On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

Battery Ecosystem: A Global Overview, Gap Analysis in Indian context, and Way Forward for Ecosystem Development

Acknowledgement

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Foreword

In November 2021, the Prime Minister of India has announced India's goals to achieve economy-wide net zero emissions by 2070. The goals are in line with India's pledge to reduce the emissions intensity of its economy by 45% from 2005 levels by 2030. Coupled with the challenges of recent years like severe air pollution, or growing impact of climate change, a large scale shift from internal combustion vehicles powered by fossil fuels to electric vehicles (EVs) powered by clean, low carbon energy sources is the need of the hour.

Accelerating the shift to electric vehicles requires a robust battery ecosystem in place. Lithium-ion chemistry is the mainstay for EV batteries at present and the country is highly import dependent for the lithium-ion cells. Recognizing this, the manufacturing of EV batteries, the most expensive component of an EV, is being incentivized through schemes such as the Production Linked Incentive (PLI). The Advanced Cell Chemistry (ACC) PLI, with budgetary outlay of INR 18,100 crore, has been approved for achieving manufacturing capacity of 50 Giga Watt Hours (GWh) and awarded.

To enhance the adoption of EVs, the government has also identified battery swapping as an alternative for bringing down upfront EV costs and reducing charging time. The Hon'ble Finance Minister, in the budget for 2022-23, announced that the Union Government will introduce a battery swapping policy and interoperability standards to improve efficiency in the EV ecosystem. NITI Aayog has developed a draft battery swapping policy in line with the ministerial expectations.

Another key factor for consideration lies with the availability of battery minerals in India, especially for lithium-ion batteries. India being a mineral rich nation lacks the abundance of minerals for Nickel, Cobalt, and Lithium. The draft battery waste management rules were published in 2020 and is nearing finalization. Circular economy of lithium-ion batteries is crucial for developing a self-sustaining battery ecosystem and creating a loop for materials being reused at the end-of-life.

A comprehensive study of the battery ecosystem is essential to provide a view of the opportunities and challenges in the segments. We hope this study serves as a useful guide for the policymakers and industry players to make informed decisions and foster the battery ecosystem to fulfil its potential to become a global proponent for EV batteries.

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Abbreviations

AC	Alternating Current
ACC	Advanced Chemistry Cell
ADR	Agreement for The International Carriage of Dangerous Goods by Road
AGM	Absorbent Glass Mat
AH	Amp Hours
AIS	Automotive Industry Standard
AMP	Ampere
ANEEL	Agência Nacional De Energia Elétrica
APAC	Asia-Pacific
ARAI	Automotive Research Association of India
ARCI	International Advanced Research Center for Powder Metallurgy and New Materials
BAAS	Battery-As-Service
BCD	Basic Custom Duties
BEV	Battery Electric Vehicle
BHEL	Bharat Heavy Electricals Limited
BIS	Bureau of Indian Standards
BLE	Bluetooth Low Energy
BMS	Battery Management System
BNDES	Brazilian Development Bank
BNEF	Bloomberg New Energy Finance
BOM	Bill of Materials
BSS	Battery Swapping Station
BTM	Behind-The-Meter
BTMS	Behind the Meter Storage
BWMR	Battery Waste Management Rules
BYD	Build Your Dreams
CAEM	Centre for Automotive Energy Materials
CAGR	Compound Annual Growth Rate
CAN	Controlled Area Network
CATL	Contemporary Amperex Technology Co., Limited
CBU	Completely Built Up
CCR	Constant Current Regulator
CCS	Combined Charging System
CEFV	Center for Environment Friendly Vehicle
CENELEC	Commission Européenne De Normalisation Électrique
CES	Customised Energy Solution
CESL	Convergence Energy Services Limited
CIM	Carriage of Goods by Rail
CMS	Central Management System
CO	Carbon Oxide
CPCB	Central Pollution Control Board
CSR	Corporate Social Responsibility
DC	Direct Current
DHI	Department of Heavy Industry
DI	Directorate of Industries
DOD	Depth of Discharge
DPIIT	Department for Promotion of Industry and Internal Trade
DRX	Discontinuous Reception
DSCR	Debt Service Coverage Ratio
DST	Department of Science and Technology

DUT	Device Under Test
EAC	Expert Appraisal Committee
EBU	European Broadcasting Union
EC	Environmental Clearance
EFCC	Enhanced Frequency Control Capability
EIA	Environmental Impact Assessment
EIS	Electrochemical Impedance Spectroscopy
ELV	End of Life Vehicle
EMF	Electromotive Force
EMP	Environmental Management Plan
EOL	End of Life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
ESG	Environmental, Social, And Governance
ESS	Energy Storage System
EU	European Union
EV	Electric Vechicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vechicle Supply Equipment
EWMR	E-Waste Management Rules
FAME	Faster Adoption and Manufacture Of (Hybrid And) Electric Vehicles
FCAB	Federal Consortium for Advanced Batteries
FCEV	Fuel Cell Electric Vehicles
FTP	Federal Emission Test Procedure
FY	Financial Year
DUT	Device Under Test
EAC	Expert Appraisal Committee
EBU	European Broadcasting Union
EC	Environmental Clearance
EFCC	Enhanced Frequency Control Capability

EIA	Environmental Impact Assessment
EIS	Electrochemical Impedance Spectroscopy
ELV	End of Life Vehicle
EMF	Electromotive Force
EMP	Environmental Management Plan
EOL	End of Life
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
ESG	Environmental, Social, And Governance
ESS	Energy Storage System
EU	European Union
EV	Electric Vechicle
EVCC	Electric Vehicle Communication Controller
EVSE	Electric Vechicle Supply Equipment
EWMR	E-Waste Management Rules
FAME	Faster Adoption and Manufacture Of (Hybrid And) Electric Vehicles
FCAB	Federal Consortium for Advanced Batteries
FCEV	Fuel Cell Electric Vehicles
FTP	Federal Emission Test Procedure
FY	Financial Year
GHG	Greenhouse Gas
GPS	Global Positioning System
GS	Genzo Shimadzu
GTR	Global Technical Regulation
GVM	Gross Vechicle Mass
HESS	Hybrid Energy Storage System
HEV	Hybrid Electric Vehicles
HFEDS	Highway Fuel Economy Driving Schedule
HHD	Hand-Held Device
HIU	Helmholtz Institute of Ulm

HLC	High Level Communication
HNI	High Net Worth Individuals
HPPC	Hybrid Pulse Power Characterization
HSN	Environmental Clearance
IATA	International Air Transport Association
ICAT	International Centre for Automotive Technology
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IIT	Indian Institute of Technology
IKI	International Climate Initiative
ILE	Ionic Liquid Electrolyte
IMDG	International Maritime Organisation, Dangerous Goods Code
INR	Indian Rupee
IOT	Internet of Things
HLC	High Level Communication
HNI	High Net Worth Individuals
HPPC	Hybrid Pulse Power Characterization
HSN	Environmental Clearance
IATA	International Air Transport Association
ICAT	International Centre for Automotive Technology
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IIT	Indian Institute of Technology
IKI	International Climate Initiative
ILE	Ionic Liquid Electrolyte
IMDG	International Maritime Organisation, Dangerous Goods Code
INR	Indian Rupee

IOT	Internet of Things
IP	Intellectual Property
IPI	International Press Institute
IRR	Internal Rate of Return
ISO	International Organization for Standardization
ISRO	Indian Space Research Organisation
ITC	Industry Technology Consortia
JBRC	Japan Portable Rechargeable Battery Recycling Center
KABIL	Khanij Bidesh India Limited
KW	Kilo-Watt
LAGP	Lithium Aluminium Germanium Phosphate
LCO	Lithium Cobalt Oxide
LDV	Light Duty Vehicles
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
LNMO	Lithium Nickel Manganese Spinel
LPG	Liquefied Petroleum Gas
LTO	Lithium Titanate
MDPI	Multidisciplinary Digital Publishing Institute
MEPL	Maharashtra Enviro Power Limited
METI	Ministry of Economy, Trade and Industry
MIIT	Meerut International Institute of Technology
MOE	Ministry of Environment and Forests
MTPA	Metric Tonnes Per Annum
MUV	Multi Utility Vehicle
MW	Mega-Watt
NA	Not Available

