Research Institute](#)

³⁵ [che.iitb.ac.in/sites/default/files/2025-05/ChemicalEnggBrochure_2024.pdf](#)

³⁶ [Battery Engineering Laboratory| E-Mobility Laboratories IIT Madras](#)

India's ACC component manufacturing ecosystem is at a nascent stage and continues to face several structural challenges that impact its competitiveness and long-term commercial viability. These challenges include dependence on imported raw materials and critical manufacturing equipment, limited domestic supply chain integration, inadequate testing and qualification infrastructure, and prolonged product qualification cycles. In addition, established global manufacturing hubs benefit from mature ecosystems, economies of scale, favorable policy support, and cost-efficient financing, resulting in a significant competitive advantage over emerging domestic manufacturers. Collectively, these factors contribute to higher production costs, longer project gestation periods, delayed revenue realization, and increased investment risk, thereby constraining the pace of domestic capacity creation and localization across the ACC component value chain.

 Dependence on imported critical raw materials and feedstock	Indian ACC component manufacturers rely heavily on imports for several battery-grade inputs, including separator-grade UHMWPE, electrolyte salts, battery-grade phosphate materials (with only ~20% domestic availability), and key CAM and AAM feedstocks. Production of synthetic graphite requires 1.28 tonnes of mesophase coke and 0.24 tonnes of coal tar pitch per tonne of anode, while natural graphite processing requires ~2.1 tonnes of graphite flakes for every tonne of battery-grade anode material.
 Limited domestic equipment manufacturing	Several critical manufacturing processes depend on imported equipment and technology. Key examples include imported jet mills and spray dryers for CAM production, specialized separator manufacturing equipment for the 20-30% UHMWPE-based Thermally Induced Phase Separation (TIPS) process, imported rolling and slitting systems for 10-15-micron aluminium foil, and dependence on imported ~1.5 m titanium drums for copper foil manufacturing.
 Process control and advanced manufacturing requirements	Battery component manufacturing requires highly precise process control and particle engineering capabilities. Challenges include ~20-hour jet milling cycles in CAM production, sub-micron particle-size control, 30-50 micron spheroidized graphite particles for AAM, separator thickness control of 9-25 microns, aluminium foil gauges of 10-15 microns, and copper foil thicknesses of ~4.5-8 microns.
 High-cost differential with China	Chinese manufacturers benefit from large-scale production, mature supply chains, government subsidies, low-cost financing, faster depreciation of assets and aggressive pricing, making it difficult for Indian manufacturers to compete on selling price at higher production costs.
 Inadequate testing, certification, and R&D infrastructure	Limited availability of domestic labs for battery-grade material characterization (particle size distribution, tap density, Initial Coulombic Efficiency (ICE), cycle-life testing) – leading to high reliance on overseas or OEM facilities and delaying product qualification with cell manufacturers. Lack of labs also increases development cost and slows commercialization of indigenous products.
 Long product qualification and commercialization cycle	Product approval by cell manufacturers typically requires 18-24 months, resulting in prolonged capacity underutilization, delayed revenue generation and weaker project economics, especially for first-time domestic manufacturers.

As a result of the structural and ecosystem-related challenges, Indian manufacturers face several cost disabilities across the ACC value chain. The next chapter provides a detailed assessment of these cost disabilities and their implications for domestic manufacturing competitiveness.

Chapter 3. ACC components cost disabilities faced by Indian manufacturers

3.1. Introduction

Findings from Chapter 1 pointed to the fact that leading companies, specifically based out of China, face significant cost advantages over their competitors. It was also observed that the disadvantage which Indian players have is due to multiple factors emerging out of a combination of higher raw material costs, limited domestic availability of critical inputs, lower economies of scale, lack of technological know-how, higher financing costs, dependence on imported technology, and comparatively higher capital expenditure requirements. These structural challenges reduce the competitiveness of Indian manufacturers leading to the country relying on imports for the upstream segment of battery manufacturing.

Accordingly, this section assesses the cost disabilities faced by Indian manufacturers across key ACC components, namely CAM (LFP), CAM (NMC), AAM (Natural Graphite), AAM (Synthetic Graphite), Electrolyte, Separator, and copper foil. This assessment of cost disability for Indian manufacturers has been carried out based on two complementary approaches:

Approach 1	Determination of average cost of manufacturing in India through data collected from industry players and landed cost of Chinese ACC components in India.
Approach 2	Validation through published international benchmark studies

Approach 1 is the primary India-specific assessment, as it compares estimated Indian manufacturing costs with the landed cost of comparable Chinese ACC components in India. It therefore provides the direct estimate of cost disabilities faced by Indian manufacturers relative to Chinese suppliers.

Approach 2 is an **international benchmarking exercise**, based on published studies comparing China with other major global manufacturing regions such as the United States, Europe, Japan, Korea, and other emerging battery supply-chain locations. It does not estimate India’s cost disability directly. Instead, it is used to **validate whether the cost gaps observed under Approach 1 are directionally consistent with broader evidence of China’s structural cost advantage** in ACC component manufacturing. The use of these two approaches provides both a component-level assessment based on Indian industry inputs and a broader validation based on international evidence.

In addition to manufacturing-cost differentials, this chapter also examines capital expenditure across key ACC components. This assessment is intended to identify component categories where the capital-cost differential relative to China is particularly significant and to distinguish between disabilities arising from recurring manufacturing costs and those arising from the upfront cost of establishing capacity. The combined assessment of operating and capital-cost differentials provides the basis for identifying the nature of intervention appropriate for each component.

3.2. Detailed methodology for estimation of cost disability factor

Approach 1: Determination of average cost of manufacturing in India through data collected from industry players and landed cost of Chinese ACC components in India

Under Approach 1, the average manufacturing cost of key ACC components in India has been estimated based on cost inputs received from industry stakeholders. The assessment has been carried out at a component level for CAM (LFP), CAM (NMC), AAM (Natural Graphite), AAM (Synthetic Graphite), Electrolyte, Separator, and copper foil.

For each component, stakeholders were requested to provide cost inputs in a defined template covering the major cost heads involved in manufacturing. These included:

1. Raw material cost	2. Conversion cost	3. Depreciation	4. Technology royalty	5. Selling, general and admin expenses	6. Finance charges
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The inputs received from industry stakeholders were used to arrive at the average Indian manufacturing cost for each component. The estimated cost build-up was then reviewed against the general cost structure of established Chinese players, based on the percentage contribution of comparable cost heads. This validation was undertaken to assess whether the Indian cost build-up was directionally consistent with industry cost structures observed among mature Chinese manufacturers.

Thereafter, the estimated Indian manufacturing cost was compared with the landed cost of comparable Chinese components in India. The landed Chinese cost was derived by using Chinese benchmark prices and adjusting them for freight, insurance, and applicable import duty. This enabled a like-for-like comparison between the cost of manufacturing the component in India and the effective cost at which comparable Chinese components can be made available in India.

The benchmark prices have been sourced from recognized market intelligence providers and industry publications covering ACC materials and components produced in China. These benchmark prices represent ex-factory prices combined with additional cost items such as freight, insurance, and transportation costs which result in a particular landed price of the component in India. Freight has been assumed at 1% of FOB price based on indicative container freight rates obtained from multiple logistics service providers³⁷. Insurance has been considered at 1.125% of FOB price in line with the Customs Valuation Rules, 2007³⁸, where insurance costs are not separately ascertainable.

Import duty has been considered exempt for parts, sub-parts, inputs or raw materials used in the manufacture of lithium-ion cells, based on the Finance Bill 2026³⁹, which provides exemption for such items up to 31st March 2028.

The cost disability under Approach 1 has been calculated using the following formula:

Cost disability (%) = [(Estimated Indian manufacturing cost/Chinese benchmark price adjusted for freight, insurance and import duty) – 1] × 100

This approach therefore combines stakeholder-based Indian manufacturing cost estimation, validation with Chinese cost-structure benchmarks, and comparison with landed Chinese benchmark prices. It provides a component-level estimate of the cost disabilities faced by Indian manufacturers relative to comparable Chinese components.

Approach 2: Rest of World (RoW) cost differential with China identified by existing global studies

³⁷ Quotations from multiple sources: Less than a Container Load (LCL) charges Aug'26 ~ US\$ 10-100/cbm : [Pazago](#), [SINO shipping](#), [Cargo from China, Freight Calculation](#)

³⁸ Customs Valuation (Determination of Value of Imported Goods) Rules, 2007, [India Code](#)

³⁹ [Finance Bill, 2026](#)

Approach 2 provides an independent validation of the findings from Approach 1 through a review of published international studies assessing battery-material competitiveness across major manufacturing regions. Unlike Approach 1, which compares manufacturing costs in India against China based on industry consultations and Chinese price benchmarks, this approach evaluates the magnitude and drivers of China's cost advantage relative to other global battery manufacturing regions, including the US, Europe, South Korea, and other emerging ACC components manufacturing hubs.

The analysis draws upon published studies and industry reports covering key ACC components and battery materials. These studies consistently assess regional differences in manufacturing costs, capital expenditure requirements, scale efficiencies, supply-chain integration, technology maturity, and operational costs across the battery value chain.

China has been adopted as the reference benchmark under this approach due to its leading position across multiple ACC component segments, extensive domestic supply-chain integration, large-scale manufacturing capacity, and established cost leadership across battery materials and intermediates. The findings are used to assess whether the competitiveness gaps observed under Approach 1 are consistent with the broader cost differentials reported between China and other major manufacturing regions globally.

3.3. Approach 1: Determination of average cost of manufacturing in India through data collected from industry players and landed cost of Chinese ACC components in India

A. Cathode Active Material

Cathode Active Material: LFP (Lithium Iron Phosphate)

LFP cathode active material production in India exhibits a material cost disadvantage when compared with Chinese benchmark prices. Based on stakeholder inputs, the average Indian manufacturing cost for CAM-LFP is estimated at US\$ 10,004 per tonne, while the average Chinese landed cost is estimated at US\$ 6,818 per tonne, resulting in a cost disability of 47%.

The Indian cost structure is heavily driven by raw material cost, which accounts for 79% of the total manufacturing cost. Conversion cost accounts for 8%, while depreciation contributes 5%. Together, raw material cost, conversion cost, and depreciation account for 92% of the Indian manufacturing cost base. In comparison, the corresponding cost heads for established Chinese players account for approximately 89% of total cost, indicating that the overall cost structure is directionally comparable, but Indian manufacturers face a higher absolute cost base.

Table 27: Indian manufacturing cost assessment – LFP Cathode Active Material (US\$/tonne)

S. No.	Cost heads	Cost in India (US\$/tonne)	% of total cost – India	% of total cost – China	Remarks
1	Raw material cost	7,906	92%	89%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025: i. Shenzhen Dynanonic ii. Hunan Yuneng iii. Jiangsu Lopal Tech
2	Conversion cost	810			
3	Depreciation	490			
4	Technology royalty	160	8%	11%	

S. No.	Cost heads	Cost in India (US\$/tonne)	% of total cost – India	% of total cost – China	Remarks
5	Selling, general and admin expenses	170			iv. <i>Hubei Wanrun New Energy</i>
6	Finance charges	468			
Total cost of manufacturing		10,004	100%		

Source 44: Data for same companies used for CAM – LFP and CAM – NMC

Validating China cost through external benchmarks:

The Chinese benchmark price trend further reinforces this competitiveness gap. Chinese CAM-LFP landed cost across the assessed period range from US\$ 5,208 per tonne to US\$ 9,191 per tonne, with an average landed cost of US\$ 6,818 per tonne.

The price trend is presented below for LFP CAM:

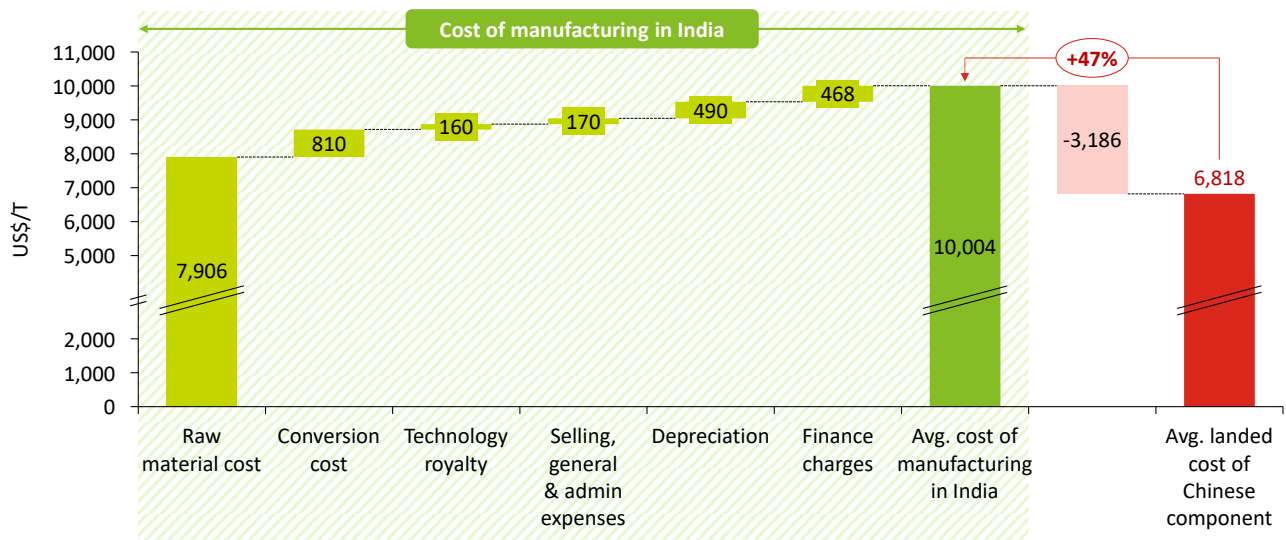
Table 28: Average Chinese benchmark prices – LFP Cathode Active Material (US\$/tonne)

CAM-LFP	May-25	Sep-25	Jan-26	Mar-26	Jul-26	Average
Chinese benchmark prices	5,100	5,280	6,800	7,200	9,000	6,676
Landed cost of Chinese component in India (including freight, insurance and duty)	5,208	5,392	6,945	7,353	9,191	6,818

Source 45: JP Morgan (May 2025-July 2026)

Overall, the CAM-LFP assessment indicates that Indian manufacturers face a significant cost disadvantage relative to Chinese suppliers. The disability is primarily linked to higher raw material costs, lower manufacturing scale, and limited domestic ecosystem maturity for LFP Cathode Active Material production. While the Indian cost-head distribution is broadly comparable with Chinese cost structures, the absolute manufacturing cost remains materially higher than the Chinese landed cost, making CAM-LFP one of the key components where domestic competitiveness gaps are clearly visible.

Figure 21: Cost disability assessment (CAM – LFP)



Source 46: Stakeholder inputs, JP Morgan (May 2025-July 2026)

Cathode Active Material: NMC (Nickel Manganese Cobalt)

NMC Cathode Active Material manufacturing in India shows a relatively lower cost disability compared with several other ACC components assessed under Approach 1. Based on stakeholder inputs, the average Indian manufacturing cost for CAM-NMC is estimated at US\$ 25,860 per tonne, compared with the average Chinese landed cost of US\$ 21,917 per tonne, resulting in a cost disability of 18%.

The Indian cost structure for CAM-NMC is primarily concentrated in raw material and conversion costs. Raw material cost accounts for 77% of the total manufacturing cost, while conversion cost accounts for 9%. Selling, general and administrative expenses account for 2%.

For established Chinese players, raw material cost, conversion cost, and depreciation together account for approximately 89% of total cost, while the remaining cost heads account for around 11%. In the Indian stakeholder inputs, raw material cost, conversion cost, and depreciation together account for 91% of the total manufacturing cost, indicating that these cost elements are directionally aligned while absolute Indian cost remains higher.

Table 29: Indian manufacturing cost assessment – NMC Cathode Active Material (US\$/tonne)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	20,000	91%	89%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025: - Shenzen Dynanonic - Hunan Yuneng - Jiangsu Lopal Tech - Hubei Wanrun New Energy
2	Conversion cost	2,263			
3	Depreciation	1,369			
4	Technology royalty	447	9%	11%	
5	Selling, general and admin expenses	475			
6	Finance charges	1,306			
Total cost of manufacturing		25,860	100%	100%	

Source 47: Data for same companies used for CAM – LFP and CAM – NMC.

Validating China cost through external benchmarks:

Accordingly, the CAM-NMC assessment places greater reliance on the comparison between total Indian manufacturing cost and Chinese benchmark prices, rather than on a detailed cost-head-level comparison. Chinese landed cost for CAM-NMC ranged from US\$ 15,426 per tonne to US\$ 30,194 per tonne during the assessed period, with an average landed cost of US\$ 21,917 per tonne. Against this benchmark, Indian manufacturing cost remains higher, resulting in a cost disability of 18%.

As per JP Morgan, the following is the price trend for NMC CAM:

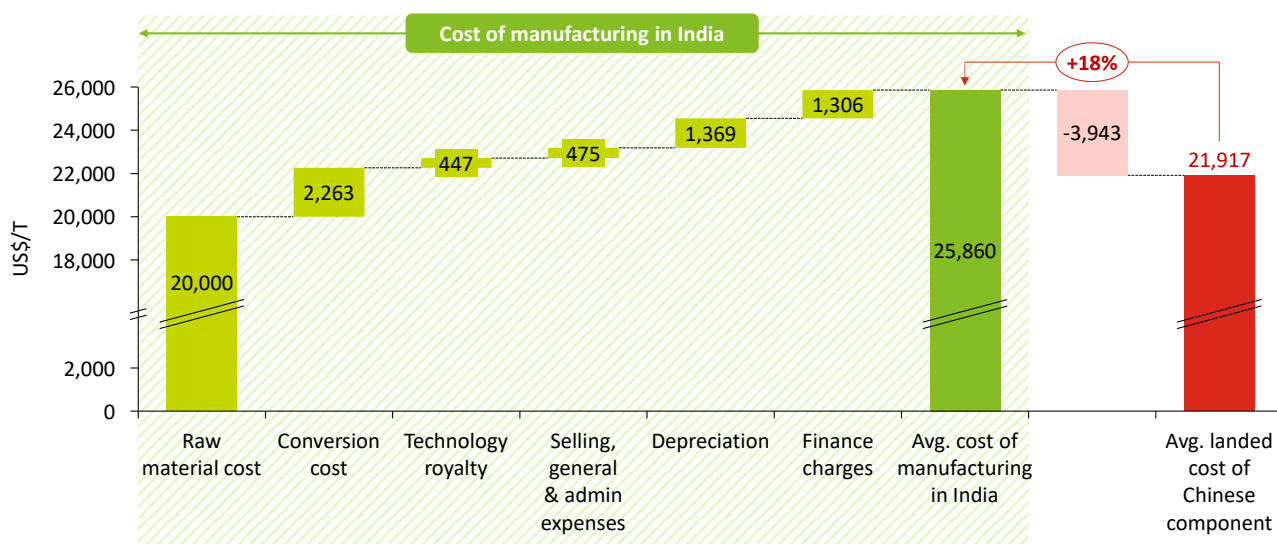
Table 30: Average Chinese benchmark prices – NMC Cathode Active Material (US\$/tonne)

CAM-NMC	Jul-24	Feb-25	Sep-25	Mar-26	Jul-26	Average
Chinese benchmark prices	16,901	15,105	17,454	28,280	29,566	21,461
Landed cost of Chinese component in India (including freight, insurance and duty)	17,260	15,426	17,825	28,880	30,194	21,917

Source 48: JP Morgan (May 2025-July 2026), Estimated Cost of EV Batteries: 2019-2025 | ANL

Overall, the CAM-NMC assessment indicates that Indian manufacturers face a moderate competitiveness gap relative to Chinese suppliers. The disability is primarily linked to raw material sourcing, dependence on imported battery-grade inputs, and lower procurement scale compared with established Chinese manufacturers.

Figure 22: Cost disability assessment (CAM – NMC)



Source 49: Stakeholder inputs, JP Morgan (May 2025-July 2026), Estimated Cost of EV Batteries: 2019-2025 | ANL [Estimated Cost of EV Batteries: 2019-2025 | ANL](#)

B. Active Anode Material

Anode Active Material: Natural Graphite

Natural graphite anode active material manufacturing in India exhibits a significant cost disability relative to Chinese benchmark prices. Based on stakeholder inputs, the average Indian manufacturing cost for AAM-NG is estimated at US\$ 5,560 per tonne, compared with the Chinese benchmark price of US\$ 3,671 per tonne, resulting in a cost disability of 51%.

The Indian cost structure for AAM-NG is more evenly distributed across raw material and processing-related costs compared with Cathode Active Materials. Raw material cost accounts for 45% of the total manufacturing cost, while conversion cost accounts for 40%.

This cost structure indicates that AAM-NG competitiveness is not driven by raw material procurement alone. Conversion cost is a particularly material cost head, reflecting the processing intensity involved in natural graphite purification, spheroidization, coating, and other value-addition steps required for battery-grade anode material. The combined share of raw material cost, conversion cost, and depreciation is 91% of the Indian manufacturing cost base, compared with approximately 85% for similar cost heads in established Chinese players.

Table 31: Indian manufacturing cost assessment – Natural Graphite Anode Active Material (US\$/tonne)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	2,500	91%	85%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025:
2	Conversion cost	2,200			
3	Depreciation	370			
4	Technology royalty	-	9%	15%	- Shanghai Putailai - Shanghai XFH Technology Co. Ltd - Shijiazhuang Shangtai Technology Co., Ltd.
5	Selling, general and admin expenses	120			
6	Finance charges	370			
Total cost of manufacturing		5,560	100%	100%	

Source 50: Data for same companies used for AAM – NG and AAM – SG

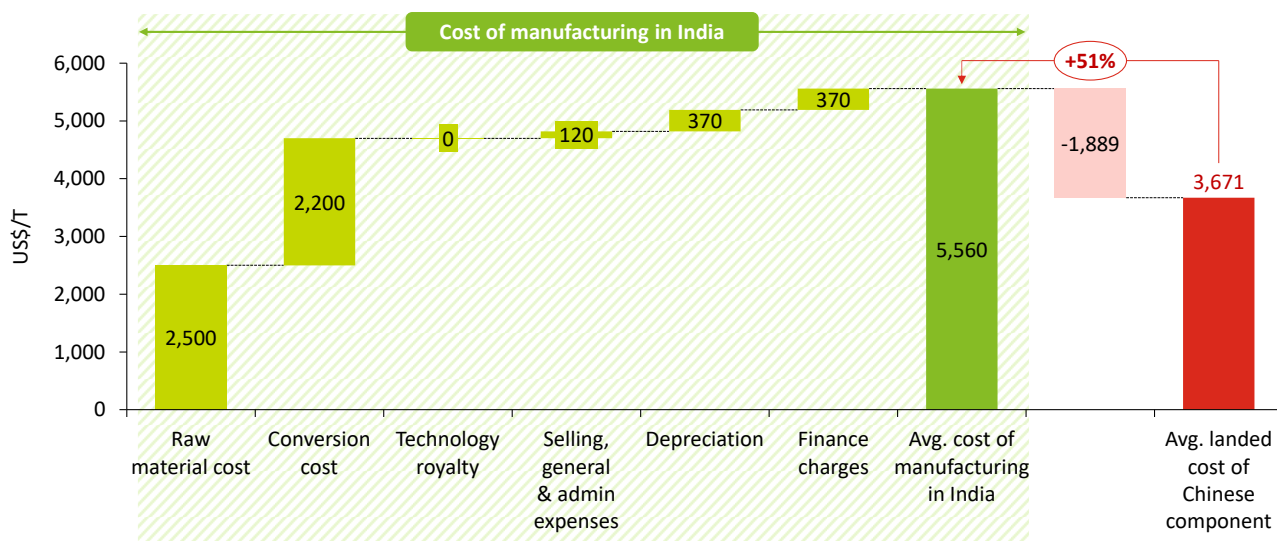
Validating China cost through external benchmarks:

The landed cost for AAM-NG in July 2026 is US\$ 3,671/ton⁴⁰, average of low-end and mid-end natural graphite. Against this cost, the Indian manufacturing cost of US\$ 5,560 per tonne implies a cost disability of 51%. This highlights that Indian manufacturers face a sizeable competitiveness gap in natural graphite anode material, driven by both material sourcing and processing economics.

Overall, the AAM-NG assessment indicates that India's cost disadvantage is linked to limited domestic scale in battery-grade graphite processing, higher conversion costs, dependence on imported or externally processed input materials, and relatively lower maturity of the domestic anode material ecosystem. Unlike CAM, where raw material cost is the key cost head, AAM-NG disability is more strongly influenced by the combined effect of raw material cost and processing cost.

⁴⁰ Trendforce

Figure 23: Cost disability assessment (AAM – NG)



Source 39: Stakeholder inputs, Trendforce

Anode Active Material: Synthetic Graphite

Synthetic graphite anode active material manufacturing in India exhibits one of the highest cost disabilities among the ACC components assessed under Approach 1. Based on stakeholder inputs, the average Indian manufacturing cost for AAM-SG is estimated at US\$ 7,622 per tonne, compared with the average Chinese landed cost of US\$ 4,738 per tonne, resulting in a cost disability of 61%.

The Indian cost structure for AAM-SG is distributed across raw material cost, conversion cost, depreciation, finance charges, and overheads. Raw material cost accounts for 42% of total manufacturing cost, while conversion cost accounts for 29%. Depreciation contributes 11%, finance charges account for 10%, selling, general and administrative expenses account for 7%, and technology royalty accounts for 1%.