NABL	National Accreditation Board for Testing and Calibration Laboratories
NAIF	Navigation and Ancillary Information Facility
NCA	Nickel Cobalt Aluminium
NEIDS	North East Industrial Development Scheme
NEV	New Energy Vehicle
NITI	National Institution for Transforming India
NMC	Lithium-Nickel-Manganese-Cobalt-Oxide
NMI	Nonmaskable Interrupt
NPV	Net Present Value
NREDCAP	New & Renewable Energy Development Corporation of Andhra Pradesh
NREL	National Renewable Energy Laboratory
OBEM	Operational Battery Effectiveness Model
OECD	Organisation for Economic Co-Operation and Development
OEM	Original Equipment Manufacturer
PARIVESH	Pro-Active and Responsive Facilitation by Interactive, Virtuous and Environmental Single-Window Hub
PAT	Profit After Tax
PCC	Pollution Control Committee
PEST	Political, Economic, Social and Technological
PHEV	Plug-In Hybrid Electric Vehicles
PIB	Press Information Bureau
PLI	Production Linked Incentive
PRO	Producer Responsibility Organizations
PSD	Power Spectral Density
QC	Quick Charge
QCBS	Quality & Cost Based Selection
QR	Quick Response
QC	Quick Charge
QCBS	Quality & Cost Based Selection
QR	Quick Response
RE	Rechargeable Battery
REESS	Rechargeable Energy Storage System
RESS	Rechargeable Energy Storage System
RMB	Renminbi
RNESL	Reliance New Energy Solar Limited
RUL	Remaining Useful Life
SAE	Society of Automotive Engineers
SEAC	State Level Expert Appraisal Committee
SECC	(Supply Equipment Communication Controller
SGST	State Goods and Services Tax
SIDC	State Industrial Development Corporation
SIM	Subscriber Identity/Identification Module
SKD	Semi Knocked Down
SLI	Starting, Lighting and Ignition
SLM	Straight Line Method
SOC	State of Charge
SOH	State of Health
QCBS	Quality & Cost Based Selection
QR	Quick Response
RE	Rechargeable Battery
REESS	Rechargeable Energy Storage System
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SAE	Society of Automotive Engineers
SEAC	State Level Expert Appraisal Committee
SECC	(Supply Equipment Communication Controller
SGST	State Goods and Services Tax
SIDC	State Industrial Development Corporation
SIM	Subscriber Identity/Identification Module
SKD	Semi Knocked Down
SLI	Starting, Lighting and Ignition
SLM	Straight Line Method
SOC	State of Charge
SOH	State of Health
SPAC	Special Purpose Acquisition Company
SPCB	State Pollution Control Board
SPG	Specific Gravity
SS	Solid-State
SSIDC	Small Scale Industrial Development Corporation
STU	Solar Tracking Unit
TED	Thermal Energy Device
TIA	Transport Initiative for Asia
TOR	Terms of Reference
TPEM	Technology Platform for Electric Mobility
TSDF	Treatment, Storage, And Disposal Facilities
UDDS	Urban Dynamometer Driving Schedule
UK	United Kingdom
UL	Underwriters Laboratories
UN	United Nations
UN GTR	United Nations Global Technical Regulation
UNECE	United Nations Economic Commission for Europe
UPS	Uninterruptible Power Supply
USA	United States of America
USD	United States Dollar
USGS	U.S. Geological Survey
VRLA	Valve Regulated Lead Acid
VSSC	Vikram Sarabhai Space Centre
VW	Volkswagen
WACC	Weighted Average Cost of Capital
WDV	Written Down Value
WEEE	Waste Electrical and Electronic Equipment
YLB	Yacimientos De Litio Bolivianos
ZEBRA	Sodium Nickel Chloride
ZEV	Zero Emission Vehicles

Executive Summary

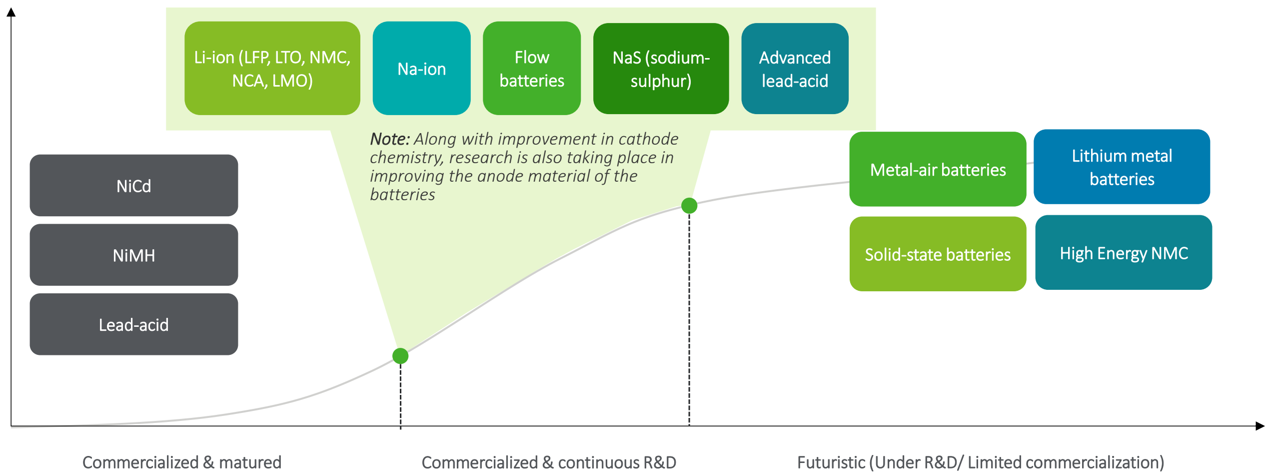
Executive summary

India is witnessing an increase in Electric vehicles (EV) adoption fueled by the Government of India's commitments on climate change commitments as well as its vision of decarbonizing the transport sector. This would lead to a substantial demand for batteries for traction applications. In addition to the demand of batteries, the technology landscape of battery chemistries is fast evolving. Innovative businesses such as battery swapping are receiving an added thrust from new market entrants and the government.

Lithium-ion, the go-to chemistry for EV batteries in India and worldwide, requires a set of minerals which aren't abundant in India. Such a condition leads to high import dependency. It is hence important to promote circularity of batteries to reduce supply chain dependencies and recycle the battery materials to put them back as inputs for battery manufacturing. Detailed study of the technologies, standards, policy & regulatory landscape, manufacturing, swapping, disposal, recycling, and reuse of batteries has been carried in this study to understand the value chain components.

Overview of Motive/Traction Batteries: Technology and Chemistry

Multiple battery technologies are available for use in traction applications. The industry has moved from matured technologies viz. lead acid, NiMH (Nickel Metal Hydride), NiCd (Nickel Cadmium) to commercialized technologies such as lithium-ion, flow batteries, etc.



A comparison of battery chemistries reveals that lead acid batteries are lower in prices, tolerant to overcharging and can withstand extreme temperatures. However, lead acid batteries have certain shortcomings since they lead to increased weight, environmental concerns due to improper handling after end-of-life, etc. Lithium-ion batteries, on the contrary, provide advantages such as availability in compact sizes, longer service life, faster charging rates, no memory effects, lower self-discharging rate, etc. These are the factors which make lithium-ion as the chemistry of choice for EV applications.

It is expected that battery demand from EVs (inclusive of all segments) will be in the range of 5 – 15 GWh by 2025 and will further increase to 30 – 112 GWh by 2030[1]. Amongst Lithium-ion batteries, LFP, NMC, and NCA are widely used in EVs. However, for Indian conditions, LFP batteries are better suited than NMC and NCA as it can adapt better to hotter climatic conditions.

[1] Deloitte analysis

As envisaged, Lithium-ion chemistries are expected to have the greater share by 2030 with technologies such as sodium-sulfur and solid-state slowly getting adopted at the later end of the decade. The cost of battery technologies is expected to reduce at a rate of ~10% CAGR from 2021 to 2030.

The reduction in cost would be highly dependent on the R&D activities being carried out. In India, institutes such as Centre for Automotive Energy Materials (CAEM), International Advanced Research Center for Powder Metallurgy and New Materials (ARCI), IIT Bombay and certain industry players such as Log9 materials, etc. are doing substantial R&D around lithium-ion technology.

Metal-air and sodium-ion batteries hold great potential for the future and address the various concerns associated with lithium-ion batteries. Metal-air batteries, for instance, use different metals such as Zinc (Zn), Lithium (Li), Aluminium (Al), Manganese (Mn), Sodium (Na), Iron (Fe) etc. Sodium-ion batteries, on the other hand, don’t involve rare metals, use raw materials that are abundantly available and hence are low-cost solutions.

The supply of batteries in India, with incentive schemes such as ACC (Advanced Cell Chemistry) PLI, is expected to be around 50 GWh by 2025 and assuming that the capacity addition is not taken up post 2025, the country would be facing shortages after 2029[1]. To address the shortages, concerted efforts are required in the form of policies and standards, adequate tie-ups for raw material imports, improved material recovery efficiencies. The mentioned efforts for addressing shortages have to be resonated through responsible battery usage (both first and second life) and disposal of batteries by users.

Overview of Motive/traction batteries Standards

For enabling uptake of EVs, it is vital to ensure that battery chemistries demonstrate adequate level of performance and safety. Availability of standards to measure performance, safety and extent of abuse tolerance of such batteries & cells is hence very important. Moreover, to ensure customer confidence in EVs, it is essential to ensure that battery chemistries can perform well in Indian conditions and more importantly there should be adequacy of standards for testing the same.

The standards for batteries can be categorized into general, safety, performance, transportation, or recycling standards. The table shown below captures the gaps in Indian standards for multiple battery chemistries widely used in EVs.

CHEMISTRY	Availability of standards in Indian context				
	General	Performance and Lifecycle	Safety	Transportation	Recycling
Lead Acid	✓	✓	✓	✓	Not available in India
Lithium-ion	✓	✓	✓	Not available in India	Not available in India
Nickel Metal Hydride	Not available in India	✓	✓	✓	Not available in India
Nickel Cadmium	Not available in India	✓	✓	✓	Not available in India

✓ means that the standard is adopted/ notified in India

Based on detailed analysis, additional test requirements and testing conditions have also been suggested based on review of international standards.

Review of policy and Regulatory Environment for traction batteries

The assessment of policies has been conducted in five key areas of viz. 1) Sourcing of raw materials; 2) Battery manufacturing; 3) R&D and supply chain development; 4) Battery swapping; and 5) Reuse & recycle. A review of National and state level policies in India India along with the measures taken in countries such as China, Australia, Brazil, South Korea, and the USA has been undertaken. Some of the key recommendations for Indian policymakers are highlighted below:

Particulars	Measures	Reference country
Sourcing Raw materials	• Funding and tax incentives could be provided to companies to build stockpile of strategic raw materials like lithium, nickel, cobalt, and rare earths	South Korea
Battery Manufacturing	• Auto companies can be mandated to meet EV credits & corporate average fuel consumption levels.	China
	• EV manufacturers could be given tax credits based on the investments made by the manufacturers	Brazil
	• A government-led initiative could be developed where major battery makers can invest in the EV battery industry (facilities and R&D) to gain competitive edge. Government in turn could support them by providing tax credit.	South Korea
R&D and Supply Chain development	• Financial assistance could be offered for research and development of EV and related components or specifically for battery technology.	China, Australia, Brazil, South Korea, Japan, USA
	• Yearly tax offsets could be given to battery manufacturers.	Australia
	• Exemption could be given on capital gains taxes	Australia
	• Growth centers could be set up in sectors related to lithium-ion battery to gain competitive advantage. This should be an Industry-led approach to drive innovation, productivity and competitiveness.	Australia
	• A national blueprint could be designed for development of lithium-ion batteries to assist the domestic supply chain of advanced batteries	USA
Battery Swapping Infrastructure	• National standard for safety in battery swapping could be developed. This will help in improving the level of safety of EVs which use the battery swap technology	China
	• Construction of battery swapping infrastructures should be promoted through financial and non-financial incentives.	China
Battery disposal, reuse & recycle	• Government could set up short term (2025) and long term (2050) battery waste recycling rates as well as rates of recovery of major battery materials	China
	• Recyclers can be offered a rebate per kg to collect, sort and process the end-of-life batteries. Participation of importers and retailers can be mandated through the scheme as well. Major battery manufacturers can be encouraged to participate in the same.	Australia
	• Financial assistance and subsidies could be offered to promote battery recycling and reuse.	South Korea

At a policy level, India has initiated measures for battery manufacturing (ACC PLI), battery swapping (Draft Battery swapping policy), battery recycling and reuse (Draft Battery Waste Management Rules). Such measures are highly encouraging and are expected to further aid the development of a robust battery ecosystem.

Overview on Battery Manufacturing for EVs

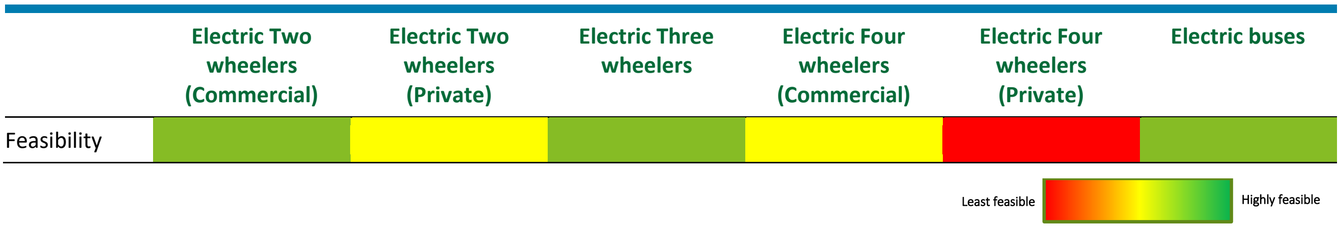
From the perspective of raw material supply, for Lithium-ion cells, there are five critical minerals viz. Lithium (21 Mn MT (Million metric ton)), Nickel (94 Mn MT), Graphite (320 Mn MT), Cobalt (87 Mn MT), and Manganese (1300 Mn MT)[2]. There are two regions which holds majority of the essential battery minerals viz. Australia and South America. Australia holds considerable reserve of all the battery minerals except for graphite, whereas, South America lacks only on Cobalt reserves.

[2] USGS 2021

Battery manufacturing, especially Lithium-ion batteries, is in the stages of infancy in India. It is expected that the Production-linked incentive scheme under the Advanced Chemistry Cell (ACC) manufacturing programme would create the desired manufacturing ecosystem for cells / batteries. Recently, the Government of India has awarded 50 GWh of cell manufacturing capacity under this programme. The capacities are envisaged to be added by 2025 and incentives for the capacities would be disbursed thereafter a period of five years on sale of cells manufactured in India[3].

Overview on Battery Swapping Infrastructure

Battery swapping provides a method for decoupling the batteries from EVs. The decoupling enables to tackle challenges in the form of range anxiety, longer charging times, higher vehicle costs, battery longevity and replacement costs. The overall attractiveness of battery swapping with respect to different EV segments is captured below.



Note: Feasibility represents feasibility for battery swapping

It is understood that battery swapping would be technically most feasible for commercial electric 2Ws and 3Ws as well as e-buses. Battery swapping can be manual or automatic based on the segment the players are addressing. Owing to its ease of use and technological simplicity, manual swapping technology is generally adopted for e-2W and e-3Ws. This is quite visible in various 2W and 3W swapping players globally as well as in India. However, for commercial e-4W and e-buses, typically robotic / automatic swapping is preferred owing the larger battery sizes and less appetite for a longer waiting time. Battery swapping service providers need to take this into account while setting up their stations.