This cost structure indicates that the competitiveness gap in AAM-SG is not driven by raw material cost alone. Conversion cost, depreciation, and finance charges together account for 50% of the Indian manufacturing cost base, reflecting the capital-intensive and energy-intensive nature of synthetic graphite production. The graphitization process requires high-temperature processing, specialized equipment, significant power consumption, and high plant utilization to achieve competitive unit costs.

When compared with established Chinese cost structures, raw material cost, conversion cost, and depreciation together account for 82% of the Indian manufacturing cost base, broadly comparable with the 85% share observed for similar cost heads among established Chinese players. The remaining cost heads account for 18% of Indian manufacturing cost, compared with 15% for Chinese companies. While the cost-head distribution is directionally aligned, the absolute manufacturing cost in India remains materially higher.

Table 32: Indian manufacturing cost assessment – Synthetic Graphite Anode Active Material (US\$/tonne)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	3,167	82%	85%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025: • Shanghai Putailai
2	Conversion cost	2,234			
3	Depreciation	874			
4	Technology royalty	80	18%	15%	

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
5	Selling, general and admin expenses	518			- Shanghai XFH Technology Co. Ltd - Shijiazhuang Shangtai Technology Co., Ltd.
6	Finance charges	749			
Total cost of manufacturing		7,622	100%	100%	

Source 52: Data for same companies used for AAM – NG and AAM – SG

Validating China cost through external benchmarks:

The Chinese benchmark price assessment further highlights this competitiveness gap. Chinese landed cost for AAM-SG ranged from US\$ 4,548 per tonne to US\$ 4,991 per tonne during the assessed period, with an average landed cost of US\$ 4,738 per tonne. Against this benchmark, the Indian manufacturing cost of US\$ 7,622 per tonne implies a cost disability of 61%.

The price trend is presented below for AAM-SG:

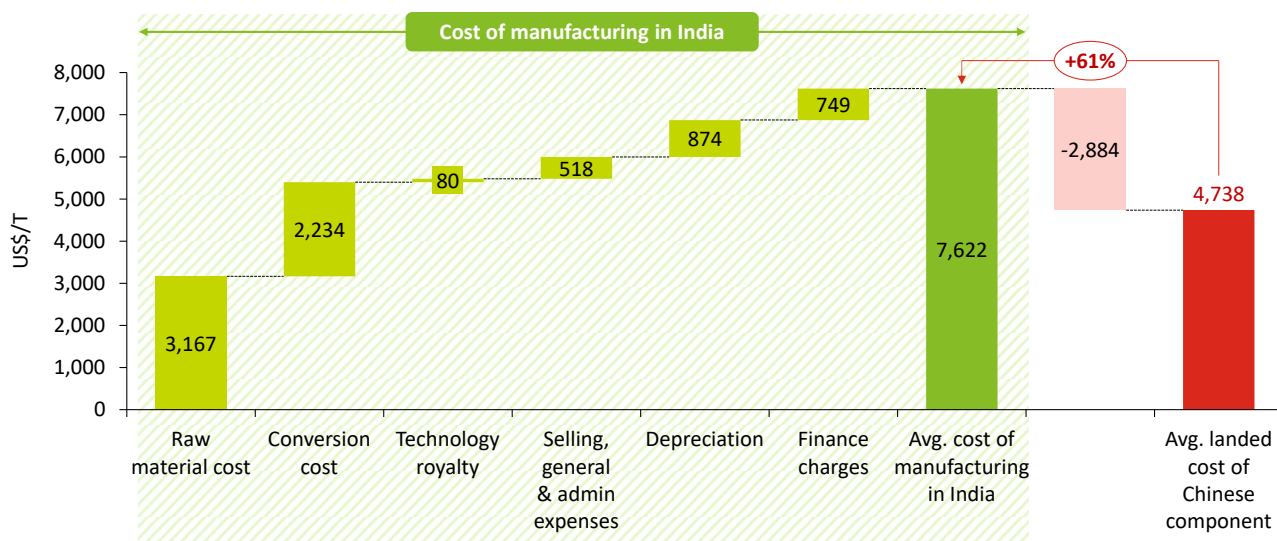
Table 33: Average Chinese benchmark prices – SG Anode Active Material (US\$/tonne)

AAM-SG	May-25	Nov-25	Jan-26	Apr-26	Jul-26	Average
Chinese benchmark prices	4,887	4,858	4,500	4,500	4,454	4,640
Landed cost of Chinese component in India (including freight, insurance and duty)	4,991	4,961	4,596	4,596	4,548	4,738

Source 53: JP Morgan (May 2025-July 2026), Trendforce

Overall, the AAM-SG assessment indicates that Indian manufacturers face a significant structural cost disadvantage relative to Chinese suppliers. The disability is primarily linked to higher conversion costs, elevated capital-related costs, financing burden, lower scale, and the limited maturity of India's domestic synthetic graphite processing ecosystem. Unlike natural graphite, where raw material and processing costs are both important, synthetic graphite competitiveness is especially sensitive to energy cost, plant utilization, graphitization efficiency, and capital intensity.

Figure 24: Cost disability assessment (AAM – SG)



Source 54: Stakeholder inputs, JP Morgan (May 2025-July 2026), Trendforce

C. Electrolyte

Electrolyte manufacturing in India exhibits a significant cost disability relative to Chinese benchmark prices. Based on stakeholder inputs, the average Indian manufacturing cost for electrolyte is estimated at US\$ 5,750 per tonne, compared with the average Chinese benchmark price of US\$ 4,182 per tonne, resulting in a cost disability of 37%.

The Indian cost structure for electrolyte is primarily driven by raw material cost, which accounts for 76% of total manufacturing cost. Conversion cost accounts for 10%, while depreciation and finance charges account for 5% each. Technology royalty and selling, general and administrative expenses account for 3% each. This indicates that electrolyte competitiveness is largely dependent on access to cost-competitive input materials, formulation capabilities, and scale of chemical processing operations.

When compared with established Chinese cost structures, raw material cost, conversion cost, and depreciation together account for 90% of the Indian manufacturing cost base, broadly comparable with the 86% share observed for similar cost heads among established Chinese players. The remaining cost heads account for 10% of Indian manufacturing cost, compared with 14% for Chinese companies. While the cost-head distribution is directionally comparable, Indian manufacturers face higher absolute manufacturing costs, particularly in raw material procurement, conversion and depreciation costs.

Table 34: Indian manufacturing cost assessment – Electrolyte (US\$/tonne)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	4,355	90%	86%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025:
2	Conversion cost	555			
3	Depreciation	260			
4	Technology royalty	150	10%	14%	- Guangzhou Tinci Materials Technology Co. - Shenzhen Capchem Technology Co - Finework(Hunan) New Energy Technology Co., Ltd
5	Selling, general and admin expenses	155			
6	Finance charges	275			

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
	Total cost of manufacturing	5,750	100%	100%	

Validating China cost through external benchmarks:

The Chinese landed cost assessment further reinforces the competitiveness gap. Chinese landed cost for electrolyte ranged from US\$ 3,064 per tonne to US\$ 5,591 per tonne during the assessed period, with an average landed cost of US\$ 4,182 per tonne. Against this landed cost, the Indian manufacturing cost of US\$ 5,750 per tonne implies a cost disability of 37%.

The price trend is presented below for Electrolyte:

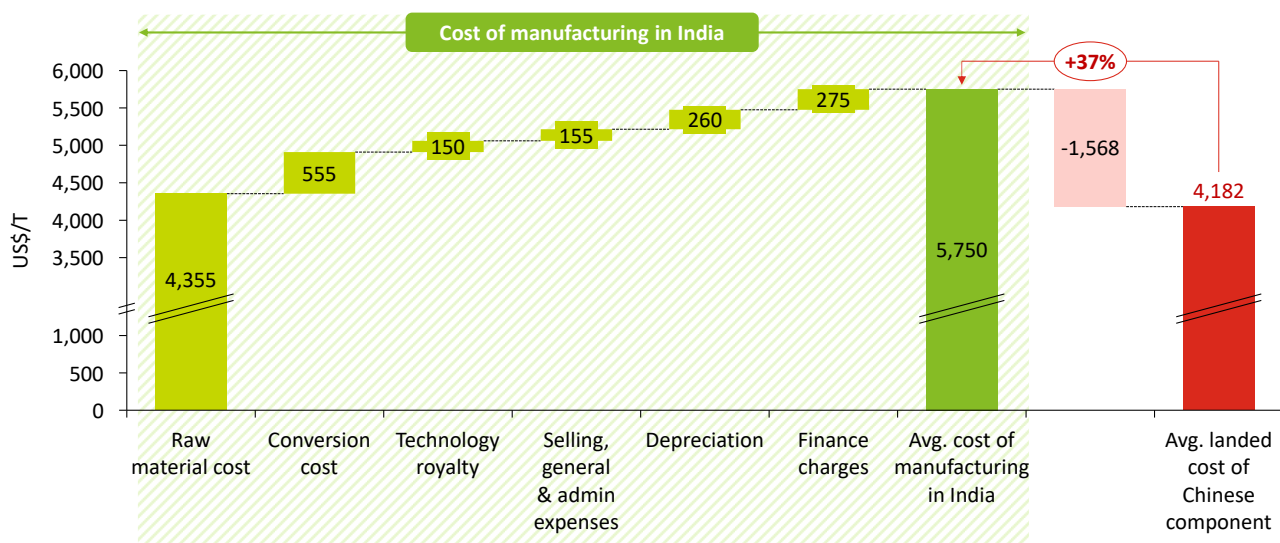
Table 35: Average Chinese benchmark prices – Electrolyte (US\$/tonne)

Electrolyte	Jul-25	Oct-25	Jan-26	Apr-26	Jul-26	Average
Chinese benchmark prices	3,000	3,075	5,475	4,350	4,575	4,095
Landed cost of Chinese component in India (including freight, insurance and duty)	3,064	3,140	5,591	4,442	4,672	4,182

Source 55: JP Morgan (May 2025-July 2026), Shanghai Metals Market

Overall, the electrolyte assessment indicates that Indian manufacturers face a material cost disadvantage relative to Chinese suppliers. The disability is primarily linked to higher raw material costs, dependence on imported or externally sourced electrolyte-grade inputs, smaller domestic manufacturing scale, and limited integration across the domestic electrolyte value chain.

Figure 21: Cost disability assessment (Electrolyte)



Source 56: Stakeholder inputs, JP Morgan (May 2025-July 2026), Shanghai Metals Market [Shanghai Metals Market](#)

D. Separator

separator manufacturing in India exhibits a significant cost disability relative to Chinese landed cost. Based on stakeholder inputs, the average Indian manufacturing cost for separator is estimated at US\$ 0.25 per sq. m, compared with the average Chinese landed cost of US\$ 0.17 per sq. m, resulting in a cost disability of 49%.

Raw material cost accounts for 39% of total manufacturing cost, while conversion cost accounts for 20%. The cost structure indicates that separator competitiveness is influenced not only by raw material procurement, but also by capital intensity, financing cost, equipment cost, technology dependence, and plant utilization. Raw material cost, conversion cost, and depreciation together account for 74% of the Indian manufacturing cost base, compared with approximately 80% for similar cost heads among established Chinese players. The remaining cost heads account for 26% of Indian manufacturing cost compared with 20% in the Chinese cost structure; this difference is mainly due to the relatively high share of finance charges and technology royalty in the Indian cost build-up.

This reflects the specialized and capital-intensive nature of separator manufacturing. Separator production requires precision equipment, process control, technology access, and high-capacity utilization to achieve competitive unit costs.

Table 36: Indian manufacturing cost assessment – Separator (US\$/sq. m)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	0.10	74%	80%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025:
2	Conversion cost	0.05			
3	Depreciation	0.04			
4	Technology royalty	0.01	26%	20%	- Yunnan Energy New Material (Group) Co., Ltd. (Semcorp) - Shenzhen Senior Technology Material Co Ltd
5	Selling, general and admin expenses	0.01			
6	Finance charges	0.04			
Total cost of manufacturing		0.25	100%	100%	

Note: The estimated Indian manufacturing cost is based on industry stakeholder inputs for their planned capacities.

Validating China cost through external benchmarks:

The Chinese landed cost assessment further supports the observed competitiveness gap. Chinese landed cost for separators ranged from US\$ 162,883 per million sq. m to US\$ 175,293 per million sq. m during the assessed period, with an average landed cost of US\$ 168,700 per million sq. m.

The price trend is presented below for Separator:

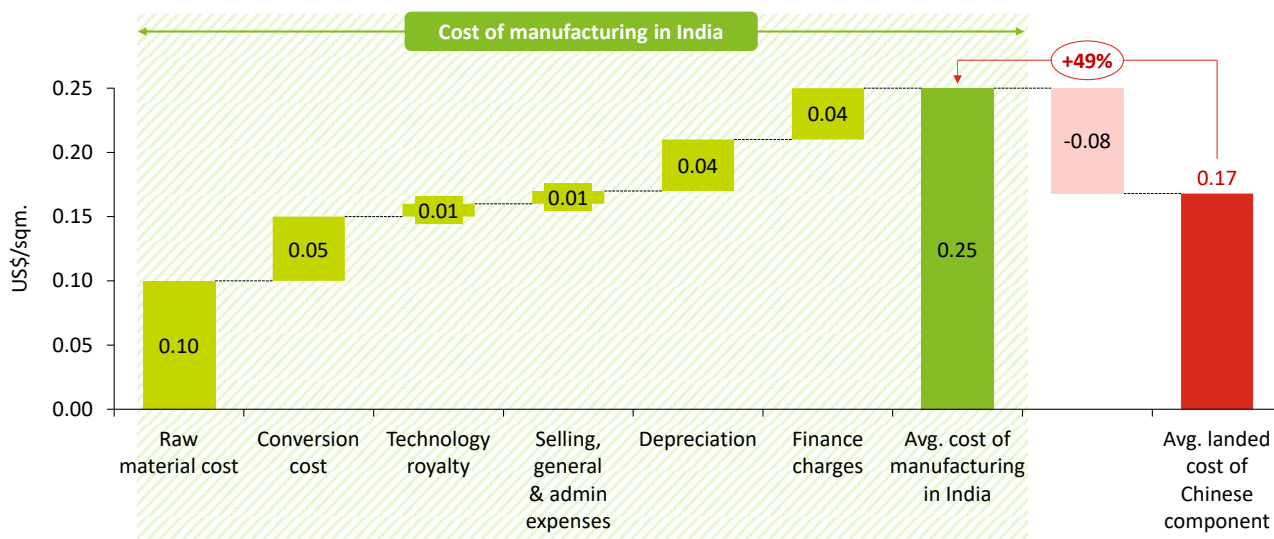
Table 37: Average Chinese benchmark prices – Separator (US\$/ sq. m)

Separator	Jul-25	Oct-25	Jan-26	Apr-26	Jul-26	Average
Chinese benchmark prices	0.170	0.172	0.159	0.159	0.159	0.165
Landed cost of Chinese component in India (including freight, insurance and duty)	0.174	0.175	0.163	0.163	0.163	0.168

Source 57: JP Morgan (May 2025-July 2026), Shanghai Metals Market [Shanghai Metals Market](#)

Overall, the separator assessment indicates that Indian manufacturers face a material structural cost disadvantage relative to Chinese suppliers. The disability is primarily linked to higher capital-related costs, financing burden, technology dependence, imported equipment requirements, lower domestic scale, and limited maturity of the separator manufacturing ecosystem.

Figure 22: Cost disability assessment (Separator)



Source 58: Stakeholder inputs, JP Morgan (May 2025-July 2026), Shanghai Metals Market [Shanghai Metals Market](#)

E. Copper Foil

Copper foil manufacturing in India shows a cost disability relative to Chinese landed cost. Based on stakeholder inputs, the average Indian manufacturing cost for copper foil is estimated at US\$ 18,705 per tonne, compared with the average Chinese landed cost of US\$ 14,787 per tonne, resulting in a cost disability of 27%.

The reported Indian cost structure for copper foil is primarily concentrated in raw material cost, which accounts for 77% of total manufacturing cost. Conversion cost accounts for 16%, while depreciation accounts for 4%. Technology royalty, selling, general and administrative expenses, and finance charges each account for approximately 1% of the reported cost base.

Given the high concentration of costs under raw material and conversion cost, the cost-head-level comparison with established Chinese players should be interpreted directionally. In the stakeholder inputs, raw material cost, conversion cost, and depreciation together account for 97% of the Indian manufacturing cost base, compared with approximately 87% for similar cost heads among established Chinese players. The remaining cost heads account for only 3% of Indian manufacturing cost, compared with 13% in the Chinese cost structure. This may reflect differences in cost classification, allocation methodology, or the extent of cost-head disaggregation available through stakeholder submissions. Accordingly, the copper foil assessment places greater reliance on the comparison between total Indian manufacturing cost and Chinese landed cost, rather than on a strict like-for-like comparison of individual cost heads.

Table 38: Indian manufacturing cost assessment – Copper Foil (US\$/tonne)

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
1	Raw material cost	14,400	97%	87%	

S. No.	Cost heads	Indian manufacturing cost	% of total cost – India	Chinese cost structure	Remarks
2	Conversion cost	3,006	3%	13%	% of total cost for China is the average of the following companies for years 2023, 2024, 2025: - Anhui Tongguan copper foil Group Co. Ltd - Guangdong Chaohua Technology Co Ltd
3	Depreciation	802			
4	Technology royalty	127			
5	Selling, general and admin expenses	235			
6	Finance charges	135			
Total cost of manufacturing		18,705	100%	100%	

Note: The estimated Indian manufacturing cost is based on industry stakeholder inputs for their planned capacities.

Validating China cost through external benchmarks:

Chinese landed cost for copper foil ranged from US\$ 12,489 per tonne to US\$ 16,336 per tonne during the assessed period, with an average landed cost of US\$ 14,787 per tonne. Against this landed cost, the Indian manufacturing cost of US\$ 18,705 per tonne implies a cost disability of 27%.

The price trend is presented below for copper foil:

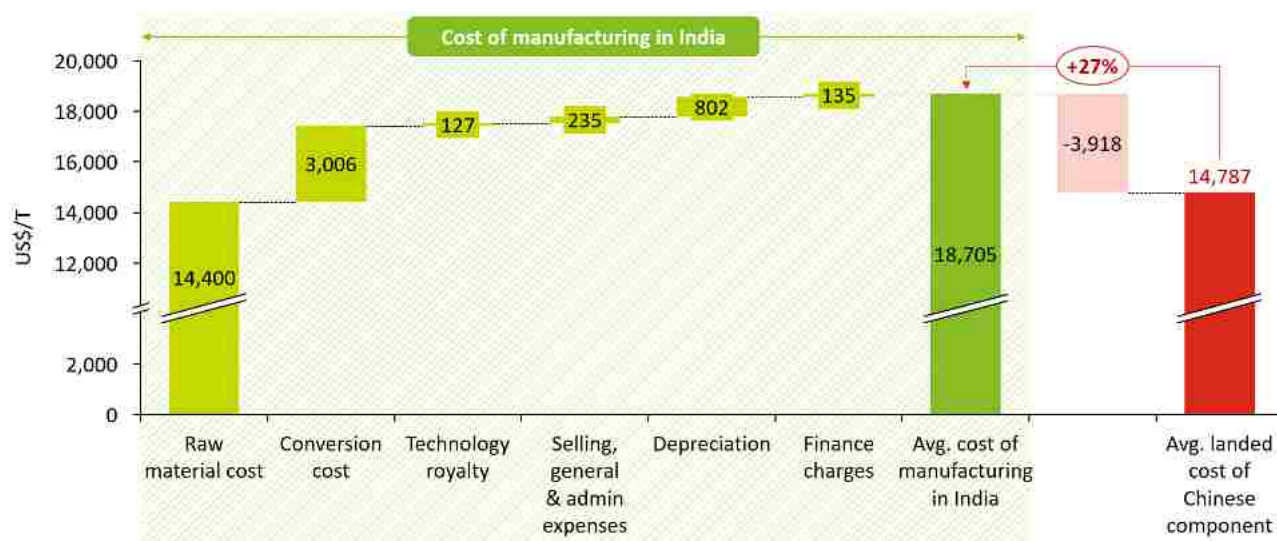
Table 39: Average Chinese benchmark prices – Copper Foil (US\$/tonne)

Copper Foil	Jul-25	Oct-25	Jan-26	Mar-26	Jul-26	Average
Chinese benchmark prices	12,230	13,365	15,627	15,177	15,996	14,479
Landed cost of Chinese component in India (including freight, insurance and duty)	12,489	13,649	15,959	15,500	16,336	14,787

Source 59: JP Morgan (May 2025-July 2026)

Overall, the copper foil assessment indicates that Indian manufacturers face a cost disadvantage relative to Chinese suppliers, although the magnitude of disability is lower than that observed for CAM-LFP, AAM-NG, AAM-SG, electrolyte, and separator. The disability is primarily linked to higher raw material procurement cost, conversion economics, manufacturing scale, and supply-chain maturity. However, given the limited disaggregation of certain cost heads in stakeholder inputs, the cost-head-level comparison should be treated as indicative, while the overall disability estimate is based on the total cost comparison with Chinese benchmark prices.

Figure 23: Cost disability assessment (Copper Foil)



Source 60: Stakeholder inputs, JP Morgan (May 2025-July 2026)

Cross-component analysis from Approach 1

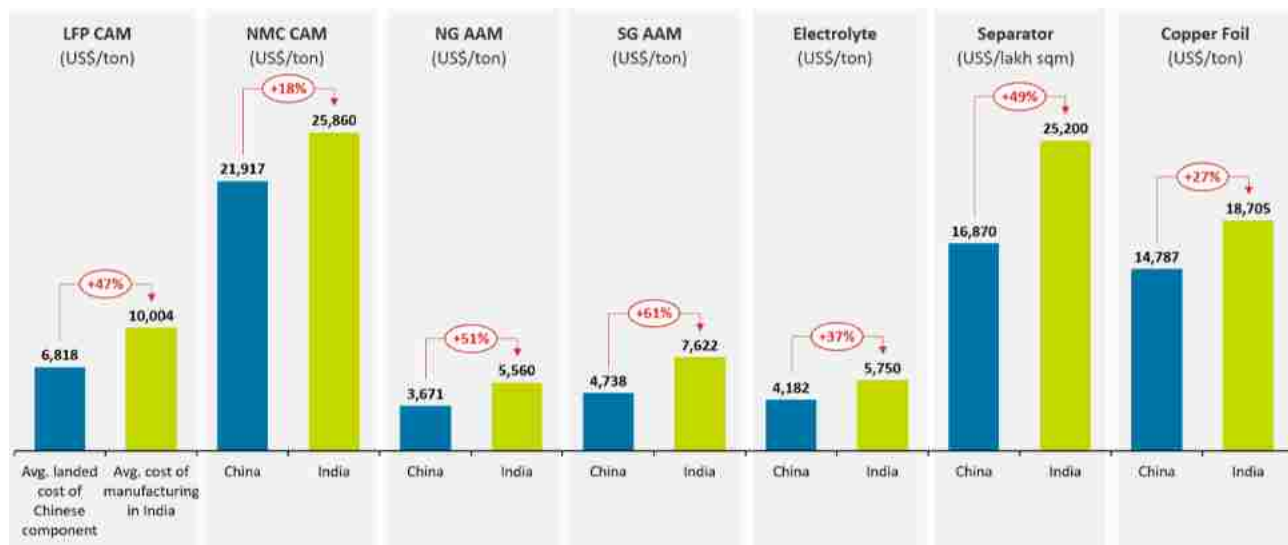
The component-level assessment under Approach 1 indicates that Indian ACC component manufacturers face cost disability across all assessed components, although the magnitude and drivers of disability vary significantly by component. Based on the comparison of Indian manufacturing cost with landed Chinese benchmark prices, the cost disability ranges from 18% for CAM-NMC to 61% for AAM-SG.

The analysis also indicates that the drivers of cost disability differ across the ACC component value chain. For CAM-LFP, CAM-NMC, Electrolyte, and copper foil, raw material cost remains the key cost head, indicating that competitiveness is strongly influenced by input sourcing, procurement scale, and domestic availability of battery-grade materials. In these components, the Indian cost structure is largely concentrated in raw material and conversion costs, suggesting that supply-chain localization and procurement efficiencies will be critical for improving competitiveness.

For AAM-NG and AAM-SG, the cost disability is influenced by both raw material and processing-related costs. For Separator, the cost disability is more strongly linked to capital intensity, technology dependence, financing cost, depreciation, equipment cost, and capacity utilization. The comparison with established Chinese cost structures also shows that Indian cost-head distributions are directionally comparable for components.

Overall, Approach 1 demonstrates that India's cost disability is not attributable to a single factor. It arises from a combination of higher input costs, lower procurement scale, limited domestic availability of critical materials, lower manufacturing scale, higher capital-related costs, technology dependence in selected components, and relatively lower maturity of the domestic ACC component ecosystem. The nature of intervention required is therefore likely to vary by component. Raw-material-linked components would require supply-chain localization and procurement scale, while processing-intensive and capital-intensive components would require technology access, lower financing costs, higher utilization, and faster ecosystem development.