Three possible business models can be employed for battery swapping which could be fleet operator driven or swapping services provider driven or OEM driven. Choosing an appropriate model is left to the decision of the concerned player. Since it has been understood that battery swapping is technically most feasible for commercial vehicles in the 2W, 3W and 4W segment, the fleet operators may choose to set up and operate the swapping stations themselves. However, in case they want to focus on their core competence only, they may choose to utilize the services of a battery swapping service provider. The primary element which would drive such decision is extent of control which the operator can have and its choice of choosing batteries as per its requirement.

At present, lack of standardization in batteries may lead to higher adoption of fleet operator owned model in the future. With increasing standardization in batteries, it is expected that many more service providers will dive into this business and offer services to a large scale of users.

Moreover, in the service provider business model, importance has to be given to the state of standardization of batteries. In case of lesser prevalence of standardized batteries and where there are a lot of unorganized players in the market, service provider should not resort to upfront purchase of batteries. This is because it is not preferable to undertake high capital investment on a specific technology / make of battery. Rather a leasing model can be adopted for batteries with certain revenue sharing agreements. However, in case of higher prevalence of standardization in batteries, service providers can resort to upfront purchase of batteries from OEMs.

The financial and economic analysis of battery swapping stations helps to understand the key factors driving the feasibility of the business. On the revenue side, the battery sizing decided at the beginning of the business and the optimal balance between the customers opting for fixed swapping rate against the customers paying on usage basis are two of the major factors to be kept in mind while operating the stations. On the cost side, rental / lease payments are a critical factor in the overall feasibility of the business. Having lower lease rental cost would provide an edge to swapping operators to attract higher number of users with competitive pricing irrespective of the payment model chosen.

[3] PIB (access here)

Overview of battery disposal

Disposal of waste battery means any operation which does not lead to recycling, recovery or reuse and includes physio-chemical or biological treatment, incineration, and deposition in secured landfill and the handover of the battery after usage to designated collection centers. These collection centers channelize the used batteries to dismantlers and recyclers. There are typically four sources for collection of batteries for disposal viz. Battery Manufacturers, automobile OEMs having EPR (Extended Producer Responsibility), Waste Collection Centers, and scrap dealers.

There are two modes for disposal of battery:

Option 1: Disposal through organized route	Option 1: Disposal through unorganized route

Chemistries such as lead acid, nickel metal hydride, and lithium-ion can be recycled and direct disposal of these batteries into landfills without processing is not permitted as per the Battery Waste Management Rules (BWMR) and E-Waste Management Rules (EWMR).

At present, there is an absence of monitoring system for battery disposal in India. Although the manufacturers are required to maintain records of the waste generated, handled and disposed and share the same to the State Pollution Control Board (SPCB), they can only account for the batteries that reach their collection centers or dealers. The dominance of the unorganized sector lies in the fact that they provide the ease of disposal to end users. Itinerant collectors travel to every nook and corner of cities to collect waste generated which is diverted to scrap dealers who send the batteries to the collection centers.

In the case of waste lithium-ion batteries, the value lies in the black mass (cathode material). From a cost perspective, transporting the black mass to recycling facilities provides a better value proposition. This gives emergence to the Hub and spoke model wherein the batteries are collected at the spokes (collection centers) spread across the nation where the primary dismantling is performed to separate the battery black mass which is then transported to a centralized hub (recycling plant) where the value from the black mass is derived. Industry players are also utilizing the generic model which collects the batteries and sends them directly to the recycling units. In countries such as Germany, collection schemes are in place which could be utilized by battery OEMs to meet their EPR requirements.

To develop the battery disposal ecosystem in India, few steps in the form of national level battery collection scheme, disposal responsibility attribution to manufacturers and vehicle OEMs, development of repository for battery end of life configuration and inclusion of municipalities in the collection process should be taken up.

Overview of Battery Recycling

Obtaining the battery minerals through recycling and re-using them in new batteries for manufacturing would greatly reduce the country's import-dependency. There are three possible technologies for recycling viz. hydrometallurgy, pyrometallurgy, and direct recycling. The summary of these technologies and their applicability to EV traction battery chemistries is shown below:

	Pyrometallurgy	Hydrometallurgy	Direct Recycling
Lithium-ion	• Matured technology for recovering metal alloys • Further refinement is required to get the desired metal • Does not recover Lithium, aluminum or inorganics • 95-99% of cobalt, nickel and copper can be recovered.	• Has high raw material recovery rates, purity and yield • Matured technology with low basic investments and emissions • Requires prior dismantling/ discharging/ crushing • Recovery rate is generally between 85-90%.	• Most energy efficient compared to other recycling processes. • Can recover anode as well • Complex process with the risk of obsolescence of technology when returned to market • ~100% of cathode and anode material recovered
Nickel Metal Hydride	• Pure metal alloys are generated	• Lower capital investment with options for recovery optimization	• Not employed for Nickel Metal Hydride batteries

	Pyrometallurgy	Hydrometallurgy	Direct Recycling
	• Matured technology but capital and energy intensive • Some companies have efficiency ~100% for Iron, nickel and cobalt.	• Recovers rare earth elements with cathode metals (>95%) and metals with efficiency >90% with electrowinning	
Lead Acid	• Mainstay of both organized and unorganized Lead acid battery recycling. • Highly matured with nearly 100% recycling efficiency	• Not generally used for lead acid batteries as pyrometallurgy provides nearly all the lead content of batteries in cost effective manner	• Not used for lead acid batteries

Pyrometallurgy is a very matured process but requires further refining for its outputs to enter into the battery value chain. On the other hand, direct recycling is a relatively newer technology, but its outputs enter into the battery manufacturing step directly. For lithium-ion batteries, hydrometallurgical recycling process is the most attractive option as it offers a good balance of robust raw material recovery / yield potential, commercial viability, scalability, and technology adaptability. In India, it has been observed that many of the players are using hydrometallurgy owing to the higher recovery rates and because of the fact that intermediates such as black mass have several alternative applications.

From an economic and financial feasibility perspective, Hydrometallurgical recycling seems to be the most feasible technology. Industry players have highlighted that transportation and battery purchase costs are the two most important contributors of recycling business. Going forward, hydrometallurgy is expected to be the mainstay for the recycling of lithium-ion batteries owing to its lower energy consumption, higher emission savings, and higher capability of battery mineral extraction in comparison to pyrometallurgy.

Recycling of waste EV batteries can be improved by utilizing the presence / reach of informal sector in collecting specific kinds of batteries for recycling. Battery manufacturers can be encouraged to design their batteries in a way that they can be easily taken for reuse and recycling. For instance, inter-cell welding could be replaced with nuts and bolts making the battery packs more convenient to be re-used and recycled.

Policy enablers in the form of Recovery rates must be specified to drive batteries away from informal sector and towards registered recyclers who have the means to obtain maximum value from waste batteries. The recovery rates can be set higher for matured chemistries and lower for new technologies and the same should be suitably reviewed and updated continuously.

Overview of battery reuse

EV batteries are subjected to changing discharge rates, extreme operating temperatures, and many partial cycles throughout their life. This results in substantial degradation of traction batteries (more so lithium-ion batteries) mainly in the first five years of their life. Traction batteries are designed such that their useful life lasts around a decade. Post that, when these batteries do not meet the performance standards, these batteries can still maintain a minimum level (80%) capacity and a self-discharge rate while at rest[4]. They can thus be suitable for second-life applications.

There are multiple methods/ processes for battery reuse as shown below:

Particulars	Battery Reconditioning	Battery Refurbishing	Battery Repurposing	Battery Reuse
Value Proposition	• Reconditioned batteries can be directly used in EVs by replacing degraded cells	• Refurbished batteries have a lower capacity but also have a lower price than a new battery	• Repurposed battery packs can be used in stationary energy storage system in commercial and	• Second life battery cells can be used in a range of consumer electronics applications

[4] Source: McKinsey & Company (access here)

Particulars	Battery Reconditioning	Battery Refurbishing	Battery Repurposing	Battery Reuse
			industrial energy storage	
SoH applicability	• > 85% (Battery Packs)	• > 80% (Battery module)	• > 80% (Battery Packs)	• < 80% (Battery module)
Customer Segments	• Professional or private customers interested in minimized downtime and performance	• Price sensitive customers: when residual value of the EV does not justify the purchase of a new LIB	• Environmentally conscious B2B or B2C customers, large energy consumers, utility and real estate companies, EV charging networks	• E-cigarette companies or vaping companies and other consumer electronics company
Key Partners	• Dealers, spare parts supplier	• Dealers, refurbishing partners, spare parts suppliers	• Energy utilities, repurposing partners, energy trading companies	• Dealers. Consumer electronics companies, reusing partners

Compared to battery recycling, reuse requires a strong policy push to enable maximum usage of batteries in multiple applications before putting them up for recycling. Following are some of the key recommendations for promoting the reuse sector in the country:

1. Provision of adequate funding to industry players for developing adequate battery handling capacity
2. Provision of funding for demonstration projects of reused batteries
3. Development of safety guidelines for management of batteries for reuse
4. Development of standards for assessing BMS information for second use applications
5. Positive policy push for battery reuse in Battery Waste Management Rules to provide a legal basis for reuse of EV batteries
6. Electronic information exchange system for consisting of battery information necessary for safe handling and reuse of EV batteries

Introduction

Introduction

The Indian EV battery industry is set to take off as penetration levels in EVs continue to surge. India's auto segment is expected to see a transformational shift this decade, with fresh investments of at least USD 8-10bn in lithium-ion cell manufacturing[5]. Support from a regulatory aspect in the form of Advanced Cell Chemistry Production Linked Incentive (PLI) Scheme and battery swapping policy would bode well for the growth of the battery ecosystem in India.

Declining lithium-ion battery prices from USD 650/kWh in 2013 to ~USD 137/kWh in 2020[6] is viewed as another key development that has intensified the energy transition though wider adoption of battery storage across use cases and applications. It is thus expected that the demand of battery storage till 2030 would range between 94 GWh to 316 GWh from Electric vehicles[7] (depending on various EV adoption rates in the country). In addition, there could be demand for battery storage energy systems from the C&I segment to enable transition of their coal based captive power plants to round the clock renewable supply and grid connected storage systems.

Such a huge requirement of battery energy storage systems would necessitate domestic value capture by planning and setting up battery manufacturing facilities specific to the requirements of electric vehicles and associated battery chemistries. The raw material could be imported to the extent indigenization is not possible which have little to no presence in India in the initial years of manufacturing with active advocacy for circularity of batteries. The production-linked incentive by Government of India for manufacturing of ACC (Advanced Chemistry Cell) is a well thought out response of the government towards energy transition and value capture.

As PLI for battery storage energy systems gain more momentum, a major concern for the Government of India will be to ensure the availability of raw materials for the lithium-ion batteries. Out of the five critical minerals for Lithium-ion batteries, only two (Manganese and Graphite) are available in India. Thus, recycling and reuse of battery energy storage systems become a critical activity to be undertaken, at scale, for ensuring the energy security for the country.

In view of the unavailability of the critical battery minerals, it is of utmost importance to develop a healthy circular economy for lithium-ion batteries in the country. The disadvantaged situation of unavailability of raw materials can be turned into a ~60 GWh[7] opportunity for battery reuse and recycling.

Batteries are the largest contributors to the cost of an electric vehicle (~35%[8]). Enablement of battery as a service (BaaS) through battery swapping could be a healthy alternative to bring down the cost of electric vehicles and boost adoption rates. Another advantage of BaaS include shorter lead time as the charging time of batteries is eliminated. It provides a form of parity with ICE vehicle fuel refilling with the reduced time for getting a fully charged battery.

Though the policymakers are taking steps to address the new and upcoming battery ecosystem, the growing pace of the electric vehicles industry needs to be matched to ensure the development of an all-round battery ecosystem, which is self-sustaining to the maximum extent possible. The battery ecosystem needs the necessary enablers in the form of value chain specific policies, standards, and monitoring mechanisms to ensure a holistic development of the industry .

The development of adequate standards by Bureau of Indian Standards (BIS) in collaboration with Automotive Research Association of India (ARAI) and International Centre for Automotive Technology (ICAT) is crucial to ensure product suitability to Indian roads without hindering innovation. At the same time, policies and rules relating to circularity of batteries,

[5] J.P. Morgan Asia Equity Research
[6] BNEF (access here)
[7] Deloitte Analysis
[8] Avendus (access here)

especially lithium-ion which are the mainstay of the EV industry, are necessary to supplement the growing battery manufacturing industry which is heavily reliant on imports.

A global overview of the steps and measures taken by countries to develop their battery ecosystem is necessary to identify the gaps in the Indian landscape.

About the study

The NDC Transport Initiative for Asia (NDC-TIA) is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) supports the initiative based on a decision adopted by the German Bundestag. THE NDC-TIA project is implemented by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The organizations partnering with GIZ for NDC TIA are World Resources Institute (WRI), International Transport Forum (ITF), International Council on Clean Transportation (ICCT), Agora Verkehrswende (AGORA), Partnership on Sustainable, Low Carbon Transport (SLoCaT), and REN21. For the India component of the project, the implementing partner is the National Institution for Transforming India (NITI Aayog).

Under the NDC-TIA India component, the project "Battery Ecosystem: A Global Overview, Gap Analysis in Indian context, and Way Forward for Ecosystem Development" is carried out by Deloitte Touche Tohmatsu India LLP.

The study is focused on documenting the status quo of battery technologies used in electric vehicles, Indian and global battery standards, and policy frameworks in India vis-à-vis global counterparts. In addition to the external environment, battery value chain elements viz. battery manufacturing, battery swapping, battery disposal, recycling, and reuse are also studied in detail to understand the technological and policy landscape in India. Owing to the nascent nature of the value chain, outputs from primary interactions have been integrated into the study to provide the picture of on ground realities.

Basis the deep understanding of technology, market and regulatory landscape, suitable recommendations have been laid out in the study. The recommendations have touched upon multiple aspects of market demand creation, monitoring, and awareness development to name a few.

Additionally, financial and economic analysis of a battery recycling plant and battery swapping stations have been carried out to understand the viability of the business and essential cost and revenue drivers. Sensitivity analysis of the model along with ideal condition outputs have been showcased to provide the view of the businesses in entirety.

Aim of the study

The study aims to conduct a deep dive into various battery technologies available for traction mobility applications and determine their suitability to Indian conditions. Emphasis on the different requirements for grid energy storage projects and traction batteries for EVs have been outlined to provide an understanding to the users for traction batteries. A desk review of multiple policies and regulations surrounding battery ecosystem in the global and Indian context to identify specific gap areas and recommend suitable bridging policies and rule has been carried out. These outcomes can be used by Ministry of Environment, Forest and Climate Change (MoEF&CC), Central Pollution Control Board (CPCB), Central Pollution Control Boards (SPCBs).

Extensive coverage of battery standards from International and Indian standard organizations in the study provide the gaps in Indian standards environment and improvement areas which could be utilized by BIS, ARAI, and ICAT. Apart from the enabling factors, the report focuses on battery manufacturing, swapping, disposal, recycling, and reuse from technology, market, and policy aspects to provide industry players and policymakers on the challenges faced on ground and necessary enablers to ease them.

Objectives of the study

The project investigates the complete value chain of motive/ traction batteries used in electric vehicle applications to ensure the sustainability of battery supply chain through a multi-stakeholder approach. The aspects of investigation are captured below:

- Supply chain for traction batteries and current scenario of sourcing, manufacturing, assembling, reuse, and recycling in India and globally
- The issues associated with the mineral extraction process necessary for the EV supply chain (specially traction batteries).
- Battery quality assessment, key gaps and ways to bridge the gaps
- Policies, Regulatory, technical and logistical barriers to the battery life extension, refurbishment, and recycling.
- Stakeholders coordination and data sharing across supply chain

About the report

To achieve the objectives of the study, the report so developed touches multiple facets of the battery ecosystem in India. The report is initiated with a chapter on motive/ traction batteries technologies and chemistries covering lead acid, lithium-ion, flow, and high temperature batteries followed by nickel metal hydride, nickel cadmium, metal-air, solid state, and sodium-ion batteries.