Figure 24: Cost disability assessment – Summary



Source 61: Stakeholder inputs, JP Morgan (May 2025-July 2026)

3.4. Approach 2: Rest of World (RoW) cost differential with China identified by existing global studies

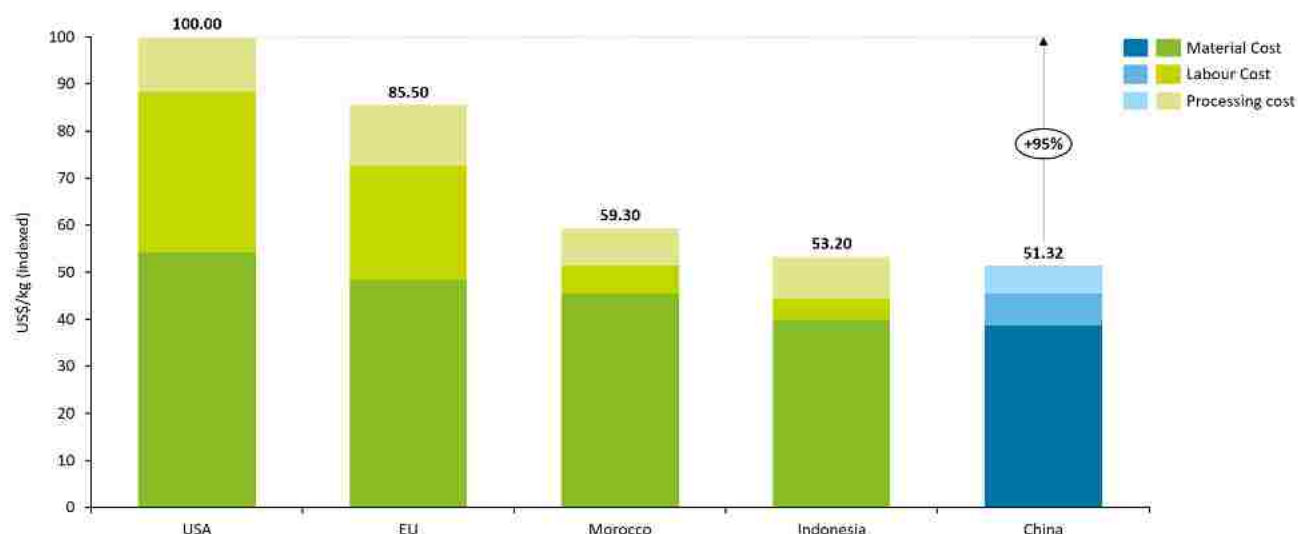
A. Cathode Active Material (CAM) and precursor to CAM (pCAM)

Lithium Iron Phosphate (LFP)

China accounts for the majority of global LFP cathode manufacturing capacity and has emerged as the global center for LFP technology development, commercialization, and large-scale production. The country's leading position has enabled the creation of an integrated ecosystem spanning raw materials, cathode manufacturing, cell production, equipment supply, and downstream battery demand. This ecosystem has translated into a significant cost advantage over other major battery manufacturing regions.

Published international benchmarks indicate that China is the lowest-cost manufacturing location among major LFP-producing regions. Using a normalized cost index where United States LFP-CAM production costs are indexed to 100, China records a relative cost index of 51.3, implying that LFP cathode manufacturing costs in China are approximately 49% lower than those in the United States. Other emerging manufacturing locations such as Indonesia (53.2) and Morocco (59.3) also exhibit competitive cost structures, while the European Union (85.5) remains materially higher than China. Cost disadvantages relative to China are prevalent across both developed and emerging battery manufacturing economies.

Figure 25: Benchmark comparison of LFP-CAM production costs (U.S. cost indexed to 100%), 2025



Source 40: [2025 Battery Report \(dev\)](#)

The arithmetic average of cost differential in CAM Manufacturing in US, EU, Morocco, and Indonesia against China is approximately 46%.

China's advantage is primarily attributable to lower manufacturing conversion costs and a deeply integrated supply-chain ecosystem. Battery manufacturing studies indicate that labor costs account for approximately 13.3% of total cell conversion costs in China, compared with 33.9% in the United States and 28.4% in Germany, even when assuming comparable factory design, equipment configuration, and operating efficiency. The results demonstrate that China's competitiveness is not solely driven by scale, but also by structural advantages in operating costs and manufacturing economics.

These advantages are particularly relevant for LFP cathode manufacturing, where competitiveness is driven largely by conversion costs, scale, and operational efficiency rather than raw material differentiation.

The cost differential is primarily driven by labour costs, which account for over 55% of the total cost gap between the United States and China. Material costs contribute approximately 32% of the overall difference, reflecting China's well-established and integrated battery materials supply chain, while processing costs account for the remaining 12%. These findings highlight that, in addition to labour cost competitiveness, access to localized raw materials, economies of scale, and mature manufacturing ecosystems are critical factors underpinning China's global leadership in LFP CAM production.

China's extensive LFP manufacturing base, integrated supply chains and large domestic demand have enabled manufacturers to achieve high utilization rates and continuous process optimization, reinforcing its position as the global center for LFP cathode production.⁴¹ Countries such as Indonesia and Morocco are emerging as low-cost, low-risk countries to supply LFP CAM to major markets. The key cost differential is evident in processing cost (other than labor cost) and material cost where Indonesia and Morocco face up to 20-40% cost differential whereas EU and US face almost 60-90%.

Nickel Manganese Cobalt (NMC)

Published international studies indicate that China maintains a structural cost advantage in the production of NMC precursors (pCAM) and NMC cathode active materials relative to other major battery manufacturing regions, including the United States, Germany, and South Korea. These advantages arise from China's extensive battery-

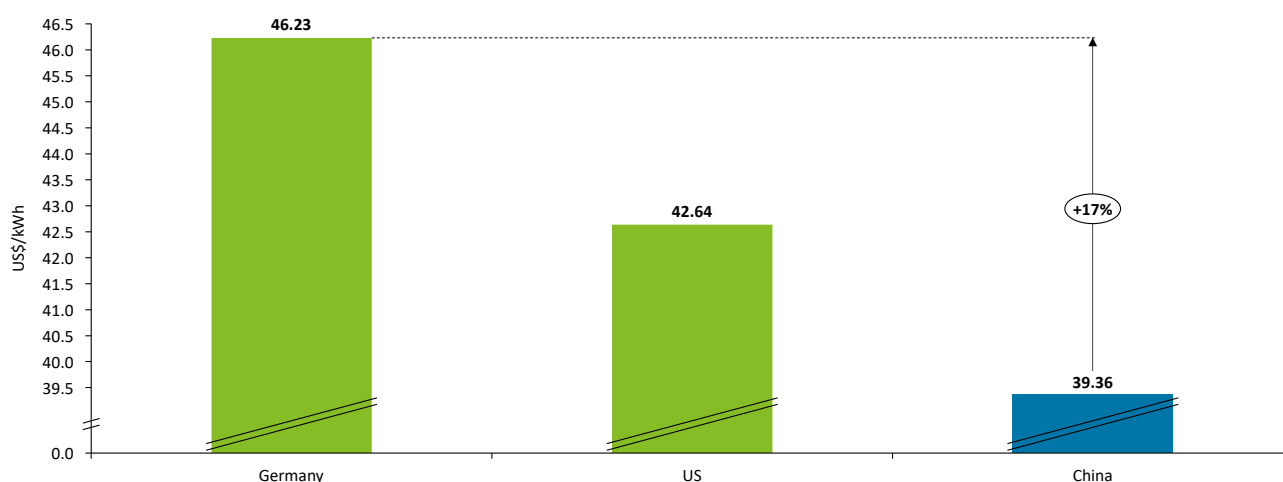
⁴¹ Volta "Battery report" published in 2025

metal refining infrastructure, vertically integrated supply chains, localized equipment manufacturing ecosystem, and large-scale commercial operations.

NMC CAM manufacturing is particularly dependent on the availability of battery-grade nickel, cobalt, manganese, and lithium intermediates. China has developed significant processing and refining capacity across these critical materials, enabling manufacturers to benefit from integrated upstream supply chains, lower logistics costs, and higher utilization rates across the value chain. These ecosystem advantages reduce both operating costs and capital requirements relative to competing manufacturing locations.⁴²

Based on a Technical Report published by Stanford Business School⁴³, Cathode production costs in **China** are estimated at **US\$39.4/kg**, compared with **US\$42.64/kg in the United States** and **US\$46.2/kg in Germany**. The report analyzed pre-cursor cost, labor cost, energy cost to determine the manufacturing cost of Cathode. The below costs include 20% margin each at pre-cursor level, and cathode level.

Figure 26: Cathode – NMC 811 total production cost (in \$/kTon)



Source 41: Stanford Report 2025

The arithmetic average of cost differential in CAM Manufacturing in US, and Germany against China is approximately 13%.

The findings are directionally consistent with the results obtained under Approach 1. While the magnitude of India's cost disability differs from the differential in international benchmarks, both approaches identify similar underlying drivers of competitiveness, raw material access, scale efficiencies, supply-chain integration, and capital cost advantages. The cost disability observed for Indian manufacturers is not an isolated phenomenon, but rather reflects structural advantages enjoyed by China relative to a broad range of competing battery manufacturing economies.

B. Anode Active Material (AAM)⁴⁴

Natural Graphite (NG)

China benefits from an integrated natural graphite ecosystem encompassing mining, purification, spheroidization and coating operations. Natural graphite AAM production costs in the **United States** are estimated at **US\$8,410/tpa**, compared with **US\$3,560/tpa in China**.

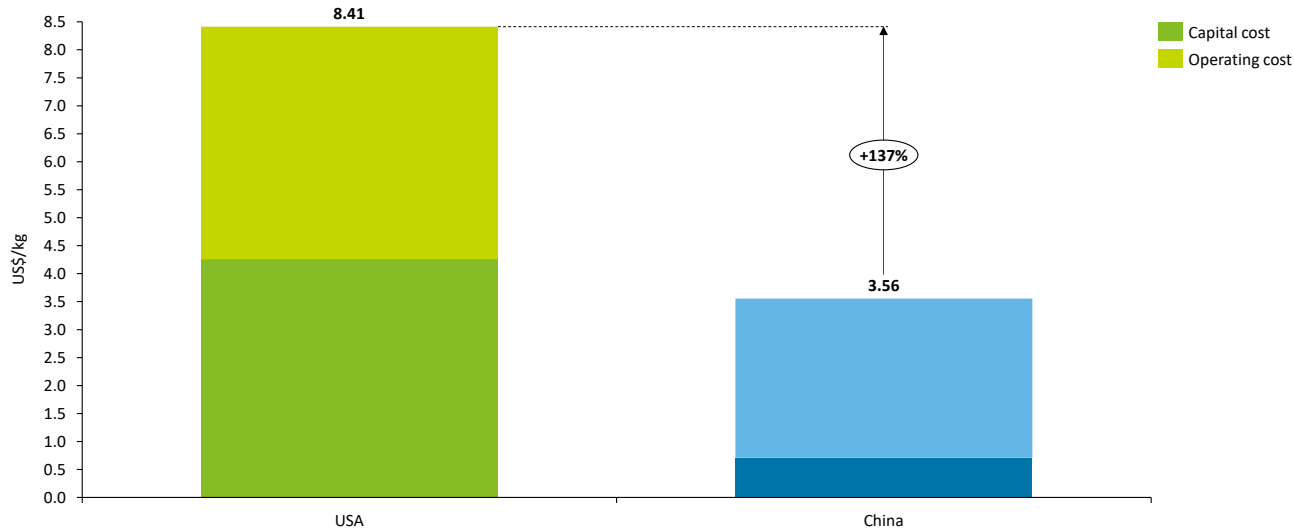
⁴² BloombergNEF Assessment "The cost of producing battery precursors in the DRC"

⁴³ Stanford report "Where Are Lithium-Ion Batteries Cheapest to Manufacture" published in 2025

⁴⁴ [Stanford Report "Securing the supply of graphite for batteries" published in 2025](#)

Similarly, capital expenditure requirements are estimated at approximately **US\$22,000/tpa in the United States**, compared with **US\$5,600/tpa in China**. The cost advantage is primarily attributable to lower processing costs, established purification technologies, lower equipment costs and extensive domestic supply chains.

Figure 27: Anode Active Material – Natural Graphite total production cost (in \$/Ton)



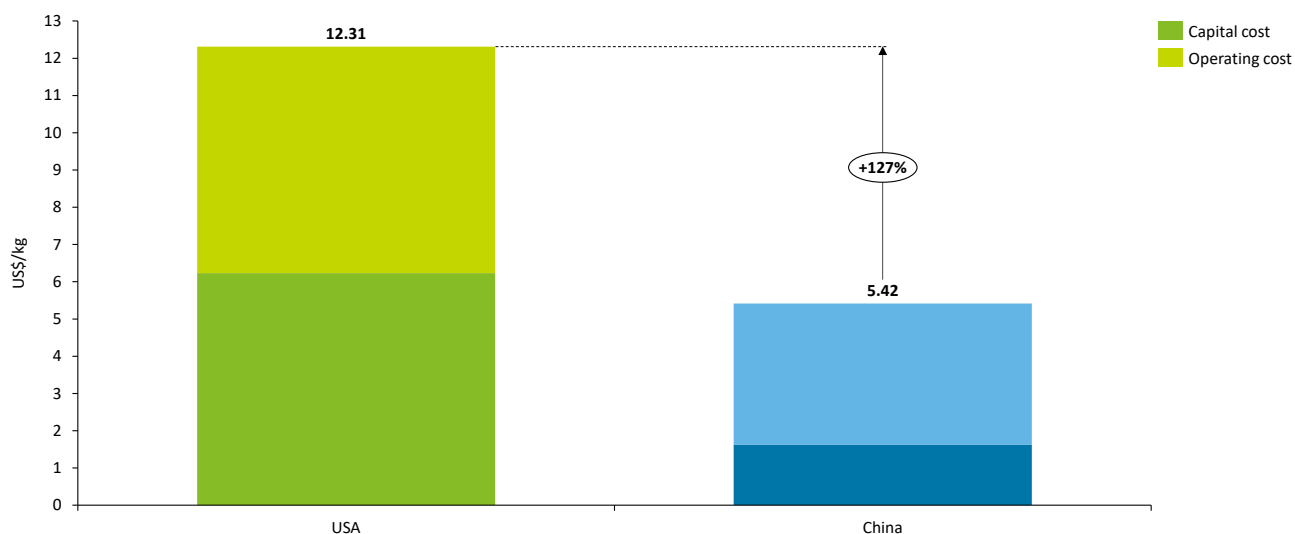
Source 42: [Stanford Report 2025](#)

The presence of established processing infrastructure, mature purification technologies, extensive domestic supply chains, and lower equipment costs enables Chinese manufacturers to achieve significantly lower production and capital costs relative to competing regions.

Synthetic Graphite (SG)

Published international studies indicate that China maintains a significant cost advantage in synthetic graphite production relative to other major manufacturing regions. Synthetic graphite production costs in the **United States** at approximately **US\$12,310/tpa**, compared with approximately **US\$5,420/tpa in China**, implying that production costs outside China can exceed Chinese levels by more than two times. Additionally, **capital expenditure** requirements for synthetic graphite facilities are estimated at **US\$28,300/tpa in the United States** compared with **US\$9,000/tpa in China**, highlighting a substantial capital cost advantage for Chinese producers.

Figure 28: Anode Active Material – Synthetic Graphite total production cost (in \$/Ton)



Source 43: Stanford Report 2025

The cost advantage is attributable to a combination of:

- Lower petroleum needle coke and processing costs;
- Mature graphitization ecosystem;
- Lower energy costs for graphitization;
- Large-scale integrated manufacturing facilities;
- Lower capital expenditure for AAM plants.

Graphitization represents the single largest cost element in synthetic graphite production and is sensitive to electricity prices and plant utilization. Consequently, China's access to competitively priced power, large-scale manufacturing facilities and integrated graphite-processing ecosystem contributes to materially lower production costs relative to other manufacturing regions.

These findings are directionally consistent with the results observed under Approach 1, where conversion costs, finance charges, and depreciation emerged as the principal contributors to the cost disability observed for synthetic graphite manufacturing. The independent evidence therefore supports the conclusion that China's competitiveness in synthetic graphite production is driven by raw material advantages, superior manufacturing economics, and capital efficiency. Also, the advantage is clear compared to other economies as well.

C. Electrolyte

China has established a leading position across the global electrolyte value chain through the development of a highly integrated ecosystem encompassing fluorochemicals, lithium chemicals, electrolyte solvents, lithium hexafluorophosphate (LiPF₆), electrolyte formulation, and downstream battery manufacturing. This integrated industrial base has enabled Chinese producers to achieve substantial economies of scale, lower logistics costs, and close coordination between raw material suppliers and battery manufacturers.⁴⁵

Chinese companies account for more than 93% (including production within and outside China) of global electrolyte market share, with leading players such as Tinci and Capchem dominating the segment and the top five firms accounting for nearly 90% of the market. This concentration enables Chinese electrolyte producers to

⁴⁵ Stanford report "Where Are Lithium-Ion Batteries Cheapest to Manufacture" published in 2025

optimize raw material sourcing, reduce logistics costs, operate large-scale production lines, and continuously refine electrolyte formulations through close engagement with downstream cell producers.⁴⁶

The manufacturers outside China typically operate at smaller scales and are often required to localize raw material supply chains, resulting in higher production costs and lower utilization rates. These structural factors contribute to a persistent price premium for non-Chinese electrolyte materials across global markets. The differential is attributed not only to scale advantages but also to the co-location of solvent manufacturing, electrolyte salt production, and battery cell manufacturing within China's battery materials ecosystem.

The findings are directionally consistent with the results under Approach 1, where higher raw material costs, supply-chain dependence, and scale-related disadvantages emerged as the principal drivers of cost differential in electrolyte production. International benchmarking therefore reinforces the conclusion that the competitiveness gap observed for Indian manufacturers reflects broader structural advantages currently enjoyed by China across the global electrolyte ecosystem.

D. Separator

China has emerged as the leading global manufacturing hub for separator, accounting for more than 65% of global lithium-ion battery separator production in 2024. This concentration of manufacturing capacity has enabled Chinese manufacturers to achieve significant economies of scale, lower conversion costs, higher asset utilization and continuous process optimization across both wet-process and dry-process separator technologies. These structural advantages have reinforced China's position as the lowest-cost producer in the global separator market.⁴⁷

China's leadership is attributed to the integrated supply chains, localized equipment manufacturing capabilities, strong domestic battery demand, and large-scale production facilities. Separator manufacturing is highly capital intensive, requiring specialized equipment, precision process control, and substantial upfront investment. Consequently, manufacturing scale and asset utilization are particularly important drivers of competitiveness.

Chinese manufacturers benefit from a mature domestic equipment ecosystem and a large customer base of battery-cell manufacturers, enabling efficient deployment of capital and lower per-unit production costs.

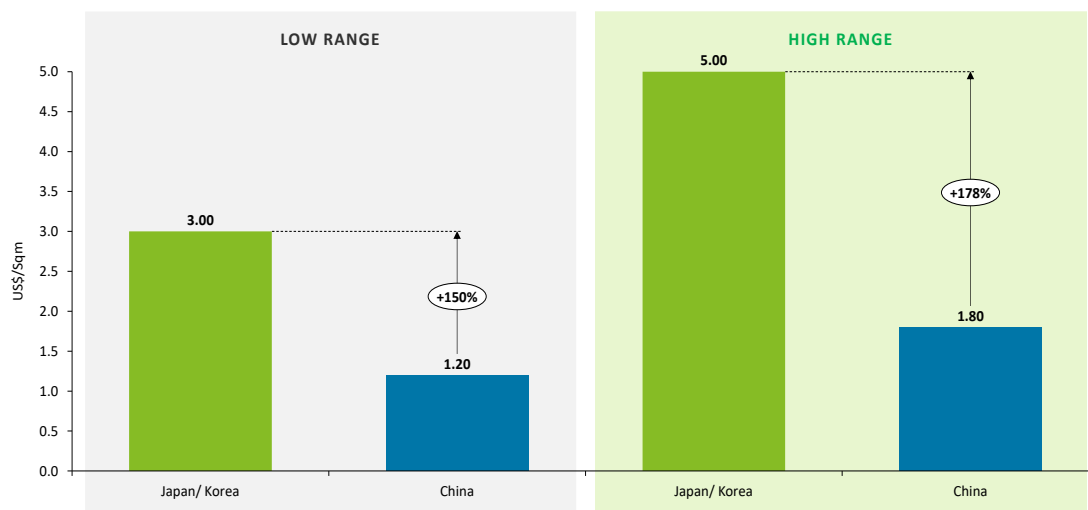
The resulting cost advantage is evident when comparing production economics across major manufacturing regions. Chinese suppliers can supply standard wet-process PE separators at approximately \$1.2-1.8/m², compared with \$3-5/m² for leading Japanese and Korean manufacturers.⁴⁸

⁴⁶ Volta "Battery report" published in 2025

⁴⁷ Global PE Separator Market Report published in 2025

⁴⁸ [CNLWI – Billion Dollar Thin-Film](#)

Figure 33: Separator price differential China vs. Japan/Korea – US\$/sq. m



Source 44: CNLWI – Billion Dollar Thin-Film

Consequently, separator manufacturers in **Japan, and Korea face a significant price differential of approximately 150-180% relative to China**, depending on technology, production scale, and product specifications. This makes it challenging for global manufacturers to compete in volume-driven market segments without localization incentives, technology differentiation, or premium product positioning.⁴⁹

The findings are directionally consistent with the results obtained under Approach 1. Both assessments identify capital intensity, manufacturing scale, financing efficiency, supply-chain integration, and technology ecosystem maturity as key determinants of competitiveness in separator manufacturing. The international evidence therefore indicates that the cost differential observed for Indian separator manufacturers is not unique to India, but reflects broader structural advantages enjoyed by China relative to a wide range of advanced and emerging battery manufacturing economies.

E. Copper Foil

China has established the world's largest battery-grade copper foil manufacturing ecosystem, supported by domestic copper refining capacity and the country's leading position in lithium-ion battery production.

Capital efficiency, supply-chain localization, and manufacturing scale are important in determining competitiveness across key battery components and materials. The country's large domestic battery manufacturing base has enabled copper foil producers to operate at significant scale and maintain high utilization rates. Chinese battery manufacturing capital costs to be approximately 28–30% lower than those in the United States, providing a structural advantage across capital-intensive battery component manufacturing segments including copper foil.⁵⁰

The observations under Approach 2 are directionally consistent with the copper foil assessment under Approach 1. The international benchmarks indicate that China benefits from scale economies, localized supply chains, high utilization levels, and lower capital costs across battery component manufacturing. This supports the broader finding that China's cost advantage is structural in nature and provides directional context for interpreting the India-China cost gap estimated under Approach 1.

Cross-component analysis from Approach 2

⁴⁹ CNLWI – Billion Dollar Thin-Film

⁵⁰ Stanford report "Where Are Lithium-Ion Batteries Cheapest to Manufacture" published in 2025

Approach 2 indicates that China's cost advantage extends across multiple ACC component segments when benchmarked against other global manufacturing regions. The findings are directionally consistent with Approach 1, where Indian manufacturers were observed to face cost differentials across all assessed components. While Approach 2 does not directly estimate India-specific costs, it validates that the competitiveness gap identified for India reflects broader structural advantages enjoyed by China across the global battery materials value chain. This reinforces the need for component-specific interventions, particularly in raw material localization, processing capability, capital cost reduction, technology access, and domestic ecosystem development.

Table 15: International benchmark cost differentials relative to China under Approach 2

Technology	Unit	Average RoW cost	China cost	RoW versus China (Cost differential)
CAM-LFP	Indexed Cost/kWh	74.5	51.32	46%
CAM-NMC	\$/kWh	44.44	39.36	13%
AAM-NG	\$/kg	8.41	3.56	137%
AAM-SG	\$/kg	12.31	5.42	127%
Separator	\$/m2	3-5	1.2-1.8	150%

3.5. Capital cost disability across key ACC components

Capital expenditure requirements represent an important determinant of manufacturing competitiveness in ACC component production. ACC component manufacturing is capital intensive and requires significant upfront investment in plant and machinery, process technology, environmental systems, automation, quality control infrastructure, and working capital support during the ramp-up phase. Therefore, differences in capital cost across manufacturing geographies can materially affect project viability, financing requirements, depreciation burden, and the time required to achieve commercial competitiveness.

Table 16: Capital cost disability across key ACC components

Technology	Unit	Indian Average CAPEX (₹ crore /unit)	Differential with avg. CAPEX in China
CAM	ktpa	46	+235%
AAM	ktpa	129	+425%

Source 45: Analysis based on confidential stakeholder inputs.

The assessment of capital expenditure across some ACC components indicates that India faces a material CAPEX disability relative to China. This indicates that capital cost differences constitute a distinct and material competitiveness challenge, particularly for new entrants seeking to establish domestic ACC component manufacturing capacity. The higher CAPEX requirement in India may be attributable to multiple factors, including dependence on imported equipment, limited domestic equipment manufacturing capability, lower scale of project execution, technology licensing requirements, weaker local vendor ecosystems, higher contingency provisioning, and limited availability of standardized plant designs for ACC component manufacturing.

In contrast, China benefits from mature domestic equipment suppliers, established engineering and procurement ecosystems, larger plant sizes, repeated project execution experience, localized supply chains, and greater process standardization across battery material manufacturing.

The upfront capital requirement is a material barrier to the establishment of domestic ACC component manufacturing capacity, particularly for new entrants required to invest at or above minimum viable scale. Higher capital intensity increases the promoter contribution and debt requirement, as well as the associated depreciation and financing burden during the initial period of low-capacity utilization and product qualification. This may delay investment decisions even when long-term domestic demand is expected to be sufficient. Therefore, even where operating costs improve over time through localization and process efficiency, elevated capital costs may continue to affect long-term competitiveness, until scale, technology access, domestic equipment development, and financing depth matures.

With a CAPEX differential of up to 425%, even the CAPEX incentive of 25% under the ECMS is insufficient to bridge the cost gap experienced by the domestic ACC component manufacturing industry.