The chapter on battery technologies is followed by an in depth review of battery standards for lead acid, lithium-ion, nickel metal hydride, and nickel cadmium chemistries from a global and Indian perspective to identify suitable gaps and suggest recommendations. The perspective of ecosystem enablers in captured through a chapter on policies and regulations for sourcing of raw materials, battery manufacturing, supply chain development, R&D, battery circularity, and swapping for India, China, Australia, Brazil, South Korea, Japan, and USA.

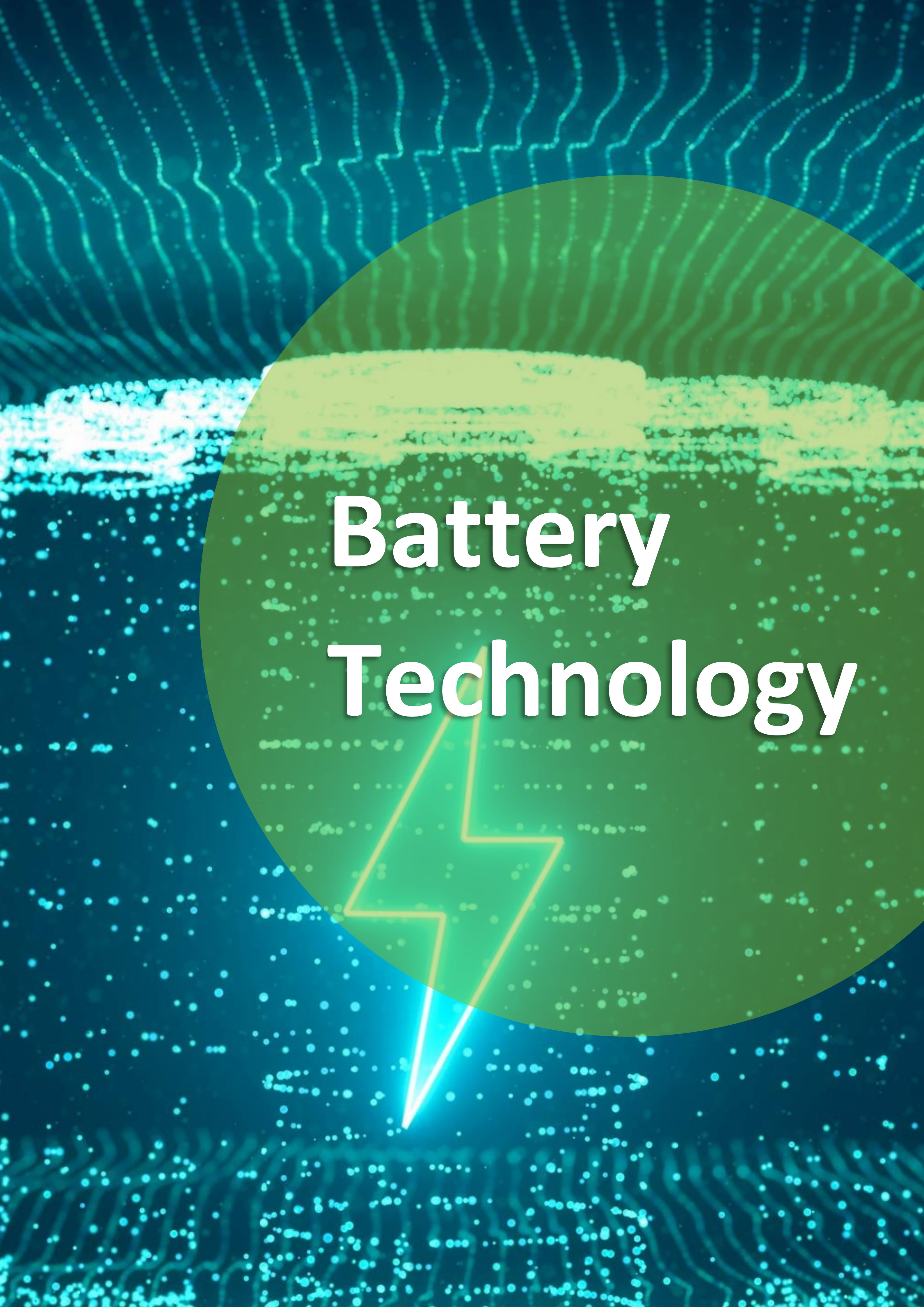
From the battery value chain perspective, battery manufacturing is first explored by outlining the key components, manufacturing process, and the levelized cost of cell manufacturing. The key developments in the Indian and global battery manufacturing space have been outlined to appraise the readers.

The emergence of battery swapping has been addressed in the report with suitable segregation of technology for different vehicle segments and supply chain analysis. Case studies of multiple battery swapping players have been presented with the financial and economic analysis of battery swapping stations.

The report also sheds light on the circularity of batteries through three chapters dedicated to battery disposal, battery recycling, and reuse. The technology and logistics, regulations and licensing requirements for each of the circularity elements have been discussed in detail. The financial and economic analysis of a recycling plant has been carried out to identify the key levers and drivers for the feasibility of the business.

The structure of the report is highlighted below:

- **Chapter 1** deals with the technologies and chemistries for motive and traction batteries and their review.
- **Chapter 2** covers the battery standards for multiple chemistries used in motive applications and provides recommendations to bridge the gaps in Indian standards.
- **Chapter 3** highlights the multiple policy and regulatory aspects for different battery ecosystem elements in global and Indian contexts.
- **Chapter 4** presents processes for battery manufacturing and features the recent developments in the Indian battery manufacturing field.
- **Chapter 5** outlines the technologies, business aspects of battery swapping with the financial and economic analysis for swapping stations serving E-2Ws and E-3Ws.
- **Chapter 6** underscores the challenges and logistics of battery disposal and the multiple processes involved in it to deal with waste batteries.
- **Chapter 7** introduces the multiple technologies for battery recycling with the financial and economic analysis of a battery recycling facility employing suitable recycling technologies.
- **Chapter 8** focuses on the technologies for reuse and provides a policy note for addressing the needs and challenges of the battery reuse sector.



Battery Technology

Chapter 1. Traction batteries in India: Technology, suitability & ecosystem

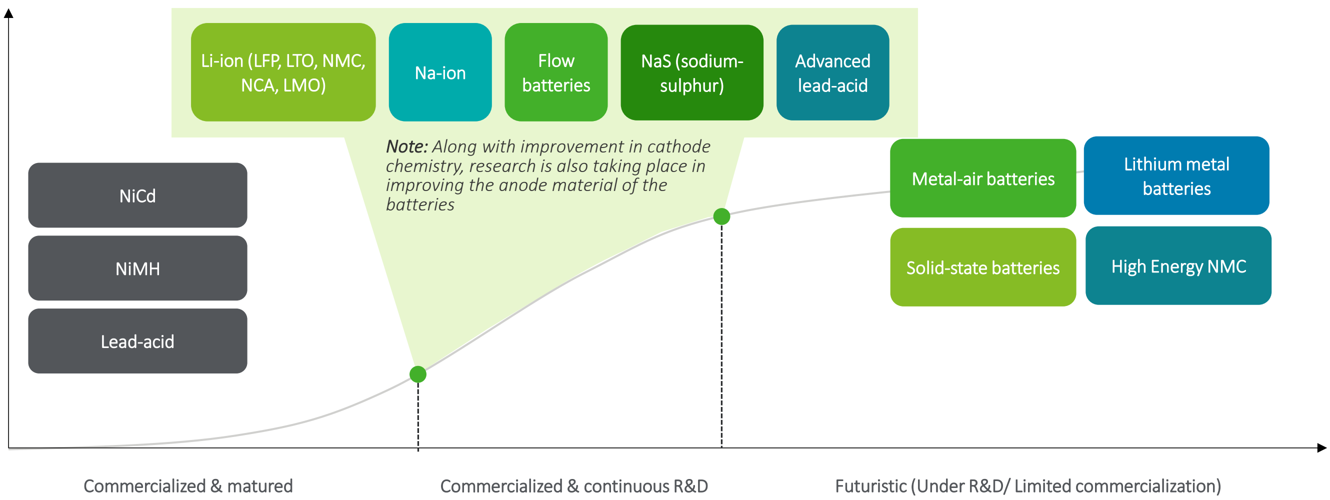
Just like the engine in an Internal Combustion Engine (ICE) vehicle, battery of an electric vehicle is its source of power. Batteries for electric vehicles of different segments have specific operational requirement and multiple battery chemistries are present for traction applications. A study of multiple battery chemistries and their applicability to Indian conditions has been carried out in the following sections of this chapter.