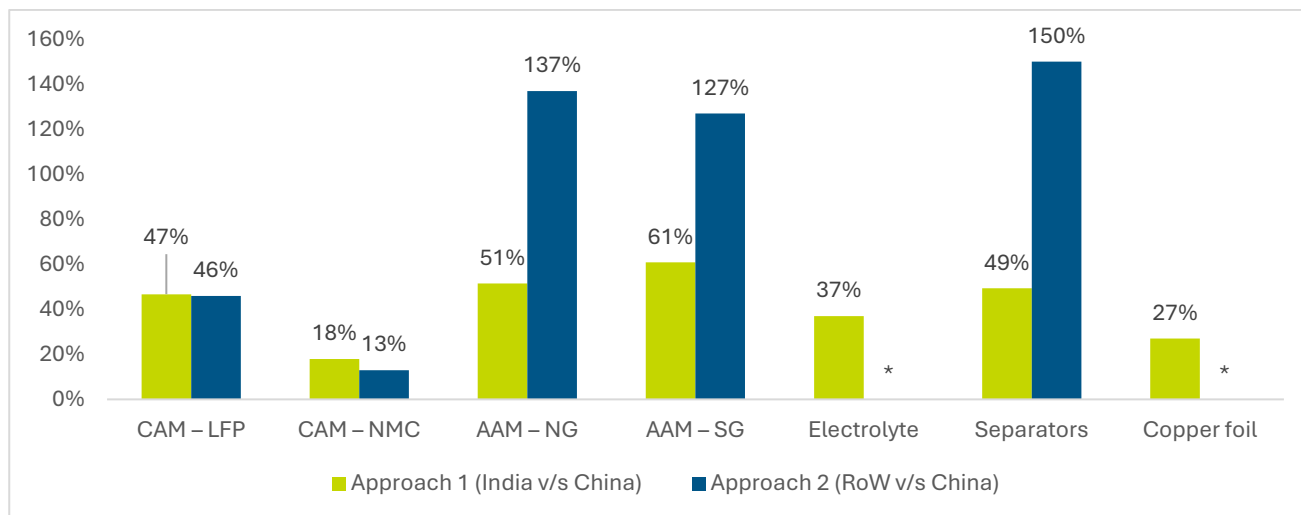
3.6. Conclusion

The assessment indicates that Indian ACC component manufacturers face an India-specific manufacturing cost disability of approximately 18% to 61% relative to landed Chinese benchmark prices under Approach 1. The disability is relatively moderate for CAM-NMC and copper foil and higher for AAM-SG, AAM-NG, CAM-LFP, separators, and electrolyte.

Approach 2 does not estimate India's cost disability but benchmarks China's cost advantage against other manufacturing regions. Its findings directionally validate Approach 1 by confirming that China's competitiveness is supported by manufacturing scale, integrated raw-material and equipment supply chains, mature processing capabilities, lower capital costs, and higher capacity utilization.

Below is a summary of cost disability observed at a component-level:

Figure 29: India-specific cost disability under Approach 1 and international benchmark differentials under Approach 2



*Data not available

The nature of the disability varies across components. For CAM, electrolyte, and copper foil, the cost gap is primarily linked to raw-material sourcing, domestic availability of battery-grade input, and manufacturing scale. For AAM, material costs are compounded by conversion costs, energy intensity, depreciation, and financing costs. separator manufacturing is particularly affected by capital intensity, technology and equipment dependence, financing costs, and capacity utilization. These findings indicate that India's cost disability is structural rather than a short-term pricing gap.

Indian manufacturers also face higher upfront capital requirements for the assessed CAM and AAM components, increasing financing needs, depreciation, and project risk during plant ramp-up and product qualification. This may constrain investment in commercially viable capacity despite expected long-term demand.

Although CAPEX support can partially address this initial investment barrier, it would not address the recurring cost disadvantage arising from higher raw-material and conversion costs, energy intensity, lower initial yields and capacity utilisation, financing costs and extended customer-qualification timelines.

OPEX support could play an important role in addressing the recurring cost disadvantage and supporting domestic manufacturers during the initial years of production.

Chapter 4. ACC components: Raw materials and manufacturing overview

Advanced Cell Chemistry (ACC) manufacturing relies on a complex value chain comprising several critical components, including Cathode Active Materials (CAM), Anode Active Materials (AAM), electrolytes, separator, and copper foil. Each component undergoes specialized manufacturing processes involving multiple chemical, thermal, and precision engineering steps and contributes differently to the overall cost structure of a battery cell. Among these, cathode active materials typically constitute the largest share of cell cost, followed by anode materials, electrolytes, and separators, with cost contributions varying across battery chemistries such as Lithium Iron Phosphate (LFP) and Nickel Manganese Cobalt (NMC).

The objective of this section is to:

- Understand the manufacturing process and key raw material requirements of each ACC component, which would be vital to gauge the capital intensity of this business.
- Enable an assessment of investment requirements, identifying supply-chain gaps, and formulating policy interventions required to establish a globally competitive battery manufacturing ecosystem in India.
- Understand strengths of India in domestic manufacturing of ACC components and identify critical areas where the country continues to be reliant on imports

4.1. Integrated ACC component manufacturing

A. Cathode Active Material (CAM):

CAM is the electrochemically active material used in the cathode (positive electrode) of an ACC. It stores and releases lithium ions during charge/discharge and governs the battery's energy density, voltage, cycle life, safety and power capability. LFP and NMC are the two chemistries most widely used in EV and energy-storage applications, offering different trade-offs between performance, safety and cost.

1. Lithium Iron Phosphate (LFP) CAM

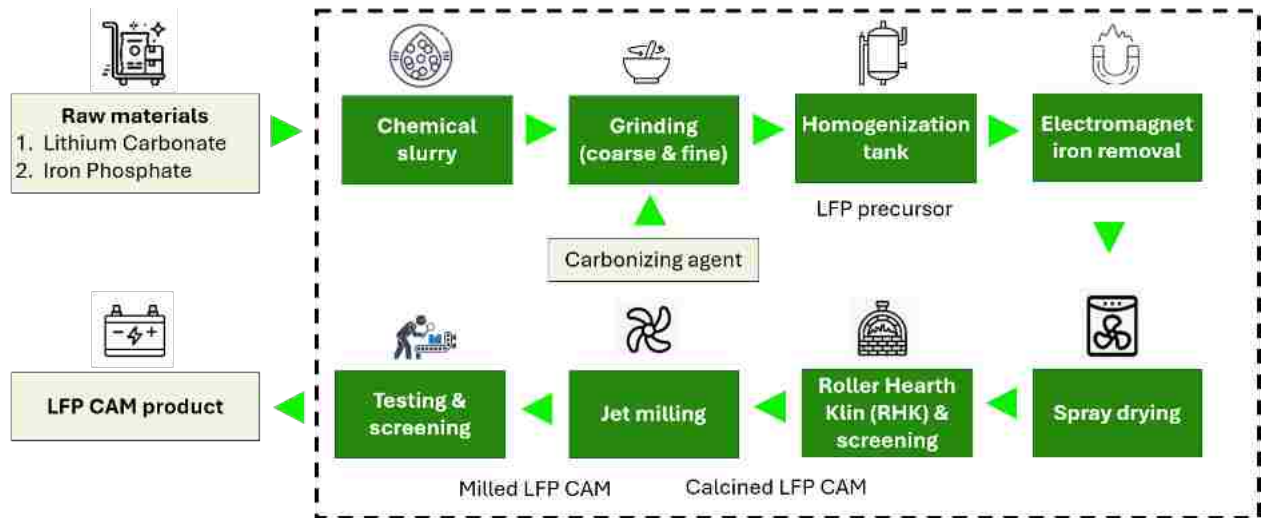
LFP CAM (LiFePO_4) forms a stable crystalline structure enabling reversible lithium intercalation. **It uses iron and phosphate rather than nickel/cobalt, giving excellent thermal stability, high safety, long cycle life and cost-effectiveness, making it the preferred chemistry for EVs, and energy storage where safety and cost are critical.**

Key manufacturing takeaways (see Annexure for full synthesis process):

- Two industrial routes: solid-state synthesis (Iron Phosphate + Lithium Carbonate + carbonizing agent) or wet-chemical synthesis (Lithium Carbonate + Iron Sulphate + Phosphoric Acid + carbonizing agent).
- Core sequence: weighing → reactor slurry formation (solid-state route)/iron phosphate precipitate (wet-chemical) → coarse and fine grinding → homogenization tank → electromagnet iron removal → spray drying → roller hearth kiln and screening → jet milling → testing and screening.
- The carbon precursor carbonizes during calcination to form the conductive coating that gives LFP its electronic conductivity.
- Critical controls: stoichiometry/composition, particle size distribution, and moisture/impurity control at every stage.

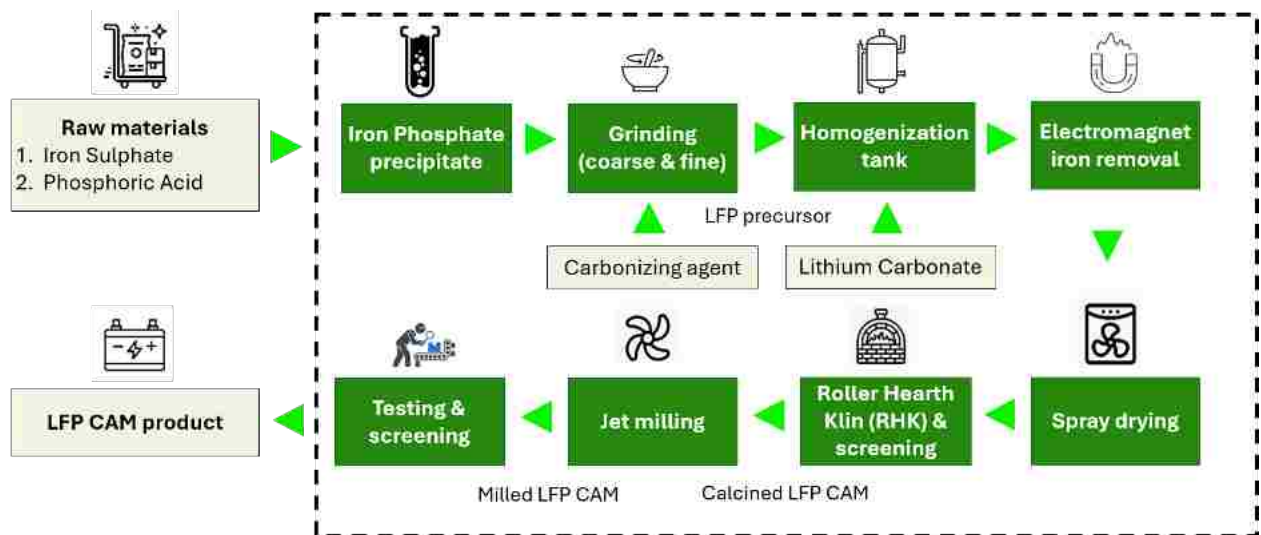
The detailed manufacturing process flow charts of both the routes are presented below.

Figure 30: Solid-state manufacturing process of LFP cathode



Source 46: As per inputs from Indian player(s).

Figure 31: Wet-chemical manufacturing process of LFP cathode



Source 47: As per inputs from Indian player(s).

Key raw materials

The table below presents the key raw materials required for LFP CAM manufacturing, including lithium, iron, phosphate and carbon sources used across various synthesis routes.

Table 17: Key raw materials required for LFP Cathode Active Material manufacturing

Key raw material		Chemical formula	Qty. required (kg per kg of product)
Lithium Carbonate		Li ₂ CO ₃	0.23-0.25
Iron Phosphate	Solid-phase	FePO ₄	0.98
Iron Sulphate	One-pot	FeSO ₄ ·7H ₂ O	1.7-1.8
Phosphoric Acid		H ₃ PO ₄	0.65
Carbon source (conductive coating)		Glucose, Sucrose, Pitch etc.	0.08-0.13
Nitrogen/Argon gas		N2/Ar	1.6
Deionized water		H ₂ O	5

Source 48: As per inputs from Indian player(s).

The rapidly expanding market necessitates a robust and resilient supply chain. To recognize the importance of a localized supply-chain, a detailed analysis of the key raw materials and the associated and alternative materials is paramount. The following table provides a comprehensive overview of key raw materials required for manufacturing. It summarizes the mineral source of each material, its role in the manufacturing process, status, and availability in India. This assessment enables a qualitative understanding of the criticality of each material, the extent of domestic availability, and potential import dependencies across the value-chain. A similar analysis has also been conducted regarding the alternative and associated raw materials used in LFP CAM production and are provided in Annexures.

Table 18: Comprehensive overview of primary raw materials for LFP CAM manufacturing

Raw material	Purpose in process	Upstream	Status in India*
Lithium Carbonate	Primary lithium source for LFP synthesis	Extraction from brine/rock and then processing	 Primarily import-dependent
Iron Phosphate	Main precursor for commercial solid-phase LFP production	Processing of Iron ore and phosphate rock	 Largely imported (70-75%), growing domestic capability
Iron Sulphate	Iron source for FePO_4 precursor synthesis for direct one-pot LFP synthesis	Processing of Iron ore	
Phosphoric Acid	Phosphate source for FePO_4 precursor synthesis for one-pot wet chemical LFP synthesis	Processing of Phosphate rocks	 Significant domestic reserve
Carbon source (conductive coating)	Forms conductive carbon coating on LFP particles during calcination	Glucose, Sucrose, Citric Acid, Pitch, Carbon Black	

Raw material	Purpose in process	Upstream	Status in India*
Nitrogen/Argon gas	Provides inert atmosphere during calcination to prevent oxidation	N ₂ /Ar	
Deionized water	Slurry preparation, precursor synthesis, washing and impurity removal	H ₂ O	

Source 49: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

India has a strong domestic ecosystem for iron ore processing, industrial acids and gases, metal oxides/sulphates, conductive carbon coating materials, and other supporting utilities. However, the LFP cathode value chain remains significantly dependent on imports for key raw materials, particularly lithium carbonate (or, lithium hydroxide), which account for the largest share of material consumption in manufacturing. In addition, nearly 70% (by quantity) of iron phosphate requirements are currently met through imports, although domestic iron phosphate precursor manufacturing capabilities are gradually emerging. Therefore, at present the conventional solid-phase route remains approximately 75% import dependent by material quantity due to reliance on lithium carbonate and battery-grade iron phosphate. In contrast, the one-pot synthesis route reduces import dependence to about 15% as domestically available iron sulphate and phosphoric acid replace imported iron phosphate, leaving lithium carbonate as the primary imported raw material⁵¹. However, the one-pot route requires greater process control and manufacturing expertise to consistently achieve battery-grade LFP.

Battery-grade specifications and performance tiers:

LFP CAM is supplied across a range of quality tiers, distinguished primarily by particle engineering, purity and tap density, as summarized in the table below. LiFePO₄ has inherently low electronic and ionic conductivity; therefore, particle size and carbon-coating quality significantly influence lithium-ion diffusion, electrical conductivity, rate capability, and usable capacity. Nano-scale primary particles (high-end grade) shorten lithium-ion diffusion pathways, supporting higher charge-discharge rates and better low-temperature performance. A well-designed particle-size distribution can also improve electrode packing and accommodate more active material per unit volume, thereby increasing volumetric energy density while maintaining acceptable power performance. Standard-grade (single mode), lower-cost LFP batteries retain the chemistry's safety and cycle-life advantages, generally offers lower rate capability and volumetric energy density than more highly engineered grades. It may therefore be suitable for stationary energy-storage applications, where space and high-rate performance are typically less critical than cost, safety, and durability.

⁵¹ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

Table 19: Technical specification comparison of LFP CAM by product grade

Parameter	Low-end	Mid-end	High-end
Purity (trace metal) (%)	≥ 99	≥ 99.8	≥ 99.95
D50 particle size (µm)	5-9 (single mode)	1.2-2 (engineered)	Bimodal: primary < 80 nm + secondary D50 5-13 µm
Tap density (g/cm ³)	0.7-0.8	0.8-1.0	1.3-1.5
Moisture content (ppm)	< 1000	< 500-800	< 500
Carbon coating	~1-2 wt%, uncontrolled uniformity	~1.5 wt%, controlled	~1.5 wt%, uniform + NASICON ⁵² /other functional coating
1st discharge capacity (0.1C)	~ 150 mAh/g	~ 155 mAh/g	~ 156-160 mAh/g
1st cycle efficiency (%)	~93-95	~95-96	≥ 96-97

Source 50: As per inputs from Indian player(s).

2. Nickel Manganese Cobalt (NMC) CAM

NMC (Lithium Nickel Manganese Cobalt Oxide) is a layered cathode combining nickel (higher energy density), manganese (structural stability) and cobalt (conductivity/electrochemical performance). **Its high specific energy and driving range make it the preferred chemistry for EVs, consumer electronics and high-performance applications.**

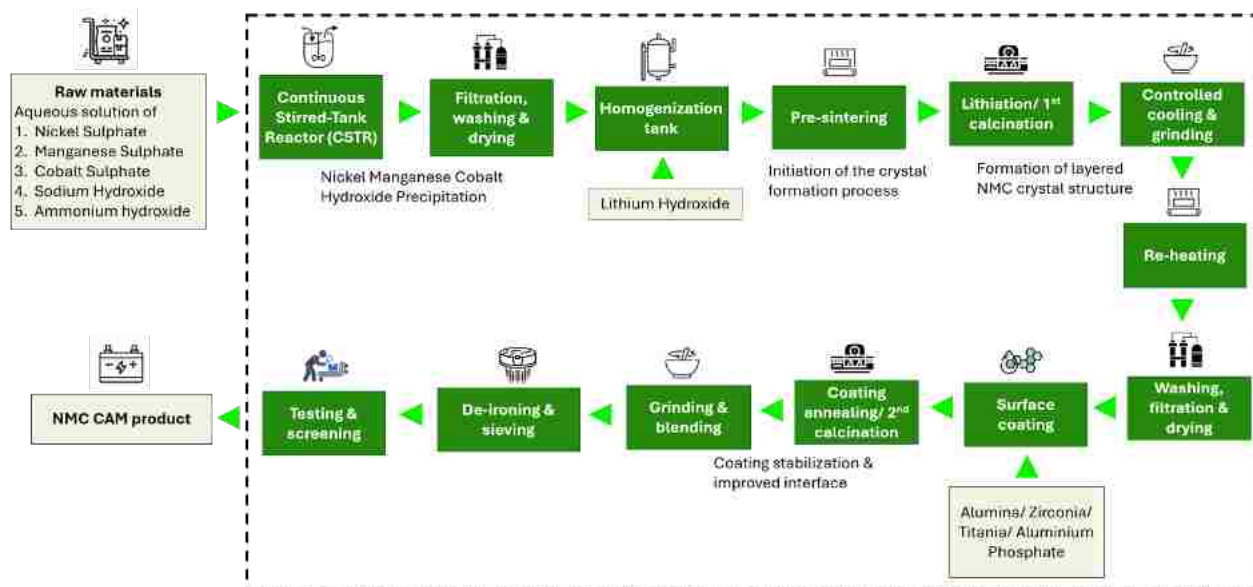
Key manufacturing takeaways (see Annexure for full process):

- Precursor NMC (P-NMC) is co-precipitated at first, then blended with Lithium Hydroxide, dopants and coating agents after magnetic separation.
- Two-stage thermal treatment: pre-sintering (600-800°C/5h) → first sintering/lithiation (800-900°C/15h, >96% O₂) → controlled cooling → crushing/jet milling → reheating (~800-900°C/2h) to form stable single-crystal particles.
- Washing (removes residual Lithium Hydroxide) → surface coating (Alumina, Zirconia, Titania, Aluminium Phosphate or Lithium Niobate to improve thermal stability and cycle life) → second calcination (coating anneal) → grinding/lot blending → de-ironing/sieving → QC/packaging.
- Exact temperature/time profile is proprietary and varies by chemistry (e.g., NMC622 vs NMC811).

The flow chart below illustrates the detailed manufacturing process.

⁵² Sodium super ionic conductor, a family of crystalline solids that exhibit exceptionally high ionic conductivity.

Figure 32: Manufacturing process of NMC cathode



Source 51: As per inputs from Indian player(s).

Key Raw Materials⁵³

The table below presents the major raw materials required for NMC CAM manufacturing, including lithium compounds, transition metal sulphates, and precipitation chemicals.

Table 20: Key raw materials required for NMC Cathode Active Material manufacturing

Key raw material	Chemical formula	Qty. required (kg per kg of product)
Lithium Hydroxide	$\text{LiOH} \cdot \text{H}_2\text{O}$	0.43
Nickel Sulphate	$\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$	2.3
Manganese Sulphate	$\text{MnSO}_4 \cdot \text{H}_2\text{O}$	0.26
Cobalt Sulphate	$\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$	0.31
Ammonium Hydroxide (25-30%)	NH_4OH	0.9-1.2
Sodium Hydroxide	NaOH	1.2
Oxygen	O_2	5.0
Deionized water	H_2O	2.50

Source 52: As per inputs from Indian player(s).

While the preceding summarizes the primary chemicals directly consumed during NMC CAM manufacturing, a broader understanding of the supply chain requires examining the upstream mineral sources, their role in the production process and the current level of domestic availability. The following table provides a comprehensive overview of the key raw materials used in NMC CAM production including their mineral origin, function within the manufacturing process, availability in India and typical quality requirements. A corresponding assessment of the alternative and associated raw materials used in NMC CAM production is presented in Annexures.

⁵³ [Single Crystal Cathode Materials for Lithium-Based Batteries: Synthesis, Scaleup, and Manufacturing, Chemical Reviews, 22, 125 \(2025\)](#)

Table 21: Raw material sources, process role, and domestic availability of raw materials for NMC CAM manufacturing

Raw material	Purpose in process	Upstream	Status in India*
Lithium Hydroxide	Primary lithium source for lithiation and formation of layered NMC	Extraction from brine/rock and then processing	 Primarily import-dependent
Nickel Sulphate	Alternative nickel source	Originates from raw mined ores and chemically processed	
Cobalt Sulphate	Alternative cobalt source		
Manganese Sulphate	Alternative manganese source		
Ammonium Hydroxide	Chelating agent to control Ph, particle growth, and precursor morphology	Produced from Ammonia and water	 Widely available domestically
Sodium Hydroxide	Precipitating agent for co-precipitation of NMC hydroxide precursor	Produced by chlor-alkali process	
Deionized water	Precursor synthesis, washing, filtration, and impurity removal	H ₂ O	
Oxygen	To achieve layered oxide structure during lithiation/sintering	O ₂	

Source 53: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

India's key strengths in NMC CAM manufacturing lie in the domestic availability of supporting process chemicals, and industrial gases. However, the localization of NMC production remains limited by a high dependence on imported critical raw materials, particularly lithium hydroxide and nickel manganese cobalt hydroxide precursors, which constitute the primary feedstocks for NMC CAM manufacturing. At present, India is completely reliant on imports for these materials, making the NMC value chain vulnerable to global supply and pricing dynamics⁵⁴. This significant import dependence, combined with the cost competitiveness and comparatively simpler supply chain of LFP chemistry, has been a key factor driving the growing adoption and preference for LFP-based batteries in the Indian market.

Battery-grade specifications and performance tiers:

Unlike LFP, NMC's grade progression is chemistry-driven (nickel content) rather than purely a processing choice, so the tiers below map to NMC111 (low-Ni) through NMC622 to NMC811. Nickel content is a direct performance lever and a direct stability trade-off i.e., more nickel means more redox-active sites and higher specific capacity, but also greater structural distortion, oxygen-release risk and microcracking on cycling which is why higher-Ni grades require surface coating (Al₂O₃/ZrO₂/AlPO₄/LiNbO₃) to suppress side reactions with the electrolyte that would otherwise drive capacity fade and gas generation. Moisture control matters for the same reason i.e., uncontrolled residual lithium hydroxide on high-Ni surfaces degrades electrode slurry quality and accelerates impedance growth in the finished cell. NMC622 is the practical choice where cycle life, safety margin and

⁵⁴ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

manufacturing tolerance matter more than maximizing range like e-buses, mid-range EVs, energy storage. NMC811 is reserved for range-focused passenger EVs, where the energy-density gain justifies the tighter moisture control, mandatory coating and closer thermal management it demands, both in manufacturing and in vehicle operation.

Table 22: Technical specification comparison of NMC CAM by product grade

Parameter	Low-end	Mid-end	High-end
Typical chemistry	NMC111 (1:1:1)	NMC622 (6:2:2)	NMC811 (8:1:1)
Purity/ residual Li compounds	Low Ni → lower residual LiOH/ Li ₂ CO ₃	Moderate residual alkali requires washing	High Ni → high residual LiOH/ Li ₂ CO ₃ , needs washing + surface coating
D50 particle size (µm)	10-12	8-11	9-12
Tap density (g/cm ³)	2.2-2.4	~2.3	~2.0 g/cm ³ (up to ~2.9 g/cm ³ with precursor optimization)
Moisture content (ppm)	Lower sensitivity, < 500 ppm typical	< 500 ppm, moderate sensitivity	Most moisture-sensitive
Reversible capacity (mAh/g)	~150-160	~170-180	~190-200
1st cycle efficiency (%)	~90	~88-90	> 88

Source 54: As per inputs from Indian player(s).

B. Anode Active Material (AAM):

AAM is the electrochemically active material used in the anode (negative electrode), it stores and releases lithium ions during charging and discharging. **Graphite is the dominant commercial anode material owing to its lithium intercalation properties, conductivity, stability, low cost and cycle life.** Silicon-graphite blends (5-7 wt% SiO₂) are an emerging area of R&D for higher capacity. AAM is classified into Natural Graphite (NG) and Synthetic Graphite (SG).

1. Natural Graphite (NG) AAM

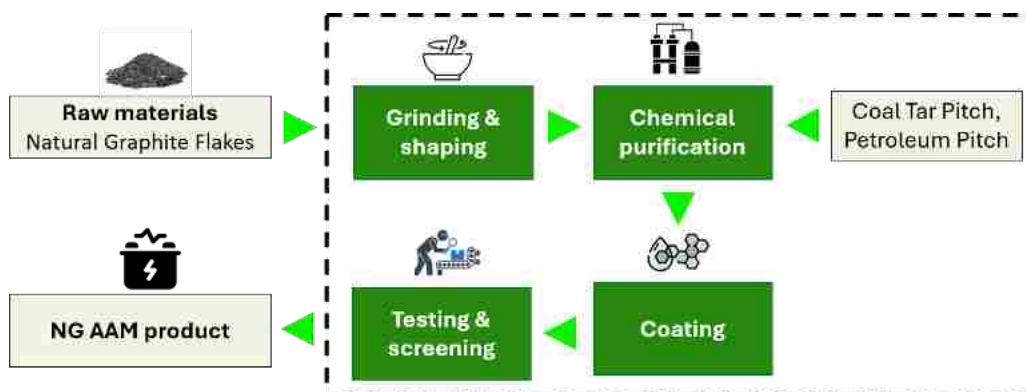
NG is produced from mined graphite ore that is beneficiated, purified, micronized, spheroidized, coated and heat-treated to battery-grade specification. **It offers lower production cost, lower carbon footprint and high specific capacity (~372 mAh/g) versus synthetic graphite, though with somewhat lower rate capability, cycle life and greater feedstock-quality variability, purity above 99.95% carbon requires extensive purification.**

Key manufacturing takeaways (see Annexure for full process):

- Natural graphite flakes → grinding and shaping.
- Purification via chemical acid leaching (Hydrogen Fluoride/ mixed-acid) or high-temperature thermal treatment (>2500°C) removes metallic/silicate impurities to >99.95% carbon purity.
- Coating with coal tar pitch or alternative carbon precursors → QC/packageing.

The detailed manufacturing workflow is shown in the flow chart below.

Figure 33: Manufacturing process of NG anode



Source 55: As per inputs from Indian player(s).

Key raw materials:

The following table outlines the major raw materials required for NG AAM manufacturing, including natural flake graphite feedstock as primary carbon source, and primary coating precursors like coal tar pitch along with other required precursors which are used throughout the purification, spheroidization, and surface coating processes to produce high-purity graphite suitable for lithium-ion battery anodes.

Table 23: Key raw materials required for NG Anode Active Material manufacturing

Raw material	Chemical formula	Qty. required (kg per kg of product) *
Natural Flake Graphite	C	2.25
Coal Tar Pitch	-	0.17
Petroleum Pitch	-	0.17
Hydrochloric Acid	HCl	2.76
Hydrofluoric Acid	HF	1.38
Nitrogen/Argon gas	N ₂ /Ar	NA
Deionized water	H ₂ O	NA

Source 56: As per inputs from Indian player(s).

* NA denotes data not available.

The table below summarizes a broader overview of the supply chain understanding of the upstream mineral sources and purification reagents involved in manufacturing. The availability and quality of the materials significantly influence production cost, localization potential, environmental footprint, and final anode performance. An equivalent analysis of the supporting process chemicals and alternative purifying chemicals for natural graphite AAM production has been included in Annexures.

Table 24: Raw material sources, process function, and domestic availability of raw materials for NG AAM manufacturing

Raw material	Purpose in process	Upstream	Status in India
Natural Flake Graphite (primary feedstock)	Primary carbon source for NG AAM production	Mined from natural graphite deposits	 Primarily import-dependent

Raw material	Purpose in process	Upstream	Status in India
Coal Tar Pitch	Carbon coating precursor to improve electrical conductivity, surface stability, and first cycle efficiency	By-product of coke oven operations in the steel industry	 Readily available domestically
Petroleum Pitch		Petroleum refinery residue	 Entirely imported
Hydrochloric Acid	Acid leaching to remove metallic impurities during purification	Industrial chemical	 Readily available domestically
Hydrofluoric Acid (where chemical purification is required)	Removes silicate and mineral impurities to achieve battery-grade purity	Industrial chemical	
Nitrogen (N₂)	Provides inert atmosphere during carbon coating and heat treatment	Air separation units	 Widely available domestically
Deionized water	Washing after purification and cleaning of graphite particles	H ₂ O	

Source 57: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

India has a strong domestic base for most processing chemicals and utilities required for NG AAM manufacturing, including coal tar pitch, purification acids, and alternative carbon coating precursor. The country also possesses graphite ore reserves, however, domestic capabilities for processing graphite ore into battery-grade graphite flakes remain limited. As a result, manufacturers continue to rely on imports of natural flake graphite, the primary feedstock for NG AAM production. In addition, certain critical inputs such as petroleum pitch are also completely imported. Therefore, India remains import dependent for less than half (approximately 40%) of its raw material requirement (by material quantity)⁵⁵.

Battery-grade specifications and performance tiers:

For natural graphite, grade differences are driven mainly by coating uniformity, particle-size control and purity levers that determine first-cycle efficiency and how close a material gets to graphite's ~372 mAh/g theoretical capacity. A tighter, well-packed particle size distribution raises tap density (and volumetric capacity), while a thin, uniform carbon coating minimizes the irreversible lithium consumed forming the SEI⁵⁶ on first charge, directly determining how much of the cell's nominal capacity is usable range from day one. Purity matters for longevity rather than day-one performance, trace iron or ash content creates localized catalytic sites that drive continuous electrolyte decomposition over the cell's life, gradually fading capacity and generating gas. Premium natural graphite with high purity, tight PSD, low surface area is worth the extra processing where long cycle life and maximum first-cycle efficiency matter.

⁵⁵ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

⁵⁶ Solid Electrolyte Interphase (SEI) is a protective chemical layer that forms on the negative electrode (anode) of a lithium-ion battery during its first charge. A stable SEI layer helps the battery hold a charge and last for many cycles.

Table 25: Technical specification comparison of natural graphite AAM by product grade

Parameter	Low-end	Mid-end	High-end
Carbon purity (%)	≥ 99	≥ 99.9	≥ 99.95
D50*	17-19	15-18	15-20
Particle Size Distribution	Broad and less controlled distribution	Narrower and better controlled distribution	Tightly controlled distribution
Tap density (g/cm ³)	~ 1.0-1.1	~ 1.05-1.15	~ 0.95-1.01
Moisture content (%)	~0.1-0.2	< 0.1	< 0.05
Ash content/Fe content	< 0.2% ash, < 50 ppm Fe	< 0.15% ash, < 30 ppm Fe	< 0.1% ash, tightly controlled Fe
Reversible capacity (mAh/g)	< 350	~ 350-360	~ 360-370
1st cycle efficiency (%)	~ 85-90	~ 90-93	≥ 93-95

Source 58: As per inputs from Indian player(s).

*D50 is a broad functional parameter rather than a precise optimum. Materials with the same D50 can still differ significantly in particle size distribution and packing behaviour.

2. Synthetic Graphite (SG) AAM

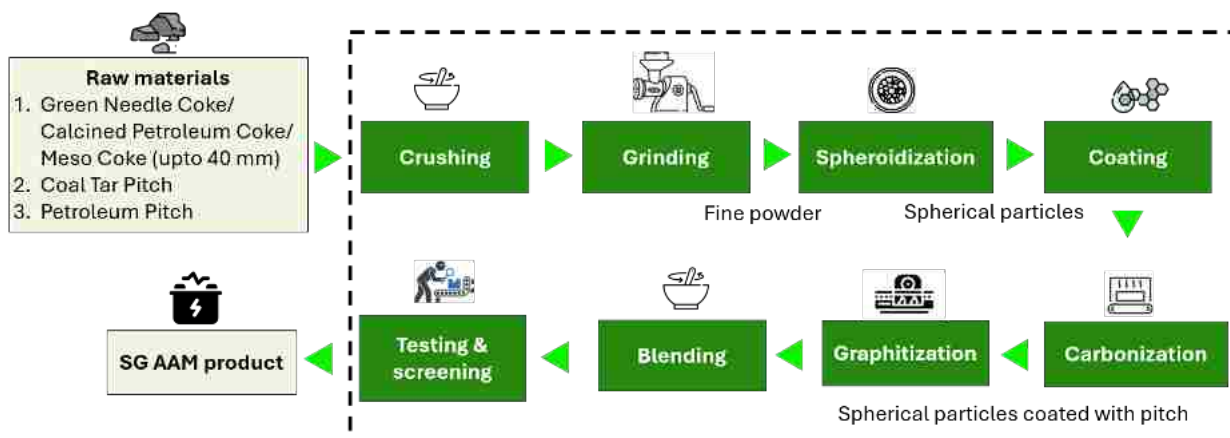
SG is manufactured by high-temperature graphitization of carbon-rich feedstocks (needle coke/ green petroleum coke, coal tar pitch). **It offers higher purity (>99.95% carbon), superior cycle life, low volume expansion and better fast-charging performance than NG, at the cost of energy intensity, manufacturing cost and carbon footprint due to graphitization at ~2800-3000°C.**

Key manufacturing takeaways (see Annexure for full process):

- Raw material prep (green needle coke/ calcined petroleum coke/ meso coke (up to 40 mm) + coal tar/petroleum pitch binder) → crushing → grinding → spheroidization/ particle shaping → coating.
- Carbonization (800-1200°C, inert atmosphere) converts the binder to a stable carbon matrix, followed by graphitization (~2800-3000°C) that transforms amorphous carbon into highly ordered graphite.
- Blending → testing/ screening → packing, graphitization is the most energy- and cost-intensive step in the entire AAM value chain.

The figure below presents the detailed manufacturing process flow.

Figure 34: Manufacturing process of SG anode



Source 59: As per inputs from Indian player(s).

Key Raw Materials:

The following table showcases the major raw materials required for SG AAM manufacturing, including petroleum coke/ needle coke as the primary carbon precursor and pitch-based binders for particle formation. These materials are utilized during mixing, shaping, carbonization, graphitization, and finishing processes to produce battery-grade synthetic graphite anode materials.

Table 26: Key raw materials required for SG Anode Active Material manufacturing

Raw material	Chemical formula	Qty. required (kg per kg of product) *
Green Needle Coke	C	2.06
Calcined Petroleum Coke	C	2.12
Coal Tar Pitch	-	0.18
Petroleum Pitch	-	0.18
Nitrogen	N ₂	1.3
Deionized water	H ₂ O	NA

Source 60: As per inputs from Indian player(s).

* NA denotes data not available.

The key materials involved across SG AAM manufacturing process, along with their mineral sources, functional role and domestic availability and typical quality specifications are summarized in the table below. The overview provides insight into supply chain dependencies, localization opportunities, and the overall readiness of the domestic ecosystem of SG production.

Table 27: Raw material sources and domestic availability for SG AAM manufacturing

Raw material	Purpose in process	Upstream	Status in India
Green Needle Coke (GNC)	Primary carbon source for SG AAM production	By-product of petroleum refining	 Primarily import-dependent
Calcined Petroleum Coke (CPC)			 Readily available domestically
Coal Tar Pitch	Binder for particle formation during mixing, shaping and carbonization	By-product of coke oven operations in the steel industry	 Completely imported
Petroleum Pitch	Alternative binder	Petroleum refinery residue	 Widely available domestically
Nitrogen (N₂)	Provides inert atmosphere during carbonization and heat treatment	Air separation units	 Widely available domestically
Deionized water	Washing and auxiliary processing operations	H ₂ O	

Source 61: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

India benefits from strong domestic availability of supporting materials and process utilities required for SG AAM manufacturing, including calcined petroleum coke, coal tar pitch, and industrial gases. However, the industry remains dependent on imports for critical feedstocks such as green needle coke and petroleum pitch, which are essential inputs for SG production. Consequently, nearly half of the raw material requirement for SG manufacturing is met through imports, highlighting persistent upstream localization challenges⁵⁷.

Battery-grade specifications and performance tiers:

Synthetic graphite is already a highly engineered material, so grade differences here mainly reflect graphitization and coating quality rather than baseline capacity and translate mainly into fast-charge tolerance and cycle life. Synthetic graphite's key advantage over natural graphite is structural: graphitization can be engineered toward more isotropic particles, giving lithium ions more uniform access paths rather than relying mainly on edge planes. This lowers the risk of lithium plating at high charge current, the primary mechanism that limits how fast a graphite anode can be charged, and a real safety and degradation concern when pushed. Premium SG grades with finer, more isotropic particles and lower surface area are what enable genuine fast-charging platforms without plating-driven capacity fade. Standard grades support normal charge rates with good cycle life at lower processing intensity. Fast-charge-capable EV platforms need premium SG (or SG/NG blends), while standard-rate applications don't need the fine, isotropic particle engineering that fast-charge tolerance requires.

Table 28: Technical specification comparison of spherical graphite AAM by product grade

Parameter	Low-end	Mid-end	High-end
Carbon purity (%)	≥ 99.7	≥ 99.9	≥ 99.95
D50 particle size (µm)	~15	11-15	9-12
Tap density (g/cm ³)	~0.85-0.9	~0.95-1.05	≥ 1.0-1.1
Moisture content (%)	≤ 0.2	< 0.1	< 0.05
Reversible capacity (mAh/g)	~350-355	~355-360	~360-365
1st cycle efficiency (%)	~93-95.5	~94-96	≥ 95-96

Source 62: As per inputs from Indian player(s).

C. Electrolyte:

The electrolyte is an ultra-high-purity solution that transports lithium ions between cathode and anode while providing high ionic conductivity, wide electrochemical stability and long-term cycling performance. **Lithium Hexafluorophosphate remains the dominant lithium salt (>92% of the total market volume⁵⁸), and Lithium Bis(fluorosulfonyl)imide is emerging for fast-charging, low-temperature and high-voltage formulations.** The salt is dissolved in a blend of carbonate solvents⁵⁹ (EC, DMC, DEC, EMC, optionally PC) chosen to balance dielectric strength (SEI formation) against viscosity/conductivity.

⁵⁷ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

⁵⁸ [Lithium Hexafluorophosphate \(LiPF₆\) Market | Market Growth Reports](#)

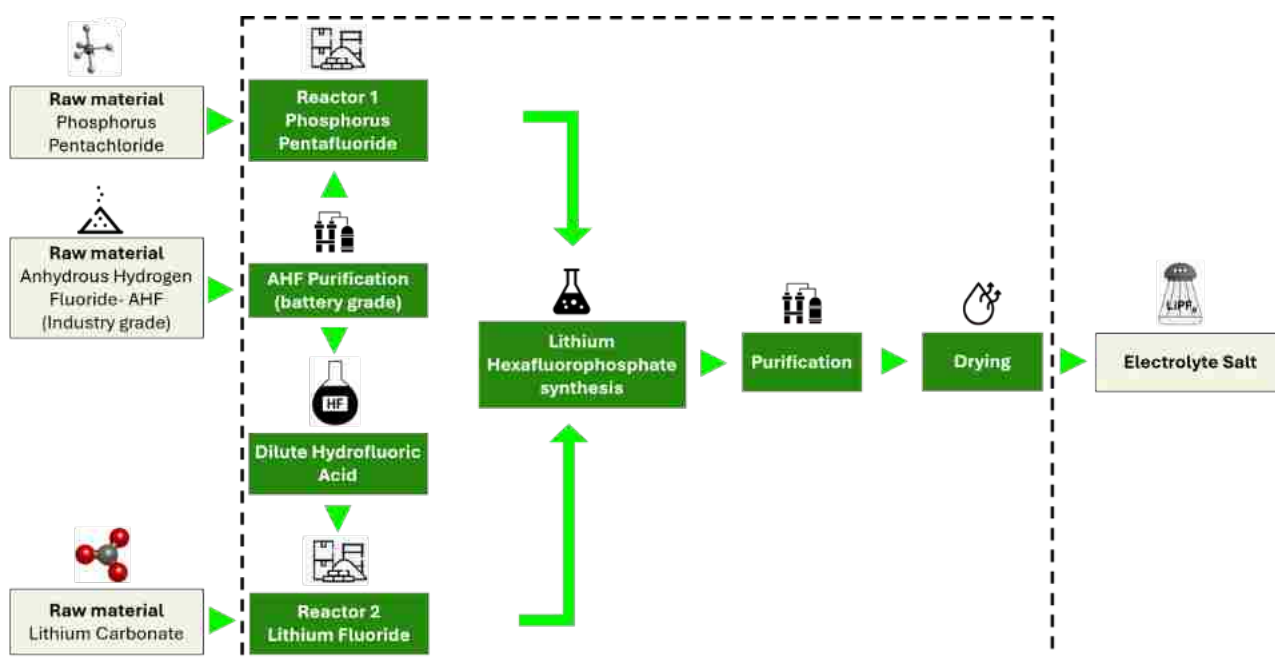
⁵⁹ Cyclic Carbonates (High Solubility & SEI Builders)- EC: Ethylene Carbonate, PC: Propylene Carbonate, Linear Carbonates (Viscosity Reducers)- DMC: Dimethyl Carbonate, DEC: Diethyl Carbonate, EMC: Ethyl Methyl Carbonate

Key manufacturing takeaways (see Annexure for full process):

- Electrolyte salts such as, **Lithium Hexafluorophosphate** (and Lithium Bis(fluorosulfonyl)imide) are either sourced externally or produced and purified to battery-grade quality for electrolyte production.
- Carbonate solvents also require battery-grade purification to eliminate moisture, particulates, and trace metal contaminants before electrolyte formulation.
- Electrolyte formulation in a controlled dry-room: electrolyte salt is dissolved into the solvent blend at set concentrations, followed by the addition of functional additives (Vinylene Carbonate, Fluoroethylene Carbonate, Lithium Bis(Oxalato)Borate, organophosphate flame retardants, etc.) according to the target cell chemistry.
- The electrolyte is then homogenized, fine-filtered (removes particles/gels), vacuum-degassed (removes dissolved gases, maintains ultra-low moisture), and subjected to QC testing (conductivity, purity, composition) before packaging.
- Ultra-low moisture control is required at every step, as trace water reacts with Lithium Hexafluorophosphate to form corrosive/toxic Hydrofluoric Acid.

The detailed manufacturing processes for both the electrolyte salt and the electrolyte are illustrated in the flowcharts below⁶⁰.

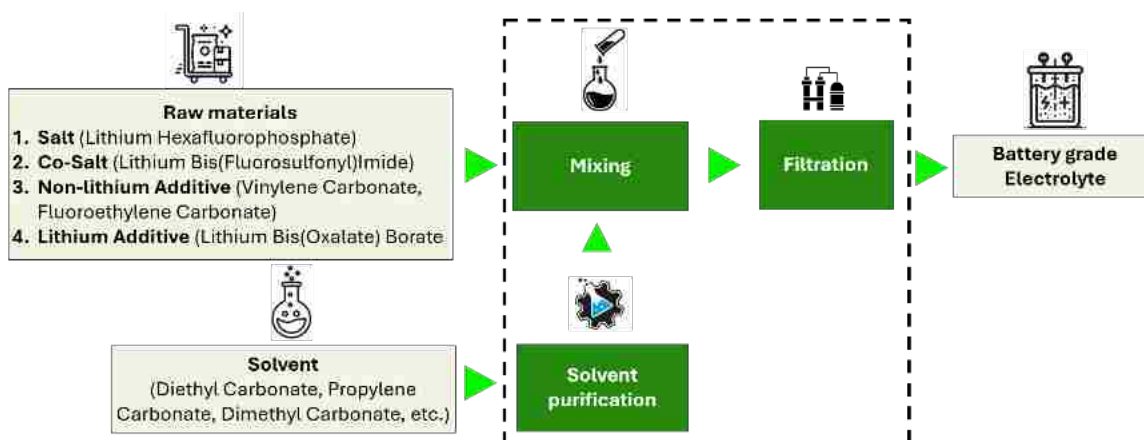
Figure 35: Manufacturing process of Electrolyte Salt



⁶⁰ [Electrolyte Formulation Process | PALL](#)

Source 63: As per inputs from Indian player(s).

Figure 36: Manufacturing process of Electrolyte



Source 64: As per inputs from Indian player(s).

Key raw materials:

The major raw materials required for lithium-ion battery electrolyte manufacturing, including lithium salts, carbonate-based solvents, and specialty additives are presented in the table below. Lithium salts provide ionic conductivity, while solvent blends facilitate lithium-ion transport between electrodes. Functional additives such as VC and FEC improve electrode interphase stability and cycle life, whereas optional organophosphate additives enhance electrolyte safety and thermal stability.

Table 54: Key raw materials required for electrolyte manufacturing

Raw material	Chemical formula		Qty. required (kg per kg of product) *
Lithium Hexafluorophosphate (LiPF ₆)	Electrolyte production	LiPF ₆	0.1-0.15
Lithium Bis(fluorosulfonyl)imide (LiFSI)		LiN(SO ₂ F) ₂	0.06
Ethylene Carbonate (EC)		C ₃ H ₄ O ₃	0.7-0.8
Dimethyl Carbonate (DMC)		C ₃ H ₆ O ₃	
Ethyl Methyl Carbonate (EMC)		C ₄ H ₈ O ₃	
Diethyl Carbonate (DEC)		C ₅ H ₁₀ O ₃	
Propylene Carbonate (PC)		C ₄ H ₆ O ₃	
Methyl Acetate (MA)		C ₃ H ₆ O ₂	
Organophosphates (optional)		Varies	0.01-0.15
Vinylene Carbonate (VC)		C ₃ H ₂ O ₃	
Fluoroethylene Carbonate (FEC)		C ₃ H ₃ FO ₃	
Lithium Bis(Oxalato)Borate (LiBOB)		LiB(C ₂ O ₄) ₂	NA
Lithium Hydroxide	Electrolyte Salt (Lithium Hexafluorophosphate) production	LiOH	15-16
Lithium Carbonate		Li ₂ CO ₃	
Anhydrous Hydrofluoric acid		HF	0.2
Phosphorus Pentachloride		PCl ₅	1.62

Source 65: As per inputs from Indian player(s).

* NA denotes data not available.

While the preceding table outlines the principal constituents, a comprehensive outlook of manufacturing feasibility also requires understanding of the origin, sourcing pathway, functional role, and domestic availability of these materials. Electrolyte production relies on combination of lithium salts (primarily lithium hexafluorophosphate), carbonate solvents, performance enhancing additives, and processing aids each with distinct supply chain characteristics and quality requirements.

Table 29: Overview of raw material sources, process function, and domestic availability for electrolyte manufacturing

Raw material	Purpose in process	Upstream	Status in India
Lithium Hexafluorophosphate (LiPF₆)	Primary electrolyte salt providing Li ⁺ ions for ionic conductivity	LiOH/Li ₂ CO ₃ , Phosphorous chemicals	 Largely imported.
Lithium Bis(fluorosulfonyl)imide (LiFSI)	Co-salt for improved conductivity, fast charging, and low-temperature performance	LiOH, Sulfur chemicals	
Ethylene Carbonate (EC)	High-dielectric solvent, dissolves lithium salts and promotes SEI formation	Ethylene oxide, Carbon dioxide	 Largely import dependent on battery-grade.
Dimethyl Carbonate (DMC)	Low-viscosity co-solvent improving ionic conductivity	Methanol, Carbon monoxide	
Ethyl Methyl Carbonate (EMC)	Co-solvent enhancing transport properties and low-temperature performance	Ethanol, Methanol, Carbonyl intermediates	
Diethyl Carbonate (DEC)	Alternative low-viscosity co-solvent	Ethanol, Carbon monoxides	 Commercially available, battery-grade supply is limited.
Propylene Carbonate (PC)	Specialty solvent for selected electrolyte formulations	Propylene, Carbon dioxide	
Methyl Acetate (MA)	Process solvent to dissolve lithium hexafluorophosphate	Methanol, Acetic acid	
Organophosphates (optional)	Flame-retardant additives improving safety and thermal stability	Phosphorous chemicals	 Imported specialty chemicals, domestic blending possible.
Vinylene Carbonate (VC)	Functional additive for stable SEI formation and improved cycle life	Ethylene carbonate derivatives	 Largely imported
Fluoroethylene Carbonate (FEC)	Functional additive for silicon anodes, fast charging, and low-temperature performance	Fluorinated organic intermediates	
Lithium Bis(Oxalato)Borate (LiBOB)	Additive improving high-temperature stability and cycle life	Lithium carbonate, Boric acid, Oxalic acid	

Raw material	Purpose in process	Upstream	Status in India
Lithium Hydroxide	Lithium source for electrolyte salt production	Extraction from brine/rock and then processing	 Primarily import dependent
Lithium Carbonate			
Anhydrous Hydrofluoric acid	Source of fluorine for electrolyte salt production	Industrial chemical	 Widely available domestically
Phosphorus Pentachloride	Source of phosphorus for electrolyte salt production		

Source 66: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

Very few of the critical raw materials required for electrolyte salt and electrolyte production are available domestically, with local capabilities largely limited to certain supporting chemicals and industrial gases. At present, key inputs such as lithium salts, battery-grade solvents, and specialty additives are predominantly imported, resulting in complete dependence on foreign sources for lithium-ion battery-grade electrolyte production.⁶¹ In addition, electrolyte salt (LiPF_6) production remains around 90% import dependent. These supply chain gaps highlight the limited localization of India's electrolyte value chain and represent a significant upstream challenge for the domestic battery manufacturing ecosystem.

Battery-grade specifications and performance tiers:

Electrolyte is defined predominantly by moisture and free-acid control and by the additive package used, both of which directly govern cycle life, safety and fast-charge capability. Electrolyte grade governs three linked outcomes: ionic conductivity (rate capability and low-temperature performance), interfacial stability (cycle life and gas generation), and the electrochemical stability window (how high a cathode voltage the cell can safely use). Moisture control is the starting point for all three, trace water hydrolyzes LiPF_6 into hydrofluoric acid, which attacks the cathode surface, dissolves transition metals and destabilizes the SEI, so tighter moisture and free-acid specs translate directly into longer calendar and cycle life. Functional additives (VC, FEC, LiBOB) build a more robust SEI/CEI and extend the voltage window the electrolyte can tolerate which is what makes high-nickel NMC cathodes and fast-charging protocols viable. A simple, single-salt, minimal-additive electrolyte performs adequately with LFP cells cycled at moderate rates, where cathode voltage and thermal stress are inherently modest, whereas high-voltage NMC chemistries, fast-charging platforms and cold-climate applications need the multi-additive, ultra-low-moisture premium formulations to avoid accelerated degradation.

⁶¹ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

Table 30: Technical specification comparison of battery-grade electrolyte by product grade

Parameter	Low-end	Mid-end	High-end
LiPF ₆ purity (%)	≥ 99.9	≥ 99.95	≥ 99.995
Salt concentration (mol/L)	1.0, single salt	1.0-1.15, basic additive	1.0-1.2, dual/multi-salt
Moisture content (ppm)	< 20-30	< 20	< 10-15/< 5-10
Ionic conductivity (25°C) (mS/cm)	~8-9	~9-10	≥ 10
Functional additives	Minimal/none	VC and/or FEC (~1-2 wt%)	VC + FEC + LiBOB/LiFSI + flame-retardant organophosphates

Source 67: As per inputs from Indian player(s).

D. Separator:

The separator is a thin microporous polymer membrane between cathode and anode that electrically insulates the electrodes (preventing internal short-circuits) while allowing lithium-ion transport.

Generally, two types of separators are used: dry-process separators and wet-process separators. In the dry process, polyolefin films, typically polypropylene, are extruded and stretched to create a microporous structure (generally without solvent extraction). In the wet process, generally used for polyethylene-based separators, the polymer is blended with a plasticizer, extruded and biaxially stretched, followed by solvent extraction of the plasticizer to form the microporous membrane.

Wet processing can produce thin membranes with relatively uniform pore structures and is widely used for separators requiring controlled porosity and mechanical properties. The preferred route depends on the target cell design, performance requirements, safety characteristics, and manufacturing cost. Mostly wet processing is preferred for better safety performance and high-energy-density cells.

Table 31: Grades of Separator

Item	Wet-process separator	Dry-process separator
Raw material	Polyethylene (PE)	Polypropylene (PP)
Thickness	7µm to 9µm	12µm to 16µm

Source 68: [Multilayer Polyethylene Separator with Enhanced Thermal and Electrochemical Performance for Lithium-Ion Batteries, Materials, 19, 342 \(2026\)](#)

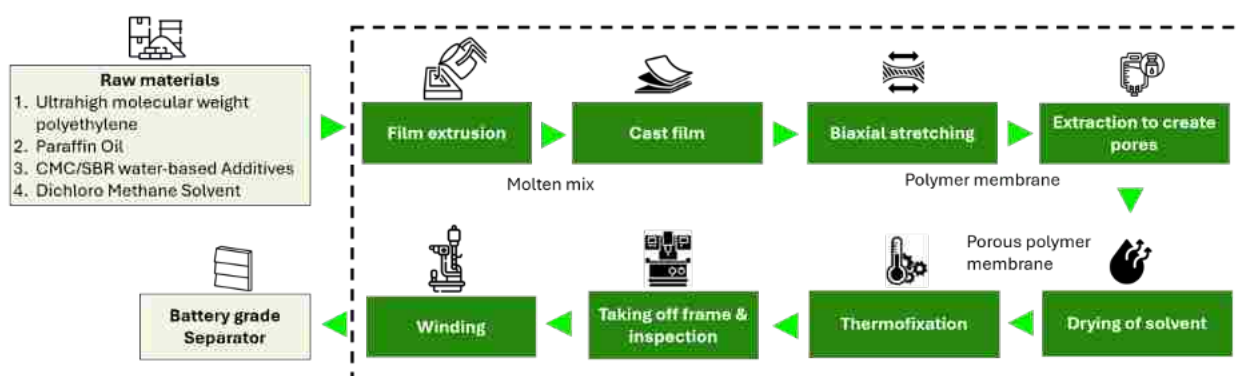
Commercial separators are PE, PP or multilayer PP/PE/PP, often with a ceramic coating (Al₂O₃/SiO₂) for thermal stability and dendrite resistance, and many include a thermal-shutdown function where the PE layer melts to close pores under abuse conditions. As NMC batteries are targeting higher energy density, manufacturers are mostly using wet-process separators. This is because wet-process separators are typically 30%–40% thinner than dry-process separators, allowing more space for other cell components. As for LFP batteries, both wet-process and dry-process separators are used by cell manufacturers.

Key manufacturing takeaways (see Annexure for full process):

- Ultra-high molecular weight polyethylene (UHMWPE) compounded with paraffin oil (plasticizer) and stabilizers followed by film extrusion and casting. The film is then biaxially stretched in both the machine direction (MD) and transverse direction (TD) to develop an interconnected microporous structure.
- The paraffin oil is subsequently removed through solvent extraction, creating the desired pore structure. The membrane is then dried and subjected to thermofixation (heat-setting) to stabilize the porous architecture and minimize dimensional shrinkage.
- Optional ceramic coating (Al_2O_3 /boehmite with binder) may be applied to enhance thermal stability, puncture resistance, and wettability. The separator then undergoes quality inspection for parameters such as thickness, porosity, tensile strength, shrinkage, and wettability, before being wound, slit into rolls, packaged, and shipped.

The following flow chart outlines the key steps involved in the manufacturing process.

Figure 37: Manufacturing process of Separator



Source 69: As per inputs from Indian player(s).

Key raw materials:

The major raw materials required for lithium-ion battery separator manufacturing, including ultra-high molecular weight polyethylene (UHMWPE) as the primary membrane-forming polymer, paraffin oil and extraction solvents for pore generation, and ceramic coating materials such as alumina and boehmite to enhance thermal stability and safety are outlined below. Binders, dispersants, and wetting agents are used during the coating process to ensure strong adhesion, uniform ceramic distribution, and consistent separator performance.

Table 58: Key raw materials required for separator manufacturing

Raw material	Chemical formula	Qty. required (gm/m ²)
Ultra-high molecular weight polyethylene (UHMWPE)	$(\text{C}_2\text{H}_4)_n$	4.39
Plasticizer (Paraffin oil)	-	0.66
Binders: polymer-additives (CMC/SBR water based)	$(\text{C}_2\text{H}_2\text{F}_2)_n$	1.41
Solvent: Dichloro Methane (DCM)	CH_2Cl_2	4.21
Coating: Alumina, Boehmite	Al_2O_3 , AlOOH	10.00

Source 70: As per inputs from Indian player(s).

Raw material costs in India are ~15-20% higher than in China due to almost 100% dependence on imported separator-grade ultra-high molecular weight polyethylene (UHMWPE) and other specialty materials⁶². As local availability of equivalent-quality materials improves, domestic sourcing is expected to increase, enhancing DVA. The following table gives the overview of the key materials used throughout the separator manufacturing process, highlighting their sources, role in production, domestic availability and typical specifications.

Table 32: Raw mineral source, role in the production and domestic availability status of the raw materials required in separator manufacturing

Raw material	Purpose in process	Upstream	Status in India
Ultra-high molecular weight polyethylene (UHMWPE): (C₂H₄)_n	Primary membrane-forming polymer used to produce the microporous separator through wet-process extrusion	Refined from crude oil	 Entirely imported
Plasticizer (Paraffin Oil)	Processing aid and pore-forming agent, extracted after stretching to generate microporous structure	Petroleum refining	 Available domestically, but imported for battery-grade
CMC/SBR binders	Binder used for ceramic coating to improve adhesion between ceramic particles and separator surface	Fluorspar, Vinylidene fluoride	 Completely imported
Di Chloro Methane (DCM)	Extraction solvent used to remove paraffin oil from the polymer matrix during pore formation	Methane, Chlorine	 Manufactured in India, imported for battery-grade
Alumina	Ceramic coating material that improves thermal stability, puncture resistance, and separator safety	Bauxite	
Boehmite	Alternative ceramic coating material providing excellent electrolyte wettability and thermal stability	Bauxite/ Alumina hydrate	

Source 71: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

In the absence of domestic separator manufacturing capabilities currently, the entire separator value chain remains fully dependent on imports. Critical inputs, including separator base films, plasticizers, binders, solvents, and coating materials are currently sourced entirely from international suppliers, highlighting a significant gap in the domestic battery materials ecosystem.

Battery-grade specifications and performance tiers:

Separator grade is largely a function of thickness and whether a ceramic coating is applied. Benchmarked against a representative commercial product line spanning commodity monolayer/trilayer films through thin, ceramic-coated high-grade membranes. Separator thickness and coating are a direct trade-off between energy density and

⁶² Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

safety margin, a thinner film frees up internal cell volume for active material (raising energy density) but has less inherent mechanical and dielectric margin against puncture or internal short-circuit, and less thermal margin before it shrinks or melts under abuse. Ceramic coating is what restores that margin on thin films, it substantially reduces thermal shrinkage at elevated temperature, which is what keeps the electrodes physically separated (preventing an internal short) if a cell is pushed toward thermal runaway. Porosity sets the separator's contribution to internal resistance, so a more open structure supports better rate capability and fast charging as long as mechanical integrity holds. Thin, ceramic-coated separators are effectively mandatory for high-energy-density, fast-charging or high-nickel-NMC cells, where both energy content and thermal risk are higher. Thicker, uncoated films remain an acceptable choice for LFP-based cells, which are inherently more thermally stable and need less separator-side safety margin to begin with.

Table 33: Technical specification comparison of battery-grade separator by product grade

Parameter	Low-end	Mid-end	High-end
Product type	25 µm monolayer/trilayer PP or PP/PE/PP (e.g., Celgard 2400/2325)	16-20 µm trilayer PP/PE/PP (e.g., Celgard 2320/H-series)	9-16 µm base film, ceramic-coated (Al ₂ O ₃ /boehmite), total ~16-22 µm
Thickness (µm)	25	16-20	9-16
Porosity (%)	39-41	40-45	40-50
Moisture/handling g	Standard dry-room handling	Standard dry-room handling	Ceramic coating is hygroscopic

Source 72: As per inputs from Indian player(s).

E. **Copper Foil:**

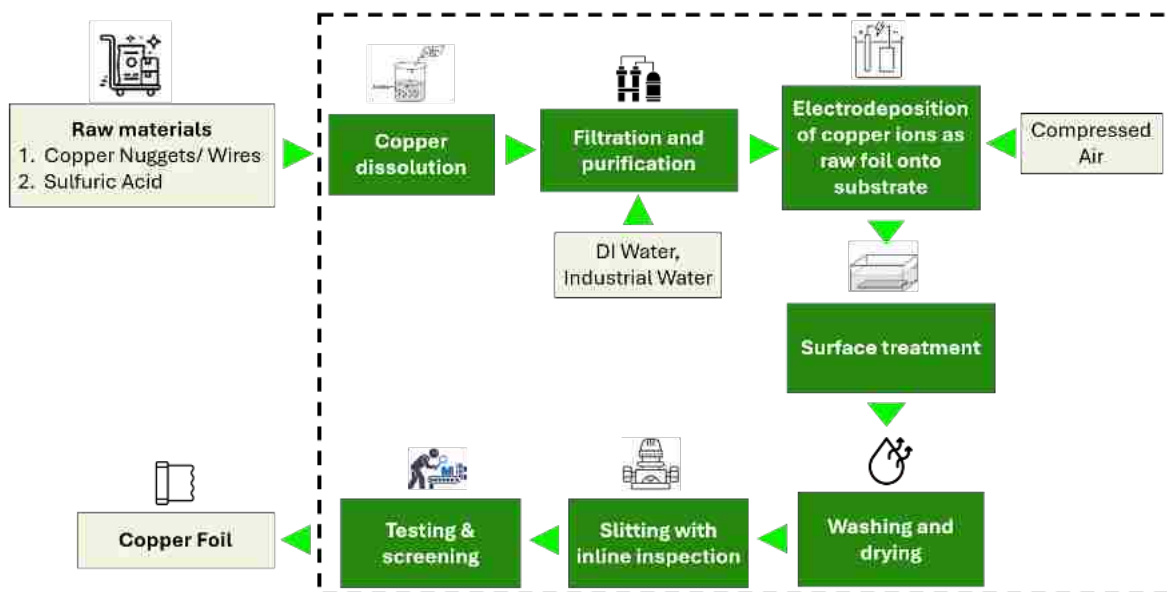
Copper foil serves as the anode current collector, providing a highly conductive pathway for electron transport. **Battery-grade electrolytic (ED) copper foil is typically 4-12 µm thick with >99.9% Cu purity, high mechanical strength, low surface roughness and strong adhesion to the anode coating, surface treatments (roughening, anti-oxidation coatings) improve coating adhesion and corrosion resistance.**

Key manufacturing takeaways (see Annexure for full process):

- High-purity copper (>99.8%, from copper nuggets/rods/wires or scrap) is dissolved in sulfuric acid to form a copper sulphate electrolyte, then filtered and purified.
- Electrodeposition: copper ions deposit onto a continuously rotating titanium drum/cathode under DC current, peeling off as a continuous raw copper foil sheet; Polyethylene Glycol, Bis-(3-sulfopropyl) Disulfide and leveller additives control grain structure, surface morphology and mechanical properties.
- Surface treatment (roughening, passivation, anti-oxidation) → washing/drying → slitting and inline defect inspection → final winding, comprehensive QC (thickness, tensile strength, conductivity, coating adhesion) → packaging/shipment.

The flow diagram below provides the detailed manufacturing process.

Figure 43: Manufacturing process of copper foil



Source 73: As per inputs from Indian player(s).

Key raw materials:

The following table presents the major raw materials required for battery-grade copper foil manufacturing, including copper feedstock, copper sulphate electrolyte components, and specialized plating additives. Copper is electrodeposited onto a rotating titanium drum from a sulfuric acid-based electrolyte, while additives such as Polyethylene Glycol (PEG), Bis-(3-sulfopropyl) Disulfide (SPS), and levelling agents are used to control surface morphology, grain structure, and mechanical properties. These materials collectively enable the production of high-quality copper foil used as the anode current collector in lithium-ion batteries.

Table 61: Key raw materials required for copper foil manufacturing

Raw material	Chemical formula
Copper Nuggets/ Wires/ Scrap Copper	Cu
Sulfuric Acid	H ₂ SO ₄
Polyethylene Glycol (PEG)	(C ₂ H ₄ O) _n
Bis-(3-sulfopropyl) Disulfide (SPS)	C ₆ H ₁₂ O ₆ S ₄
Surface treatment	-
Deionized Water	H ₂ O

Source 74: As per inputs from Indian player(s).

The table below presents the source of the raw mineral, purpose in the production and domestic availability of all primary materials required for copper foil manufacturing.

Table 62: A comprehensive overview of the raw materials required for copper foil manufacturing

Raw material	Purpose in process	Upstream	Status in India
Copper Nuggets/ Wires/ Scrap Copper	Primary copper feedstock used to prepare copper sulphate electrolyte	Copper ore refined through smelting and electrorefining	 Largely available domestically.

Raw material	Purpose in process	Upstream	Status in India
Sulfuric Acid	Maintains electrolyte conductivity and pH, improves deposition efficiency	Produced from elemental sulfur or recovered from metal smelters	 Readily available in India with large domestic production.
Polyethylene Glycol (PEG)	Suppressor additive that controls copper deposition rate and reduces surface roughness	Petrochemical feedstocks (ethylene oxide derived from ethylene)	 Produced in India, but battery-grade PEG is partly imported.
Bis-(3-sulfopropyl) Disulfide (SPS)	Brightener/accelerator, promotes fine-grained deposition and improves tensile properties	Specialty sulfur-based organic chemical synthesized from petrochemical intermediates	 Largely imported.
Deionized water	Washing and auxiliary processing operations	H ₂ O	 Fully available domestically
Surface treatment chemicals	Improve adhesion between copper foil and anode active material while enhancing corrosion resistance	Specialty inorganic and organosilane chemicals	 Mostly imported

Source 75: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

While most raw materials and process chemicals required for copper foil manufacturing are readily available domestically, the primary constraint lies in the limited commercial-scale capability to produce battery-grade ultra-thin copper foil. The challenge is driven less by raw material availability, with import dependence remaining 'very low (at around 5%) and more by gaps in advanced manufacturing technology, process know-how, and quality control required to meet battery-grade specifications⁶³. As a result, the localization of high-performance copper foil for lithium-ion battery applications remains constrained despite a strong domestic raw material base.

Battery-grade specifications and performance tiers:

Copper foil specs use different parameters than the powder/film materials above i.e., thickness and mechanical properties replace particle size and tap density, since it is a solid current-collector foil. Foil thickness trades energy density against mechanical robustness through two distinct failure modes. First, thinner foil is more prone to tearing or cracking during electrode calendaring, slitting and tight-radius winding process for cylindrical cells, where a foil failure breaks the current path and creates a local capacity/power dead zone. Second, the anode active material expands and contracts on every charge-discharge cycle so the foil must retain enough elongation to activate with that expansion over thousands of cycles without cracking. Surface roughness governs adhesion between foil and anode coating i.e., too smooth and the coating delaminate over life, gradually raising internal resistance and fading capacity and too rough and it adds inert mass without a performance benefit. Ultra-thin,

⁶³ Import dependency has been estimated using a material consumption-weighted approach, based on the import/localization status of key raw materials obtained through primary industry inputs and their consumption (kg) per kg of finished product. Percentages represent material-level import dependence and are not based on import value or production capacity.

high-tensile, nano-twin-structured foil is the right choice for high-energy-density, tightly wound cylindrical formats where both energy density and cycling durability are being pushed. Standard-gauge foil remains appropriate wherever mechanical stress on the current collector is lower as in most prismatic and pouch designs.

Table 34: Technical specification comparison of battery-grade copper foil by product grade

Parameter	Low-end	Mid-end	High-end
Copper purity	≥ 99.7	≥ 99.8	≥ 99.9
Thickness (μm)	10-20	8-10	4-6
Tensile strength (MPa)	250-350	350-550	500-800
Surface roughness (matte side)	Rz ~2.5-3.5 μm/Ra ~0.3-0.5 μm	Rz ≤ 2.0 μm/Ra ≤ 0.2 μm	Rz ≤ 1.2-1.4 μm/Ra ≤ 0.15 μm

Source 76: As per inputs from Indian player(s).

4.2. Summary

The manufacturing of lithium-ion battery ACC components including **cathode active materials (LFP and NMC), anode active materials (natural and synthetic graphite), electrolyte salts and electrolytes, separators, copper foil** requires highly controlled manufacturing processes to consistently achieve battery-grade specifications. Product performance depends not only on raw material availability but also on precise process control, advanced equipment, proprietary manufacturing know-how, stringent contamination management, and robust quality assurance throughout the value chain.

The manufacturing complexity of ACC components also results in significant upfront capital requirements. Dependence on imported equipment, specialized process technologies, precision-control systems, testing facilities and environmental infrastructure increases the investment required to establish battery-grade manufacturing capacity in India. This capital intensity represents an additional barrier for new domestic facilities seeking to achieve commercially viable scale.

India possesses a strong foundation in several upstream industrial inputs, including refined copper, aluminium, sulfuric acid, phosphoric acid, industrial gases, graphite ore, and petrochemical feedstocks. However, domestic capabilities for manufacturing high-value battery-grade materials and precision components remain uneven. While commodity-grade raw materials are largely available, significant gaps persist in precursor synthesis, specialty chemical production, ultra-thin foil manufacturing, separator film technology, battery-grade electrolyte formulations, and advanced surface treatment technologies. Bridging these gaps will require investments in manufacturing technologies, process development, equipment localization, quality systems, and ecosystem-wide capability building to establish a globally competitive battery manufacturing supply chain.

Key observations:

- **Battery material and component manufacturing is process-intensive rather than resource-intensive.** Achieving battery-grade performance requires stringent control over purity, particle size distribution, morphology, moisture content, coating uniformity, thickness variation, contamination, and process consistency. Manufacturing know-how and process optimization remain key competitive differentiators.
- **India has strong localization potential in upstream materials.** Domestic industries already provide a robust supply base for refined copper, aluminium, industrial acids, industrial gases, graphite ore, solvents, and several commodity chemicals, providing a solid foundation for localization of the battery manufacturing ecosystem.
- **Import dependency remains concentrated in high-value specialty materials.** India continues to rely heavily on imports for lithium chemicals, nickel and cobalt salts, cathode precursors, separator films,

electrolyte salts and additives, specialty binders, conductive additives, and advanced surface treatment chemicals. These materials contribute disproportionately to both supply chain risk and overall battery cost.

- **Manufacturing complexity is another bottleneck for localization.** The largest challenges arise from precision coating technologies, electrochemical synthesis, ultra-thin foil production, biaxial stretching of separator films, precursor engineering, advanced purification processes, proprietary formulations, and maintaining consistent battery-grade quality at commercial scale. This varies significantly across battery components. Natural graphite AAM is of medium complexity, while LFP CAM and spherical graphite AAM are high due to more demanding processing requirements. CAM- NMC, electrolyte, separator, and copper foil are manufactured with very high complexity, requiring precise process control, specialized technologies, and stringent quality standards. Overall, five of the seven components rely heavily on imported machinery and specialty process technologies.
- **Component-wise opportunities for India in manufacturing processes differ across the value chain:**
 - ✓ **Cathode active materials:** Cathode manufacturing is highly process-intensive, requiring precursor synthesis, calcination, surface coating, and stringent quality control. India has stronger localization potential for LFP due to the market demand and a strong chemical industry, while NMC remains highly import dependent because of nickel, cobalt precursors, and proprietary manufacturing technologies. Key opportunities lie in precursor production, battery-grade calcination, and process know-how.
 - ✓ **Anode active materials:** Natural graphite manufacturing is relatively mature, relying on purification, spheroidization, and coating, whereas synthetic graphite requires energy-intensive graphitization and advanced furnace technologies, making it more complex. India has relatively strong upstream material base for anode active materials, particularly for natural graphite and carbonaceous feedstocks, but limited battery-grade processing capabilities. Expanding purification, graphitization, coating, and synthetic graphite production offers significant localization potential.
 - ✓ **Electrolytes:** India's established chemical industry provides a basic foundation for electrolyte manufacturing; however, battery-grade electrolytes require ultra-high purity lithium salts, moisture-free processing, and proprietary formulations. Dependence on imported lithium salts and specialty additives remains high. Therefore, limited opportunities exist in domestic lithium salt production, electrolyte formulation, and additive manufacturing.
 - ✓ **Separator:** Separator manufacturing is among the most technology-intensive battery components, requiring microporous membrane production, biaxial stretching, ceramic coating, and precision quality control. India has limited commercial manufacturing capability and continues to rely heavily on imports.
 - ✓ **Copper foil:** Although India has a strong copper refining base, manufacturing ultra-thin battery-grade copper foil requires advanced electrodeposition technology and precision process control. Domestic capability remains limited, resulting in continued import dependence. Investment in ultra-thin foil manufacturing and surface treatment technologies can significantly strengthen localization.
 - ✓ **Binders, conductive additives and specialty chemicals:** Leverage India's specialty chemical sector to localize advanced polymer binders, carbon additives, electrolyte additives, and surface treatment chemicals.
- **India's competitive advantage lies in integrating its strong metals, chemicals, and process industries with advanced battery manufacturing technologies.** Strategic investments in precursor manufacturing, specialty chemicals, precision manufacturing equipment, quality systems, and process know-how can substantially reduce import dependence while positioning India as a global manufacturing hub for battery materials and components.

Chapter 5. Recommendations

India's battery demand is projected to increase from approximately 33 GWh in 2025 to 236 GWh by 2032 and nearly 600 GWh by 2037. However, the domestic manufacturing base for key Advanced Chemistry Cell (ACC) components remains significantly below the scale required to support this growth. Domestic capacity is currently limited for Cathode Active Material (CAM), Anode Active Material (AAM) and electrolyte, while manufacturing of separators and battery-grade copper foil remains at an early stage.

This gap is important because **battery materials and components account for approximately 76% of total cell manufacturing cost**, with cathode and anode materials being the largest cost elements. As a result, increasing domestic cell-manufacturing capacity without developing the upstream component ecosystem could result in India assembling cells domestically while continuing to import a significant share of the materials and components required to manufacture them. This would limit domestic value addition, expose cell manufacturers to global supply and price fluctuations, and reduce the broader economic benefits of developing an integrated battery manufacturing ecosystem in India.

The assessment indicates that domestic manufacturers face a significant **India-specific manufacturing cost disadvantage of approximately 18%–61%** across the ACC components assessed. The disadvantage is even more pronounced in the initial investment required to establish CAM and AAM manufacturing capacity, with estimated CAPEX in India approximately **235%–425% higher than in China**. These disadvantages arise from a combination of higher raw-material and financing costs, dependence on imported equipment and technology, limited domestic supplier ecosystems, lower initial plant utilization and yields, and longer product-development and customer qualification timelines.

Importantly, **the nature and magnitude of the cost disadvantage vary across components**. Raw-material costs are the primary driver of the disadvantage for CAM, electrolyte and copper foil, while conversion costs, energy consumption, financing costs and depreciation are particularly important for AAM and separators. This suggests that the competitiveness challenge cannot be addressed through a single policy instrument or a uniform level of support across all components.

Based on the assessment, five key policy recommendations are proposed to support the development of a competitive domestic ACC component ecosystem:

Figure 38 Key recommendations for promoting domestic manufacturing of ACC components



5.1. Key recommendations

Recommendation 1: Provide fiscal support in the form of CAPEX/OPEX incentive for setting up 50 GWh of domestic ACC component manufacturing capacity

India's battery demand is expected to reach approximately 236 GWh by 2032, while industry players have announced approximately 220 GWh of ACC manufacturing capacity, of which approximately 67 GWh is expected to be commissioned by FY2028-29.

This development of cell capacity needs to be accompanied by adequate domestic manufacturing of the critical materials and components required to supply these cells. Based on stakeholder consultations undertaken as part of this study, domestic ACC component manufacturers intend to establish more than 50 GWh equivalent of ACC capacity provided there is adequate government support. Therefore, a target of at least 50 GWh of domestic ACC component manufacturing capacity should be considered for the proposed fiscal support measure(s).

The assessment in Chapter 3 indicates that domestic ACC component manufacturers face disabilities on both fronts: higher upfront capital expenditure and higher recurring manufacturing costs relative to established Chinese manufacturers. The magnitude and drivers of these disabilities vary materially across components, the assessed manufacturing-cost disability ranges from **approximately 18% to 61%**.

This disability arises from structural factors, including higher raw-material and conversion costs, dependence on imported battery-grade inputs and specialised equipment, higher financing costs, lower initial capacity utilisation and yields, and longer product-qualification timelines. These factors affect the recurring cost of domestic production and are not addressed merely by reducing the initial cost of establishing manufacturing capacity.

The fiscal support framework may be structured through any one of the following three options:

1. Capex and Opex Support

2. Opex Support

3. Capex Support

- 1. CAPEX and OPEX support:** A hybrid support structure may be considered, comprising a **CAPEX subsidy of 25%** of eligible capital expenditure, together with a **component-specific OPEX incentive** that may be linked to eligible sales and calibrated to offset approximately 30% of the assessed cost disability. This approach is broadly aligned with the incentive structure proposed under the **Rare Earth Permanent Magnet Scheme**, which combines disbursement of 15% of eligible investment as CAPEX subsidy along with a sales-linked incentive.

ACC component	Proposed CAPEX subsidy	Proposed OPEX incentive
CAM – LFP	25%	14%
CAM – NMC	25%	5%
AAM – NG	25%	15%
AAM – SG	25%	18%
Electrolyte	25%	11%
Separator	25%	15%
Copper Foil	25%	8%

The lower OPEX support against the cost disability is based on the expectation that part of the current cost disability would reduce as the domestic ecosystem matures. Higher production volumes, improved capacity utilization, process optimization, localization of inputs and equipment, lower scrap rates, and improved yields are expected to progressively reduce manufacturing costs. Government support should therefore address only a portion of the cost disability, while encouraging manufacturers to improve productivity, undertake innovation and achieve cost optimization.

The hybrid structure would provide support across investment, commissioning, and commercial production, while enabling periodic monitoring and course correction based on project implementation, capacity utilization, domestic value addition, and eligible sales. This structure recognizes that support is required both at the capacity-

creation stage and during commercial operations. The 25% CAPEX subsidy would partially address the initial investment barrier, while the OPEX incentive would provide support during the ramp-up and commercialization period.

- 2. OPEX support:** A production-linked OPEX incentive may be provided to address the recurring manufacturing-cost disability identified in Chapter 3. As the magnitude of the disability differs across ACC components; the incentives should be determined separately for each component rather than through a uniform rate. The incentive may be linked to eligible sales and calculated to **offset 60% of the assessed cost disability**. OPEX support may be provided for a tenure of 5-7 years, exact tenure to be determined by the Government.

The proposed rates are set out below:

ACC component	Assessed OPEX cost disability	Proposed OPEX incentive
CAM – LFP	47%	28%
CAM – NMC	18%	11%
AAM – NG	51%	31%
AAM – SG	61%	37%
Electrolyte	37%	22%
Separator	49%	29%
Copper Foil	27%	16%

Note: Aluminium battery foil may be excluded from support given the sufficiency of the existing domestic aluminium ecosystem.

The higher OPEX incentive reflects the absence of CAPEX assistance and the resulting higher financing, depreciation and project-risk burden retained by the manufacturer.

The proposed support is not intended to compensate manufacturers for the entire cost disability. Manufacturers would continue to bear a significant share of the cost disability and retain adequate commercial risk. This will encourage the industry to undertake process innovation, improve yields, reduce scrap rates, localize inputs, and achieve higher capacity utilization. Since the incentive would be disbursed only after commissioning and commencement of sales, the applicable rate should be sufficient to provide a meaningful commercial benefit despite the deferred nature of the support.

- 3. CAPEX support:** A CAPEX subsidy of 50% of the project cost on *pari-passu* basis may be provided to partially offset the high upfront investment required to establish ACC component manufacturing facilities on a commercially viable scale. This approach is broadly aligned with the CAPEX-linked incentive under the **Semicon India programme**, which provides fiscal support of 50% of Project Cost on *pari-passu* basis.

ACC component	Proposed CAPEX subsidy (<i>pari-passu</i> basis)
CAM – LFP	50%
CAM – NMC	50%
AAM – NG	50%
AAM – SG	50%
Electrolyte	50%
Separator	50%
Copper Foil	50%

A CAPEX-linked incentive would directly support the procurement and commissioning of new plant and machinery and could accelerate capacity creation. The 50% CAPEX subsidy would support a significant share of the investment risk, however manufacturers and industry participants would retain operational risk, and will have to continuously innovate to bridge the manufacturing-cost disability.

A CAPEX subsidy can reduce the upfront investment requirement and facilitate capacity creation. However, **CAPEX support in isolation may not address the recurring manufacturing-cost disability faced by domestic**

producers after commencement of commercial operations. Domestic output may therefore remain more expensive than imported components, resulting in low-capacity utilisation, continued operating losses and an inability to sustain manufacturing operations during the ramp-up and customer-qualification period.

The most effective support option needs to be determined by the Government after considering component-wise cost disability, capital intensity, gestation period, fiscal implications, and ease of monitoring.

The support provided should be made **sector/ end-use agnostic** to enable indigenization of the required ACC component manufacturing capacity. Eligibility and disbursement may be linked to committed capacity, eligible investment, domestic value addition, commissioning, actual sales, and other performance conditions determined by the Government.

Expected outcome: Facilitation of ACC component manufacturing facilities at commercially viable scale, reduction in the initial cost disability and lower dependence on imported ACC components.

Implementing Ministry/Agency: Ministry of Heavy Industries, in coordination with the Ministry of Finance and other relevant ministries.

Indicative timeline: Short-term (FY2026-27)

Recommendation 2: Establish national testing, certification and qualification infrastructure for ACC components

It is proposed that a network of National ACC components Testing, Certification and Qualification Facilities be established by upgrading and integrating relevant capabilities available across existing national laboratories and academic institutions.

The facilities should provide standardized chemical, physical, electrochemical, safety and performance testing across CAM, AAM, electrolyte, separators and battery-grade copper foil. The network should also enable component-level testing and representative cell-level validation required for preliminary product qualification.

The proposed facilities should operate through **designated centres of excellence** for different component categories rather than through a single stand-alone institution. This would consolidate specialised capabilities, reduce duplication of capital-intensive equipment, and minimize the cost and time associated with engaging multiple laboratories. Common testing protocols, accredited facilities and standardized reporting formats should be developed in consultation with component manufacturers, cell manufacturers and standards bodies. These Centres would also serve as a collaborative R&D hub with IITs, CSIR, IISERs, and BARC to accelerate commercialization⁶⁴.

Test results generated through the network may be recognized for preliminary supplier qualification across participating cell manufacturers and government-supported programmes. Final commercial approval should continue to remain with the respective cell manufacturer, considering the compatibility requirements of specific cell chemistries, designs and manufacturing processes.

The network should also include access to limited pilot-scale facilities for preparing and validating representative component samples. This would help bridge the present gap between laboratory-scale development and the volumes required for customer qualification.

The proposed facilities and labs may include the following:

⁶⁴ Industry input

Sr. No.	Proposed facility/ lab
1.	Battery Materials Synthesis and Pilot Reactor Facility
2.	Kilo-Scale CAM and AAM Production Line (Scale-up Unit)
3.	Electrolyte Salts and Functional Formulation Lab
4.	Separator and Polymer Processing Lab
5.	Current Collector and Interface Engineering Lab
6.	Binder, Additive and Electrode Chemistry Lab
7.	Advanced Characterization and Materials Chemistry Lab
8.	Interface and Degradation Science Lab
9.	Electrochemical Benchmarking Facility
10.	Reliability and Accelerated Aging Lab
11.	Safety and Abuse Testing Facility
12.	Dry Room and Controlled Atmosphere Facility
13.	Prototype Electrode and Cell Fabrication Unit (Secondary Validation)
14.	Materials Data and Digital Intelligence Platform
15.	Quality, Standards and Certification Support Cell
16.	Buildings and Allied Infrastructure

Expected outcome: Reduced testing costs and qualification timelines, lower dependence on overseas facilities, improved consistency of test results, greater availability of independent third-party validation, and faster commercialization of domestically manufactured components.

Implementing Ministry/Agency: Ministry of Heavy Industries, Department of Science and Technology and Bureau of Indian Standards, in collaboration with relevant national institutions, accreditation bodies and industry.

Indicative timeline: Short-term (FY2026-27)

Recommendation 3: Develop domestic battery raw-material processing and mineral capabilities

It is proposed that a phased programme be developed to strengthen domestic capabilities across the **upstream raw-material value chain** for ACC component manufacturing.

The initial focus should be on **establishing processing, refining and purification capabilities** to convert domestically available and imported feedstocks into battery-grade materials through **an incentive scheme**. Priority may be given to materials where projected domestic demand can support commercially viable processing capacity.

Over the longer term, the programme should progressively support mineral exploration, resource development and responsible domestic mining of relevant battery minerals, where technically, environmentally and commercially

viable. International supply partnerships should continue to supplement domestic availability during this transition.

The programme should be supported through technology partnerships, research and development, infrastructure support and appropriate fiscal interventions, based on the requirements of individual materials and their respective value chains.

Expected outcome: Increased domestic availability of battery-grade materials, higher domestic value addition, and progressive reduction in dependence on imported processed materials and mineral resources.

Implementing Ministry/Agency: Ministry of Mines, Ministry of Heavy Industries, Department of Science and Technology, in coordination with state governments, research institutions and industry.

Indicative timeline: Short-term (FY2027-28)

Recommendation 4: Develop domestic capital-goods manufacturing capabilities for ACC components

It is proposed that a **phased programme** be introduced to develop domestic capabilities for **manufacturing the specialised plant and machinery** required for ACC component manufacturing facilities by providing **capital subsidy**.

The programme should initially prioritise equipment, sub-systems and engineering services for which India has an existing manufacturing base or a feasible pathway to localization. More technologically complex equipment may subsequently be localised through industry-led development, technology partnerships, licensing arrangements and joint ventures with established global equipment manufacturers.

Demand aggregation and collaboration between ACC component manufacturers, domestic engineering companies and research institutions should be encouraged to support equipment development, validation and commercial deployment. Access to specialised imported machinery should continue where adequate domestic alternatives are not available at the required scale, quality or technical specifications.

Expected outcome: Development of a domestic capital-goods ecosystem for ACC component manufacturing, reduction in dependence on imported plant and machinery, improved access to maintenance and technical support, and increased domestic value addition across the ACC manufacturing value chain.

Implementing Ministry/Agency: Ministry of Heavy Industries and Department for Promotion of Industry and Internal Trade, in coordination with the Department of Science and Technology, Ministry of Micro, Small and Medium Enterprises, research institutions and industry.

Indicative timeline: Medium-term (FY2028-30)

Recommendation 5: Develop integrated battery-material and component manufacturing clusters

It is proposed that **integrated battery-material and component manufacturing clusters** be developed in locations with an existing or emerging base in battery manufacturing, chemicals, metals, automotive production or port-led logistics.

The clusters should enable the co-location of raw-material and intermediate suppliers, ACC component manufacturers, cell manufacturers, equipment suppliers, testing institutions and recycling facilities. Such

integration would reduce logistics costs, improve coordination across the value chain and facilitate faster product development and qualification.

The clusters should provide **plug-and-play access** to critical shared infrastructure, including reliable and competitively priced power, industrial water, effluent treatment, hazardous-material handling, specialized storage, logistics, testing facilities and skill-development infrastructure. Pre-approved industrial land and coordinated statutory clearances would further reduce project-development timelines.

The clusters may be developed through collaboration between the Central and state governments and private developers. Location selection should consider proximity to announced cell-manufacturing capacity, access to industrial feedstocks, availability of utilities, environmental infra, logistics connectivity and skilled personnel.

Expected outcome: Lower infrastructure and logistics costs, reduced project-development timelines, stronger supply-chain integration and improved competitiveness through co-location and shared facilities.

Implementing Ministry/Agency: Ministry of Heavy Industries and Department for Promotion of Industry and Internal Trade, in coordination with state governments and industrial-development agencies.

Indicative timeline: Medium-term (FY2028-30)

5.2. Conclusion

India's ACC component-manufacturing challenge cannot be addressed through a single incentive or policy intervention. The assessment indicates simultaneous disadvantages in capital cost, recurring manufacturing cost, scale, testing, technology and industrial infrastructure. It is therefore proposed that the Government facilitate domestic ACC component manufacturing capacity sufficient to support **50 GWh of annual cell manufacturing by 2032**.

The interventions should be implemented as a coordinated package. Fiscal support would enable establishment and commercially viable operation of domestic manufacturing capacity, while the complementary interventions would address the structural ecosystem constraints required for supported manufacturers to become commercially competitive over time.

Chapter 6. Annexures

6.1. Stakeholder inputs

A. Cathode Active Material (LFP)

i. Capital investment

Cost head	Company 1	Company 2	Company 3	Company 4	Average Investment (crore/ ktpa)
<i>Technology</i>	<i>LFP</i>	<i>LFP</i>	<i>LFP</i>	<i>LFP</i>	<i>LFP</i>
Land and site development	0.3	4.5	1.3	0.7	1.7
Project engineering and consultancy	0.8	1.3	1.8	1.1	1.3
Plant building and civil works	5.9	10.8	2.5	4.9	6
Technical know-how (Transfer of Technology (ToT) costs, etc.)	0	3.6	1.7	6	2.8
Plant and machinery	16.6	17.5	42.5	15.4	23
Trial run (Preliminary and pre-operating expenses, etc.)	0.1	1.6	1.7	0.7	1
Soft costs (Margin money for working capital, etc.)	3.1	15.8	0.0	1.9	5.2
Contingency costs	1.2	0.7	2.5	3.2	1.9
Others	0	0	0	12.2	3
Total (in cr/ ktpa)	28	56	54	46	46

ii. CAM-LFP: Cost of manufacturing

CAM-LFP (US\$/ ton)					
Parameters	Company 1	Company 2	Company 3	Company 4	Estimated Indian manufacturing cost
Raw material cost	7,800	8,525	7,500	7,800	7,906
Processing cost	820	950	700	770	810
Technology royalty	-	220	100		160
Selling, General and Admin expenses	60	170	150	300	170
Finance charges	390	700	580	200	468
Depreciation	340	-	580	550	490
Total cost of Manufacturing	9,410	10,565	9,610	9,620	10,004

iii. CAM-NMC: Cost of manufacturing

CAM-NMC (US\$/ ton)		
Parameters	Company 1	Estimated Indian manufacturing cost
Raw material cost	20,000	20,000
Processing cost	2,263	2,263
Technology royalty	447	447
Selling, General and Admin expenses	475	475
Finance charges	1,306	1,306
Depreciation	1,369	1,369
Total cost of Manufacturing	25,860	25,860

B. Anode Active Material

i. Capital Investment

Cost head	Company 1	Company 2	Company 3	Company 4	Average Investment (crore/ ktpa)
<i>Technology</i>	<i>NG, SG</i>	<i>SG</i>	<i>SG</i>	<i>SG</i>	<i>SG</i>
Land and site development	1.5	26.8	2.5	8.2	9.8
Project engineering and consultancy	3.9	-	4.0	4.4	3.1
Plant building and civil works	21.2	-	6.0	23.6	12.7
Technical know-how (Transfer of Technology (ToT) costs, etc.)	-	-	1.0	-	0.3
Plant and machinery	90.3	49.5	80.9	69.4	72.5
Trial run (Preliminary and pre-operating expenses, etc.)	0.5	-	2.0	4.9	1.9
Soft costs (Margin money for working capital, etc.)	15.3	-	-	37.5	13.2
Contingency costs	5.9	-	-	12.1	4.5
Others	-	27.7	7.7	8.2	10.9
Total (in cr/ ktpa)	138.6	104.0	104.1	168.4	128.7

ii. AAM-SG: Cost of manufacturing

AAM-SG (US\$/ ton)					
Parameters	Company 1	Company 2	Company 3	Company 4	Estimated Indian manufacturing cost
Raw material cost	5,100	1,800	3,978	1,790	3,167
Conversion cost	1,550	2,200	2,166	3,020	2,234

Technology royalty	0	0	80	0	80
Selling, General and Admin expenses	110	1,200	150	610	518
Finance charges	580	600	704	1,110	749
Depreciation	400	600	824	1,670	874
Total cost of Manufacturing	7,740	6,400	7,902	8,200	7,622

iii. AAM-NG: Cost of manufacturing

AAM-NG (US\$/ ton)		
Parameters	Company 1	Estimated Indian manufacturing cost
Raw material cost	2,500	2,500
Conversion cost	2,200	2,200
Technology royalty	0	0
Selling, General and Admin expenses	120	120
Finance charges	370	370
Depreciation	370	370
Total cost of Manufacturing	5,560	5,560

C. Electrolyte

i. Capital Investment

Cost head	Company 1	Average Investment (crore/ ktpa)
Land and site development	5.4	5.4
Project engineering and consultancy	1.5	1.5
Plant building and civil works	13	13
Technical know-how (Transfer of Technology (ToT) costs, etc.)	8.3	8.3
Plant and machinery	17	17
Trial run (Preliminary and pre-operating expenses, etc.)	1.9	1.9
Soft costs (Margin money for working capital, etc.)	18.9	18.9
Contingency costs	0.9	0.9
Others	0	0
Total (in cr/ ktpa)	67	67

ii. Cost of Manufacturing

Electrolyte (US\$/ ton)

Parameters	Company 1	Company 2	Estimated Indian manufacturing cost
Raw material cost	4,500	4,210	4,355
Conversion cost	750	360	555
Technology royalty	150	-	150
Selling, General and Admin expenses	200	110	155
Finance charges	420	130	275
Depreciation	420	100	260
Total cost of Manufacturing	6,440	4,910	5,750

D. Separator

i. Capital Investment

Cost head	Company 1	Average Investment (crore/million sq. m)
Land and site development	0.08	0.08
Project engineering and consultancy	-	-
Plant building and civil works	0.50	0.50
Technical know-how (Transfer of Technology (ToT) costs, etc.)	0.07	0.07
Plant and machinery	4.05	4.05
Trial run (Preliminary and pre-operating expenses, etc.)	-	-
Soft costs (Margin money for working capital, etc.)	-	-
Contingency costs	-	-
Others	0.26	0.26
Total (in ~crore/ million sq. m)	5	5

ii. Cost of Manufacturing

Separator (US\$/ million sq. m)			
Parameters	Company 1	Company 2	Estimated Indian manufacturing cost
Raw material cost	57,000	142,000	99,500
Conversion cost	50,000	52,000	51,000
Technology royalty	12,000	10,000	11,000
Selling, General and Admin expenses	16,000	5,000	10,500
Finance charges	28,000	60,000	44,000
Depreciation	62,000	10,000	36,000
Total cost of Manufacturing	225,000	279,000	252,000

6.2. Manufacturing process and alternative raw materials for ACC components

This section presents a detailed discussion of the manufacturing processes for the five key Advanced Chemistry Cell (ACC) components, along with the corresponding sources and inputs required at each stage of production. While the key takeaways and comprehensive process flow charts are provided in [Chapter 4](#), the following sections describe each manufacturing process in greater detail to provide a clearer understanding of the production steps, and critical raw materials.

1. LFP CAM:

In an LFP cell, the CAM is primarily LFP, with the chemical formula LiFePO_4 . LFP is known for its excellent thermal stability, high safety, long cycle life, and cost-effectiveness. LFP utilizes iron and phosphate as its primary constituents, eliminating the need for expensive and supply-constrained metals such as nickel and cobalt. The chemistry exhibits strong resistance to thermal runaway and provides stable performance over extended charge-discharge cycles, making it particularly suitable for electric vehicles, energy storage systems, electric buses, and other applications where safety, durability, and cost are key considerations.

The following sections discuss the manufacturing process^{65,66,67} and key raw materials involved in the production of battery-grade LFP CAM.

i. Manufacturing process:

The manufacturing of LFP begins with **raw material preparation**, which typically follows either a solid-phase route (utilizing Lithium Carbonate with Iron Phosphate) or a wet-chemical synthesis route (utilizing Lithium Carbonate with Iron Sulphate and Phosphoric Acid). Consequently, the primary precursors required across these methods include lithium carbonate or lithium hydroxide, thermal phosphoric acid, iron powder (or, anhydrous iron phosphate).

In the wet-chemical synthesis pathway, iron sulphate and phosphoric acid are first reacted under controlled conditions to produce an **iron phosphate precipitate**, which serves as the primary precursor for LFP synthesis. The precipitate is subsequently subjected to **coarse and fine grinding** to reduce particle size and improve homogeneity.

The ground precursor is then transferred to a **homogenization tank**, where lithium carbonate and a designated carbonizing agent are incorporated to form a uniform precursor slurry. The carbonizing agent is uniformly dispersed within the mixture and subsequently forms a conductive carbon coating during high-temperature calcination, improving the electrical conductivity and electrochemical performance of the final LFP material.

The homogeneous slurry passes through an **electromagnetic iron removal** stage to eliminate any ferrous contaminants introduced during upstream processing, thereby ensuring high product purity. The purified slurry is then **spray dried** to produce a free-flowing precursor powder with controlled particle size distribution and moisture content.

The dried precursor powder is fed into a **roller hearth kiln (RHK)** for calcination and sintering at elevated temperatures, where lithium reacts with the iron phosphate precursor to form the crystalline lithium iron phosphate structure. Following calcination, the material undergoes screening to remove oversized particles and ensure a consistent feed for downstream processing.

The calcined LFP is subsequently processed through **jet milling** to achieve the desired particle size distribution, tap density, and morphology required for electrode manufacturing. Finally, the finished material is subjected to testing and screening, where critical quality parameters including chemical composition, particle size distribution,

⁶⁵ [Status and prospects of lithium iron phosphate manufacturing in the lithium battery industry, MRS Communications, 14, 888-899 \(2024\)](#)

⁶⁶ [Methods of synthesis and performance improvement of lithium iron phosphate for high-rate Li-ion batteries: A review, Engineering Science and Technology, an International Journal, 19, 178-188 \(2016\)](#)

⁶⁷ [Recent Development in Carbon-LiFePO₄ Cathodes for Lithium-Ion Batteries: A Mini Review, Batteries, 8, 133 \(2022\)](#)

tap density, moisture content, impurity levels, and electrochemical performance are verified to ensure compliance with battery-grade specifications.

The **solid-state synthesis route** shares most of its downstream manufacturing steps with the wet-chemical process, with the **primary distinction lying in the precursor preparation stage**. Unlike the wet-chemical route, where iron sulphate and phosphoric acid are reacted to first produce an iron phosphate precipitate, the solid-state route directly combines commercially available **lithium carbonate and iron phosphate** to prepare chemical slurry. The slurry is subsequently subjected to **coarse and fine grinding**, followed by the addition of a **carbonizing agent** in a **homogenization tank** to ensure uniform mixing. After **electromagnetic iron removal**, the precursor is **spray dried**, calcined in a **roller hearth kiln (RHK)** under an inert atmosphere, screened, **jet milled**, and finally **tested and screened** to achieve battery-grade LFP CAM. Owing to the elimination of the iron phosphate synthesis step, the solid-state route is comparatively simpler and is widely adopted commercially due to its high yields, lower scrap rates, and proven scalability to GWh-scale production. However, it remains associated with approximately 75% import dependency for key raw materials, primarily driven by lithium carbonate and commercially sourced iron phosphate.

ii. Alternative and associated raw materials:

The following table presents an assessment of alternative and associated raw materials used in LFP CAM production, covering their mineral sources, applications, and availability in India. The analysis provides insights into material criticality, substitution potential, and supply-chain dependencies across the value chain.

Table 35: Overview of alternative and associated raw materials used in LFP CAM production

Raw material ^{68,69}	Purpose in process	Upstream	Status in India*
Lithium Hydroxide	Alternative lithium source used by some manufacturers	Extraction from brine/rock and then processing	 Primarily import-dependent
Iron Oxide	Alternative iron source used in solid-state or carbothermal reduction routes	Processing of Iron ore	 Signif cant domestic reserve
Iron Oxalate	Widely used in lab-scale and specialty LFP synthesis		
Ammonium Dihydrogen Phosphate	Alternative phosphate source	Processing of Phosphate rocks	

Source 77: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

2. NMC CAM:

Lithium Nickel Manganese Cobalt Oxide (NMC) is a layered cathode active material that combines nickel, manganese, and cobalt to achieve a balanced combination of energy density, power capability, and cycle life. Nickel contributes to higher energy density, manganese enhances structural stability, and cobalt improves electronic conductivity and electrochemical performance. Owing to its high specific energy and longer driving

⁶⁸ [Phosphate Rock Supply Chain | EPA](#)

⁶⁹ [Mine to market: critical minerals supply chain for domestic value addition in lithium-ion battery manufacturing | NITI Aayog](#)

range, NMC is widely used in electric vehicles, consumer electronics, and high-performance battery applications where maximizing energy storage while maintaining good safety and durability is essential.

The following sections discuss the manufacturing process^{70,71,72,73} and key raw materials associated with NMC CAM manufacturing.

i. Manufacturing process:

The manufacturing process of NMC CAM begins with the preparation and weighing of raw materials, including lithium hydroxide, nickel sulphate, manganese sulphate, cobalt sulphate, sodium hydroxide, and ammonium hydroxide, doping agents, and coating agents. The precursor (nickel manganese cobalt hydroxide) is typically synthesized separately through a co-precipitation process followed by filtration, washing and drying and serves as the starting material for CAM production. Accurate weighing is critical to maintaining the required chemical composition and ensuring consistent electrochemical performance. The compound is then passed into homogenization tank to get thoroughly mixed with lithium hydroxide and then subjected to pre-sintering at 600-800°C for 5 hours which helps stabilize the crystal structure and prepare the material for complete lithiation. This is followed by the first sintering (calcination) step at around 800-900°C for approximately 15 hours under an oxygen-rich atmosphere (>96% oxygen), where the material fully reacts with lithium to form the desired layered oxide cathode structure.

The material is then subjected to controlled cooling to promote crystal ordering and minimize cation mixing before further processing. The calcined material is subsequently crushed and jet milled to reduce particle size and improve uniformity. A subsequent high-temperature reheating step at approximately 800-900°C for about 2 hours further enhances crystallinity, particle integrity, and electrochemical performance, resulting in stable single-crystal NMC particles. The exact temperature profile and holding time may vary depending on the NMC chemistry (e.g., NMC622, NMC811) and the manufacturer's proprietary process. It is then washed using deionized water to remove surface residual lithium compounds (LiOH and Li₂CO₃) and other impurities, followed by filtration and drying to obtain a clean and stable intermediate material.

The NMC powder is then **coated** with protective surface layers such as alumina (Al₂O₃), zirconia (ZrO₂), titania (TiO₂), aluminium phosphate (AlPO₄), or lithium niobate (LiNbO₃), that improve thermal stability, reduce side reactions with the electrolyte, and enhance cycle life. A **second calcination (coating annealing)** step is carried out to strengthen the coating and stabilize the final cathode structure. Following heat treatment, the material undergoes post-processing operations including **grinding and lot blending** to achieve a uniform particle size distribution and consistent batch quality.

In the final stage, the material passes through magnetic **separation and de-ironing** systems to remove any trace metallic impurities. The product is then **sieved** to ensure particle size uniformity, weighed, packed, and prepared for dispatch. The resulting NMC CAM offers high energy density, excellent cycle performance, and reliable electrochemical stability, making it widely used in electric vehicle batteries and advanced energy storage applications.

ii. Alternative and associated raw materials:

The following table outlines the alternative and associated raw materials relevant to NMC CAM production, along with their mineral origins, applications, and availability in India. It also assesses substitution potential and supply-chain dependencies.

⁷⁰ [Review on the synthesis of LiNi_xMn_yCo_{1-x-y}O₂ \(NMC\) cathodes for lithium-ion batteries, Materials Today Energy, 28, 101066 \(2022\)](#)

⁷¹ [Low-cobalt active cathode materials for high-performance lithium-ion batteries: synthesis and performance enhancement methods, J. Mater. Chem. A., 11, 3789-3821 \(2023\)](#)

⁷² [Process design for calcination of nickel-based cathode materials by in situ characterization and multiscale modeling | Brookhaven National Laboratory](#)

⁷³ [Co-precipitation synthesis of nickel-rich cathodes for Li-ion batteries, Energy Reports, 8, 67-73 \(2022\)](#)

Table 36: Overview of alternative and associated raw materials used in NMC CAM production

Raw material ^{74,75}	Purpose in process	Upstream	Status in India*
Lithium Carbonate	Alternative lithium source used for selected NMC chemistries	Extraction from brine/rock and then processing	 Primarily import-dependent
Nickel Manganese Cobalt Hydroxide	Alternative nickel, cobalt, and manganese source	Originates from raw mined ores and chemically processed	

Source 78: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

3. Natural Graphite (NG)

Natural Graphite (NG) is produced from naturally occurring graphite ore, which is mined and subsequently beneficiated, purified, micronized, spheroidized, coated, and heat treated to meet battery-grade specifications. The battery-grade natural graphite exhibits excellent lithium-ion storage capacity, high energy density, and good electrochemical performance, making it a widely adopted anode material for electric vehicle batteries and energy storage systems. However, compared to synthetic graphite, it generally exhibits slightly lower rate capability, reduced cycle life, and greater variability in raw material quality. In addition, achieving battery-grade purity (>99.95% carbon) requires extensive purification, which may involve chemical or thermal treatment depending on the feedstock quality.

The following sections describe the manufacturing process^{76,77,78,79,80,81} and key raw materials involved in NG AAM manufacturing.

i. Manufacturing Process:

The manufacturing process begins with **natural graphite flakes**, which serve as the primary raw material for natural graphite anode active material production. The graphite flakes are first subjected to **grinding and shaping**, where they are milled and spheroidized to achieve the desired particle size, morphology, and particle size distribution required for battery applications. This step produces spherical graphite particles with improved tap density, packing density, and electrochemical performance.

The shaped graphite is subsequently processed through **chemical purification** to remove metallic and mineral impurities and achieve battery-grade purity, typically exceeding 99.95% carbon. Purification is generally carried out using acid leaching or high-temperature thermal treatment, followed by washing and drying to ensure the stringent purity levels required for lithium-ion battery applications.

The purified graphite is then blended with **coal tar pitch, petroleum pitch, or other carbonaceous coating precursors** and subjected to a **coating process**. During this step, the precursor forms a uniform carbon layer on the graphite surface, which is subsequently carbonized under an inert atmosphere to enhance electrical

⁷⁴ IEA, Global Supply Chains of EV Batteries (2022)

⁷⁵ USGS Mineral Commodity Summary

⁷⁶ [Graphite processing from beneficiation to final product: a review focused on purification of natural and recycled materials, Separation and Purification Technology, 380, 135068 \(2026\)](#)

⁷⁷ [Updated Production Inventory for Lithium-Ion Battery Anodes | Argonne National Laboratory](#)

⁷⁸ [Natural Graphite Anode Material | Wastewater Resources](#)

⁷⁹ [Impact of Spheroidization of Natural Graphite on Fast-Charging Capability of Anodes for LIB, Batteries, 9, 9060305 \(2023\)](#)

⁸⁰ [Advanced graphite for your lithium-ion battery production | Hosokawa Micron Group](#)

⁸¹ From minerals to materials, Supplementary report: Graphite | CSIRO | May 2024

conductivity, first-cycle coulombic efficiency, surface stability, and cycling performance while reducing irreversible lithium loss.

Finally, the coated material undergoes **testing and screening**, where particle size distribution, tap density, purity, moisture content, coating uniformity, metallic impurities, and electrochemical performance are evaluated. The material is screened to ensure consistency and compliance with battery-grade specifications before being packaged as the **finished natural graphite anode active material** for lithium-ion battery manufacturing.

ii. Alternative and associated raw materials:

The table below provides an overview of the alternative and associated raw materials relevant to natural graphite AAM production, highlighting their mineral origins, functional roles, and domestic availability.

Table 37: Overview of alternative and associated raw materials used in natural graphite AAM production

Raw material	Purpose in process	Upstream	Status in India
Sulfuric Acid (optional)	Used with other acids during chemical purification	Sulfur-based chemical industry	 Readily available domestically
Alternative Carbon coating precursors (Phenolic resin etc.)	Alternative carbon coating materials depending on process route	Petroleum or biomass-derived carbon sources	

Source 79: Status in India is based on inputs from Indian player(s).

*Harvey Balls represent the localization status in India: empty = fully imported, solid = domestically available, half-filled = partially imported, and one-quarter-filled = 75% imported.

4. Synthetic Graphite (SG)

Synthetic Graphite (SG) is manufactured through the high-temperature graphitization of carbon-rich feedstocks such as petroleum needle coke, petroleum coke, coal tar pitch, or other petroleum-derived carbon materials. The production process typically involves raw material preparation, mixing with binder pitch, forming (extrusion or molding), carbonization, graphitization (2800-3000°C), crushing, milling, classification, purification, particle shaping, carbon coating, and final heat treatment to produce battery-grade graphite with controlled particle morphology and high purity. The graphitization process transforms amorphous carbon into a highly ordered graphitic structure, resulting in excellent electrical conductivity and structural stability.

Synthetic graphite offers high purity (>99.95% carbon), excellent electrical conductivity, superior cycle life, low volume expansion, and outstanding fast-charging performance compared to natural graphite. Its highly controlled particle size distribution and consistent quality make it particularly suitable for high-performance electric vehicle batteries, fast-charging applications, and premium energy storage systems.

The following sections present the manufacturing process^{82,83,84,85} and key raw materials associated with SG AAM manufacturing.

⁸² [Preparation of synthetic graphite from bituminous coal as anode materials for high performance lithium-ion batteries, Fuel Processing Technology, 172, 162-171 \(2018\)](#)

⁸³ [Material and Energy Flows in the Production of Cathode and Anode Materials for Lithium Ion Batteries | Argonne National Laboratory](#)

⁸⁴ [Graphite Lithium Ion Battery Anode Material: Advanced Compositions, Synthesis Routes, And Performance Optimization For High-Energy Applications](#)

⁸⁵ [Prospective Life Cycle Assessment of Synthetic Graphite Manufactured via Electrochemical Graphitization, ACS Sustainable Chem. & Engg., 10, 13607-13618 \(2022\)](#)

i. Manufacturing Process:

The manufacturing process begins with **raw material preparation**, where carbon-rich feedstocks such as green needle coke, calcined petroleum coke (CPC), or mesophase coke, together with coal tar pitch or petroleum pitch as the binder, are selected based on the targeted electrochemical performance. The feedstocks are first **crushed** to reduce the particle size, followed by **grinding** to produce a fine powder with a controlled particle size distribution suitable for downstream processing. The finely ground material is then subjected to **spheroidization**, where the irregular carbon particles are transformed into spherical particles. This step improves tap density, packing density, and electrode compaction, thereby enhancing the volumetric energy density and electrochemical performance of the final anode material.

The spheroidized particles are subsequently **coated** with coal tar pitch or petroleum pitch under controlled conditions to form a uniform carbon precursor layer on the particle surface. The coating enhances electrical conductivity, mechanical integrity, first-cycle coulombic efficiency, and cycling stability while reducing irreversible lithium loss during battery operation. The coated particles then undergo **carbonization**, typically at 800-1200°C under an inert atmosphere. During this stage, the coating precursor is pyrolyzed to form a stable amorphous carbon layer tightly bonded to the graphite particles. This carbon coating improves surface stability and prepares the material for the subsequent high-temperature treatment.

Following carbonization, the material is subjected to **graphitization**, the most energy-intensive stage of the process. The material is heated to approximately 2800-3000°C, where the disordered carbon structure is converted into highly ordered graphitic layers. This transformation significantly improves crystallinity, electrical conductivity, lithium-ion diffusion, and cycle life, resulting in battery-grade synthetic graphite.

After graphitization, the material is **blended** to ensure batch-to-batch consistency and achieve the desired electrochemical properties. The blended product then undergoes testing and screening, including particle size distribution, tap density, carbon purity, moisture content, surface area, and electrochemical performance testing. Oversized particles and impurities are removed through screening to meet battery-grade specifications.

The qualified material is finally packaged as the finished Synthetic Graphite Anode Active Material (SG AAM), ready for use in lithium-ion battery cell manufacturing.

5. Electrolyte

The electrolyte manufacturing process involves the formulation of an ultra-high-purity electrolyte solution that facilitates lithium-ion transport between the cathode and anode while providing high ionic conductivity, wide electrochemical stability, and long-term cycling performance. The process begins with the procurement of battery-grade lithium salts, predominantly lithium hexafluorophosphate (LiPF_6), which is used in over 90% of commercial lithium-ion batteries due to its high ionic conductivity and compatibility with carbonate-based electrolytes. Emerging high-performance formulations may also incorporate lithium bis (fluorosulfonyl) imide (LiFSI) or lithium bis (trifluoromethanesulfonic) imide (LiTFSI) to enhance fast-charging capability, low-temperature performance, and high-voltage stability.

The lithium salt is dissolved in a carefully optimized blend of high-purity organic carbonate solvents, typically ethylene carbonate (EC), dimethyl carbonate (DMC), diethyl carbonate (DEC), and ethyl methyl carbonate (EMC). EC provides a high dielectric constant that facilitates lithium salt dissociation and stable solid electrolyte interphase (SEI) formation, while linear carbonates such as DMC, DEC, and EMC reduce viscosity and improve ionic conductivity. Depending on the target cell chemistry, propylene carbonate (PC) may also be incorporated in selected formulations.

The subsequent sections discuss the manufacturing process and key raw materials involved in lithium-ion battery electrolyte manufacturing^{86,87,88,89}.

i. Manufacturing Process:

The manufacturing of lithium-ion battery electrolyte begins with the **production or procurement** of battery-grade electrolyte salts, primarily lithium hexafluorophosphate (LiPF_6), along with advanced lithium salts such as LiFSI . LiPF_6 is manufactured by reacting phosphorus pentachloride (PCl_5) with anhydrous hydrofluoric acid (HF) to fluorinate PCl_5 , while lithium hydroxide/carbonate (LiOH or Li_2CO_3) is converted to lithium fluoride (LiF) which will eventually make LiPF_6 .

Simultaneously, high-purity organic carbonate solvents such as ethylene carbonate (EC), dimethyl carbonate (DMC), diethyl carbonate (DEC), and propylene carbonate (PC) are procured and subjected to battery-grade purification. The **purification** process removes moisture, particulate matter, and trace metallic impurities that could negatively affect battery performance and cycle life.

Following solvent purification, electrolyte formulation is carried out in a controlled dry-room environment. The purified lithium salt (typically LiPF_6) is dissolved into the solvent blend at predetermined concentrations. Performance-enhancing additives, including vinylene carbonate (VC), fluoroethylene carbonate (FEC), lithium bis(oxalato)borate (LiBOB), LiFSI , **organophosphate flame-retardant additives**, and other proprietary additives are incorporated according to the target battery chemistry to improve cycle life, fast-charging capability, thermal stability, and solid electrolyte interphase (SEI) formation.

The mixture is continuously **agitated** until a homogeneous electrolyte solution is obtained. The formulated electrolyte is subsequently filtered through fine-micron filters to **remove** any residual particles such as, undissolved particles, gels, and trace contaminants that may cause internal short circuits or reduce battery reliability and ensure high purity. Filtration is carried out under inert atmosphere to prevent moisture contamination. The filtered electrolyte is subjected to **vacuum degassing** to eliminate dissolved gases and air bubbles while maintaining ultra-low moisture levels. This improves electrolyte stability, filling consistency during cell assembly, and long-term electrochemical performance. Comprehensive quality tests, including conductivity, impurity analysis, and chemical composition verification, are performed before approval.

The final product is a battery-grade electrolyte that provides efficient lithium-ion transport between the cathode and anode while ensuring the safety, performance, and long-term reliability of lithium-ion batteries used in electric vehicles, energy storage systems, and consumer electronics.

6. Separator

A separator is a thin, microporous polymer membrane positioned between the cathode and anode in a lithium-ion battery. It functions as an electrical insulator, preventing direct contact between the electrodes and thereby eliminating internal short-circuits, while simultaneously allowing the free transport of lithium ions. Commercial separators are primarily manufactured from polyethylene (PE), polypropylene (PP), or multilayer PP/PE/PP structures, selected for their excellent chemical stability, mechanical strength, and electrochemical compatibility with lithium-ion battery electrolytes. The separator must exhibit high porosity, uniform pore size distribution, excellent electrolyte wettability, low ionic resistance, and dimensional stability to ensure efficient ion transport and consistent battery performance.

The separator is one of the most critical safety and performance components in lithium-ion batteries. Besides facilitating uniform electrolyte distribution and minimizing internal resistance, it provides mechanical separation

⁸⁶ [Drying of electrolyte mixtures containing acids with molecular sieves, WO2015004236A1](#)

⁸⁷ [Process and system for producing \$\text{LiPF}_6\$, and mixture crystal, composition, electrolyte solution and lithium battery containing \$\text{LiPF}_6\$, WO2021115316A1](#)

⁸⁸ [European Li-Ion Battery Advanced Manufacturing for Electric Vehicles](#)

⁸⁹ [LiPF₆-EC-EMC electrolyte for Li-ion battery, Journal of Power Sources, 107, 18-23 \(2002\)](#)

between electrodes while maintaining high ionic conductivity. Modern battery separators frequently incorporate ceramic coatings (Al_2O_3 or SiO_2), surface modifications or functional polymer coatings to improve thermal stability, puncture resistance, electrolyte wettability, and resistance to lithium dendrite penetration.

The next sections present the manufacturing process^{90,91,92,93,94} and key raw materials required to manufacture separators.

i. Manufacturing process:

The manufacturing process begins with the **preparation of the polymer feedstock**. Ultra-high molecular weight polyethylene (UHMWPE) is used as the primary membrane-forming polymer and is blended with a plasticizer, typically paraffin oil, together with processing aids and stabilizers. The mixture is compounded under controlled temperature and shear conditions to ensure uniform dispersion and homogeneous melt characteristics required for separator production.

The prepared polymer blend is then subjected to **film extrusion**. The homogeneous polymer blend is fed into a twin-screw or single-screw extruder and melt-processed through a precision slit die to produce a continuous polymer film. The extruded film is rapidly cooled using chill rolls to stabilize its morphology and obtain uniform thickness prior to orientation.

The extruded film then undergoes **stretching (biaxial orientation)**. During this step, the film undergoes sequential or simultaneous stretching in the machine direction (MD) and transverse direction (TD).

Following orientation, the film undergoes **solvent extraction** using suitable organic solvents (commonly dichloromethane or equivalent extraction solvents) to remove paraffin oil and other extractable components. This step generates the separator's controlled porous structure, which determines electrolyte uptake, ionic conductivity, and thermal shutdown characteristics. After solvent extraction, the separator film is thoroughly dried to **remove residual solvent and moisture**. **Thermofixation/ heat setting** is subsequently carried out under controlled tension to stabilize the porous structure, minimize shrinkage, and improve dimensional stability during battery operation.

The porous separator film is then subjected to **slitting, winding, and edge trimming**. The film is slit into precise widths according to customer specifications, and the edges are trimmed to ensure dimensional uniformity and eliminate defects that could affect battery assembly.

After slitting, depending on the battery application, the separator undergoes **ceramic coating** using Al_2O_3 , boehmite (AlOOH) and polymeric binders such as PVDF or acrylic binders. The coating improves thermal stability, electrolyte wettability, puncture resistance, and adhesion with electrodes while significantly reducing thermal shrinkage at elevated temperatures. The coated separator is then processed through **slitting and roll formation**. The separator film is wound into rolls suitable for efficient handling, storage, and transportation. Proper winding control is maintained to prevent wrinkles, tension-related issues, and contamination.

The finished separator rolls undergo comprehensive **quality inspection**. Critical parameters including thickness, basis weight, porosity, tensile strength, puncture resistance, thermal shrinkage, electrolyte wettability, ionic resistance, coating adhesion, and surface defects are evaluated to ensure compliance with battery-grade specifications.

⁹⁰ [Recent Progress of High Safety Separator for Lithium-Ion Battery, Green Chemical Technology](#), 1, 10006 (2024)

⁹¹ [Introduction to Separator Production Process](#)

⁹² [A review of recent developments in membrane separators for rechargeable lithium-ion batteries](#), Energy Environ. Sci., 7, 3857-3886 (2014)

⁹³ [Method for preparing lithium-ion battery separator, WO2017152731A1](#)

⁹⁴ [Manufacturing Processes of Microporous Polyolefin Separators for Lithium-Ion Batteries and Correlations between Mechanical and Physical Properties, Crystals](#), 9, 1013 (2021)

Finally, the separator rolls undergo **packaging and shipment**. The separators are packaged to prevent moisture absorption and contamination during transportation and are then shipped to battery manufacturers for integration into ACC production.

7. Copper Foil

Copper foil serves as the anode current collector in lithium-ion batteries, providing a highly conductive pathway for electron transport during charging and discharging. Battery-grade electrolytic copper foil typically has a thickness of 4-12 µm and requires high electrical conductivity (>99.9% Cu purity), excellent mechanical strength, low surface roughness, and strong adhesion with the anode active material. Surface treatments such as roughening and anti-oxidation coatings are commonly applied to improve coating adhesion, corrosion resistance, and long-term electrochemical performance. The cost of copper foil is primarily driven by the price of high-purity copper cathodes, electricity consumption during electrodeposition, and surface treatment processes.

The manufacturing process^{95,96,97,98,99,100,101,102} and key raw materials are discussed in the following sections.

Manufacturing Process:

The manufacturing of electrolytic copper (ED) foil for lithium-ion battery applications begins with the selection of high-purity copper raw materials. Copper nuggets, copper rods, or copper wires with a purity typically greater than 99.8% are used to ensure consistent electrochemical, mechanical, and electrical performance. High-purity copper produced from refined cathode sources minimizes impurities that can adversely affect foil quality, conductivity, grain structure, surface characteristics, and electrochemical deposition behaviour. Sulfuric acid and process additives are also sourced and prepared to formulate the electrolyte solution used during copper deposition.

In the **copper dissolution** stage, the copper raw material is dissolved in a controlled sulfuric acid-based electrolyte system to produce a copper sulphate solution containing copper ions. The dissolution process is carefully controlled to achieve the desired copper concentration, electrolyte composition, and solution chemistry required for stable electrodeposition. Additives and process chemicals may be incorporated to regulate grain growth, improve deposit uniformity, and optimize the physical properties of the final foil.

The resulting copper sulphate solution is then subjected to **filtration and purification**. During this step, suspended particles, metallic contaminants, and other impurities are removed through multiple filtration and purification systems. Maintaining a highly purified electrolyte is essential because impurities can lead to surface defects, pinholes, poor mechanical properties, and inconsistent thickness distribution in the deposited foil. Continuous monitoring and purification ensure stable electrolyte quality and consistent foil production.

Following purification, the electrolyte is transferred to electrodeposition cells where the copper foil is produced. In the **electrodeposition process**, copper ions from the electrolyte are deposited onto a continuously rotating metallic drum or cathode substrate under the influence of direct current. As copper ions gain electrons at the cathode surface, a thin and uniform copper layer gradually forms. Critical parameters such as current density, electrolyte temperature, copper ion concentration, drum speed, and electrolyte circulation are tightly controlled to achieve the desired foil thickness, grain structure, surface roughness, and mechanical properties. Depending on battery requirements, foil thicknesses typically range from a few micrometres to several tens of micrometres.

⁹⁵ [Copper Foil Metal: Advanced Manufacturing Technologies, Surface Engineering, And High-Performance Applications In Electronics And Energy Storage](#)

⁹⁶ [Raw copper foil production process | CSTitaniums](#)

⁹⁷ [Advances in electrolytic copper foils: fabrication, microstructure, and mechanical properties, Rare Metals, 44, 757-792 \(2025\)](#)

⁹⁸ [Method for producing electrolytic copper foil, CN112543822A](#)

⁹⁹ [Copper foil having uniform thickness and methods for manufacturing the copper foil, US9711799B1](#)

¹⁰⁰ [Electrodeposited copper foil manufacture | Tex Technology INC.](#)

¹⁰¹ [Lithium Battery Copper Foil Process | AEF](#)

¹⁰² [Manufacturing method of high-tensile-strength lithium-ion battery copper foil, CN110629257A](#)

After electrodeposition, the copper foil undergoes **surface treatment** to enhance its adhesion performance and long-term stability in battery applications. Surface treatment modifies the foil morphology and chemistry to improve bonding with the anode coating during electrode manufacturing. These treatments improve peel strength, corrosion resistance, thermal stability, and compatibility with battery manufacturing processes.

The treated foil then passes through **washing and drying** operations. Residual electrolyte, sulfuric acid, treatment chemicals, and contaminants are removed using multiple stages of deionized water washing. Following washing, the foil is dried using controlled hot-air or infrared drying systems to eliminate moisture while preserving the integrity of the treated surface.

Once dried, the copper foil is subjected to **slitting and inline inspection**. Wide master rolls are slit into customer-specified widths using precision slitting equipment. Simultaneously, advanced inspection systems continuously monitor the foil surface for defects such as pinholes, scratches, wrinkles, inclusions, thickness variations, edge defects, and surface contamination. Inline quality control ensures that only foil meeting stringent battery-grade specifications proceeds to the final stage.

The finished copper foil is then **wound into final rolls** under carefully controlled tension conditions to prevent deformation or damage. Comprehensive **quality testing** is conducted to verify thickness uniformity, tensile strength, elongation, conductivity, surface roughness, coating adhesion, and dimensional accuracy. After successful inspection and certification, the copper foil rolls are **packaged** in moisture-protective materials and prepared for shipment.

NOTES

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