1.1 Battery technologies

Battery is one of the most common type of energy storage technologies that stores energy in the form of chemical energy and later converts it into electrical energy when required. Batteries are categorized into two types: primary and secondary battery. Primary batteries are non-rechargeable as the electrochemical reactions in these batteries are non-reversible. Examples of primary batteries include most of the alkaline and dry cell batteries. On the other hand, secondary batteries are rechargeable and can be used continuously during their lifetime by recharging them once the charge has been drained out. Secondary batteries include lead acid batteries, lithium-ion batteries, Nickel cadmium, etc.

As the traction batteries are rechargeable in nature, this chapter will focus only on secondary batteries. Commercial stages of key secondary battery technologies are presented in the figure below.

Figure 1: Commercial stage of key battery technologies



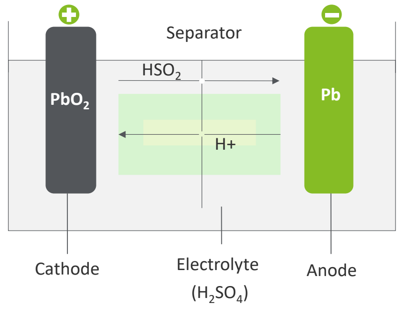
Source: Deloitte analysis

In the sections below, we will discuss all key battery technologies highlighted in Figure 1 in detail – battery compositions, applications, technical characteristics, and their advantages and disadvantages.

Lead acid

Lead acid battery is the cheapest and one of the most common types of rechargeable batteries available. Lead acid batteries are also known as wet batteries and they comprise of electrolytes for storing electrical energy. It contains lead dioxide in the positive plate, lead in the negative plate, and an electrolyte solution with a high concentration of aqueous sulfuric acid in a charged state. Each cell has the capability to provide an EMF of 2.1 volts. The battery consists of several cells placed in series to give the required voltage. The battery must first receive charge in order to enable the battery to produce a voltage. The voltage applied must be greater than 2.1 volts to enable the flow of current into the cell, otherwise the charge would flow out of it.

Figure 2: Lead Acid Battery Schematic



The increase in demand of commercial and heavy-duty vehicles, increase in manufacturing capabilities and rapid commercialization in the APAC region have directly resulted in the rapid growth in demand of lead acid batteries. The global lead acid battery market is dominated by a few large producers such as GS Yuasa, Johnson Controls, Enersys, Exide Technology and East Penn. The key applications and performance characteristics of lead acid batteries are given below:

Key applications of lead acid batteries are:

Electric Vehicles (e-2w)	Stationary Storage	Forklift & sweeper trucks	Marine	Telecom

Key performance characteristics[9] of lead-acid batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
30-50 Wh/kg	30-50 W/kg	500-1000 cycles	79-90%	0.05C - 0.2 C

Pros and cons of lead acid batteries are highlighted below:

PROS

- **Low price:** As compared to lithium-ion batteries, lead acid batteries costs significantly less for a similar set up. Lead acid batteries typically have a lower purchase (average cell cost of $65/KWh) and installation cost as compared to lithium-ion batteries
- **Tolerant to overcharging:** Flooded lead acid batteries are tolerant to overcharging making them less prone to thermal runaways which reduces chances of catching fire or exploding as compared to lithium-ion batteries
- **Temperature tolerance:** Lead acid batteries have a temperature tolerance of -40° C to +50° C. AGM batteries are resistant to cold weather damage. When frozen, the electrolyte held in the glass mat won't expand like liquid preventing cracks in batteries.

CONS

- **Weight:** Most lead acid batteries are heavy. For traction applications, a lead acid battery would weigh more than three times to that of a lithium-ion battery
- **Sulfation:** This phenomena occurs in lead acid batteries during normal operation upon subjecting to insufficient charging. Due to this, some of the lead sulphate does not recombine into electrolyte and coverts into a stable crystalline form that does not dissolve on recharging. It results in longer charging times, low efficiency, and higher battery temperature
- **Serious environmental concerns:** Lead acid batteries have serious environmental concerns. Lead and sulfuric acid both can contaminate soil and groundwater if they leak. This can further cause fires, explosion and damage the ecosystem

[9] US department of Energy (OSTI) (Access here), NREL, USAID

Lead acid battery can be further categorized as two types based on the chemistry:

#	Type	Details
1	**Flooded**	• These are generally used in stationary or large UPS, standalone energy systems and cars. A liquid electrolyte is used in Flooded lead acid batteries to trigger a chemical reaction. On connecting the battery, the acid of the battery bonds with the lead plates, thereby sending across an electric current. • In Flooded lead acid batteries, the individual cells can be accessed by the user and the liquid electrolyte is free to move in the cell compartment. The battery dries out frequently and distilled water must be added on quite frequently. Hence, this requires periodic equalization. Also, these conditions make it essential that the specific gravity of the electrolyte must be maintained regularly. • These batteries are mostly used in stationary applications.
2	**Valve Regulated Lead Acid (VRLA) Batteries**	• They are commonly known as sealed lead acid batteries. The user cannot access the individual cell components. It has limited electrolyte absorbed into a plate separator, thereby forming a gel. The oxygen recombination happens within the cell due to the proportioning of positive and negative plates. • It is also characterized by the presence of a relief valve that retains the battery contents irrespective of the positions of the individual cells. Their construction allows them to be mounted in any orientation. While they don't require regular maintenance, they do require cleaning and regular functional testing. They are used where large amounts of storage is necessary at a low cost, such as off grid power systems and large portable electric devices. • The VRLA batteries are of two types: • Absorbent Glass Mat Batteries (contains of fiberglass mesh between the battery plates to contain the electrolyte) • Gel Batteries (uses gel as an electrolyte)

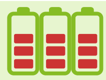
Advanced lead acid

The chief limiting factors of Lead Acid Batteries were the poor cycle life and their weight. To address these issues while still reaping benefits of the traditional lead acid batteries, a new generation of batteries was developed. Advanced lead acid batteries focus on increasing the cycle life and/or reducing the weight of the lead acid batteries so they can increasingly be employed as traction batteries in EV or HEV applications.

Advanced lead acid batteries have significantly improved the charge-discharge performance while retaining the high-power density of lead acid batteries. These batteries have higher reliability and safety, but it cannot cope up with complex working conditions. When these batteries are charged and discharged with high currents, negative sulfation occurs which effectively prolongs the service life of these batteries as compared to lead acid batteries.

The key applications and performance characteristics of advanced lead acid batteries are given below:

Key applications of advanced lead acid batteries are:

		
Electric Vehicles (e-2w)	**Grid Service**	**Other commercial applications**

Key performance characteristics[10] of advanced lead-acid batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	c-rate
30-50 Wh/Kg	180 W/kg	2500-4500 cycles	79-90%	0.05C- 0.2 C

[10] Battery University (access here), Victron Energy (access here),

Pros and cons of advanced lead acid batteries are highlighted below:

PROS

- **Longer cycle life:** Advanced Lead acid batteries have a longer cycle life (2500-4500 cycles) as compared to lead acid batteries (500-1000 cycles)
- **Reduction in sulfation:** Advanced lead acid batteries have reduced sulfation compared to lead acid batteries
- **Wide temperature tolerance:** Advanced lead acid batteries have a wider temperature tolerance range (-30° C to +65° C) than lead acid batteries (-40° C to +50° C)

CONS

- **Serious environmental concerns** are associated with these batteries due to use of toxic lead
- These batteries are **still under development and experimentation phase,** as compared to commercialized lithium or nickel-based batteries

Advanced lead acid battery can be further categorized as two types based on the chemistry:

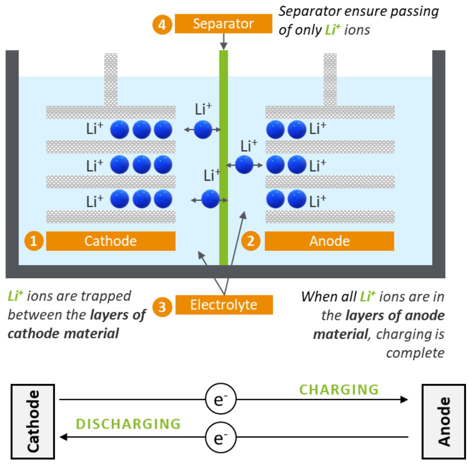
#	Type	Details
1	**Lead Carbon Batteries**	• In traditional lead acid batteries, premature failure or decay of battery is mostly due to the rapid accumulation of lead sulfate on the surface of negative plates under HRPSoC operations. In Lead carbon batteries, carbon is directly added as an admixture to both positive and negative plates in a VRLA battery. • The addition of excess carbon reduces the sulfation, thereby improving cycle life under HRPSoC conditions. This has led to significant improvement in charge and discharge performance as well due to better electrochemistry. Due to carbon's excellent conductivity, the internal resistance is also reduced. • These batteries have high charge acceptance and a wider temperature tolerance (-30°C to 60°C). They have higher charging efficiency (95%). These batteries can be used in various applications such as to store renewable energy, in microgrids, in hybrid power systems and in EVs.[11]
2	**Bipolar Lead Acid Battery**	• In bipolar batteries, the cells are stacked like a sandwich, so the negative plate of a cell would become the positive plate of the next. The cells are further separated by a bipolar plate from each other. At the end of the entire stack, single plates act as anode and cathode. • This is a simplified construction and ensures reduced weight because of the absence of bus bars joining cells and due to fewer plates. These batteries cost less, charge faster and have a longer cycle life than traditional lead batteries. These batteries are increasingly being experimented for use in Hybrid electric vehicles.[12]

[11] High Performance Lead carbon Battery towards renewable energy storage, J Yin, N Lin, Z Lin, Y Wang, C Chen, J Shi, J Bao, H Lin, S Feng, W Zhang
[12] Bipolar electrodes for next generation rechargeable batteries, T Liu, Y Yuan, X Tao, Z Lin, J Lu

Lithium-ion

Lithium-ion batteries are rechargeable batteries which were initially developed for the consumer electronics sector. Lithium-ion batteries use lithium as a core. The electrolyte carries lithium ions which are positively charged from the anode to cathode and vice versa through the separator. Free electrons in the anode are created by the movement of the lithium ions. This creates a charge at the positive current collector. The electric current then flows from the said charge collector through a given device to the negative charge collector. This battery undergoes charging and discharging in cycles when lithium ions move between anode and cathode, thereby generating electricity. Energy stored by the battery is affected by the repetition of these charging and discharging cycles.

Figure 3: Lithium-ion battery Schematic



Lithium-ion batteries can use several items as its electrodes, the most common cathode is Lithium Cobalt oxide, whereas the most common anode is graphite. Lithium Magnesium Oxide and Lithium Iron Phosphates are some other common cathodes. Lithium-ion batteries use ether as electrolyte. The rapid growth of the EV market is driving the growth of Lithium-ion batteries.

The key applications and performance characteristics of lithium-ion batteries are given below:

Key applications of lithium-ion batteries are:

			
Electric Vehicles (e-2w, e-3w, e-4w, e-buses)	**Stationary Storage**	**Consumer Electronics**	**Medical Applications**

Key performance characteristics[13] of lithium-ion batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
100-325 Wh/Kg	4000-6500 W/kg	1000-4000 cycles	85-95%	1C-10C

Pros and cons of lithium-ion batteries are highlighted below:

PROS

- **Compact size,** as compared to bulky lead acid batteries
- **Longer service life:** Lithium-ion batteries have a longer service life (1000-4000 cycles) as compared to lead acid batteries (500 – 1000 cycles)
- **Faster charging rate,** as well as compared to lead acid batteries
- **No memory effects:** In certain batteries, after repeated charging/ discharging the batteries memorizes the decreased life cycle, hence the next time the battery is charged, it will have a significantly shorter operating life

CONS

- **Protection circuitry to establish safe operation limits:** Overcharging lithium-ion batteries can create unstable conditions inside the battery, increasing pressure and causing thermal runaway. Hence, they need a protection circuitry to prevent excessive buildup of pressure and cut flow of ions when temperature is high
- **Unusable after deep discharge:** Deep discharges could potentially damage the lithium-ion battery permanently. It can lead to internal metal plating causing a short circuit, thereby making the battery unsafe and unusable. Deep discharge limit

[13] US Department of energy (OSTI) (Access here), NREL, Clean Energy Institute (University of Washington), USAID

- **Doesn't require priming:** Primming is a conditioning cycle applied to improve battery performance which is used in nickel-based batteries. Lithium-ion batteries do not require primming to improve battery performance
- **Lower self-discharging rate:** Self discharging rate of 0.35 – 2.5% as compared to lead acid batteries which have a self-discharge rate of 5%

(2 -2.5 V) should be set, and the battery should not be discharged lower than the limit

- **Restrictions in transportation:** All lithium-ion cells and batteries are forbidden for transport as cargo on passenger aircrafts as they can pose an unreasonable risk to safety, health and property when transported
- **Sensitivity to high temperatures:** Lithium-ion batteries must not be charged above 45^{o} C and discharged above 60^{o} C. These limits can be pushed higher at the expense of cell life.

Based on the material used to manufacture the cathode, Li-ion batteries are classified into below types:

#	Type	• Details
1	**LFP (Lithium Iron Phosphate)**	• LFP chemistry uses Phosphate as cathode material for rechargeable lithium batteries. The Li-phosphate combination offers good electrochemical performance along with low resistance due to nanoscale phosphate material, and hence offers high current rating and long cycle life. This chemistry has high tolerance to heat and is one of the safest cathode materials available.
2	**NMC (Lithium Nickel Manganese Cobalt Oxide)**	• The combination of nickel and manganese is known for high specific energy and high density which is used in NMC. Nickel is known for its high specific energy but poor stability; manganese has the benefit of forming a spinel structure to achieve low internal resistance but offers a low specific energy. Combining the metals enhances each other strengths. Addition of cobalt increases the stability further but increases the cost. These batteries are now taking over LFP because of their high specific energy and excellent thermal characteristics.
3	**LCO (Lithium Cobalt Oxide)**	• The LCO batteries were first developed by Sony in 1991. The chemistry has high specific energy and long-life cycle and has been used in numerous consumer electronics such as cells, tablets, laptops, and cameras. Manufacturers prefers LCO because of its ease of manufacturing characteristics. The battery consists of a cobalt oxide cathode $LiCoO_2$ cathode (~60% Co) and a graphite carbon anode. The cathode has a layered structure and during discharge, lithium ions move from the anode to the cathode
4	**NCA (Lithium Nickel Cobalt Aluminium Oxide)**	• NCA batteries have been around since 1999. Similar to NMC, it offers high specific energy and specific power, and a long-life span. NCA is not as safe as other lithium-ion chemistries and require special safety monitoring measures.
5	**LMO (Lithium Manganese Oxide)**	• LMO concept was first introduced in year 1983 by *Materials Research Bulletin*[14]. It was then commercialized in year 1996. The architecture of the cell is a three-dimensional spinel structure that improves ion flow on the electrode due to lower internal resistance and improved current handling. A further advantage of spinel structure is high thermal stability and enhanced safety, but the cycle and calendar life are limited. The cell consists of $LiMn_2O_4$ cathode and graphite anode.
6	**LTO (Lithium Titanate)**	• In these batteries, Li-titanate replaces the graphite in the anode of a typical lithium-ion battery and the material forms into a spinel structure. The cathode can be lithium manganese oxide or NMC. Instead of using carbon particles on its surface as other lithium batteries do, Lithium Titanate utilizes lithium-titanate nanocrystals. The benefit of this alteration is that the surface area of the anode of the Lithium-Titanate battery is about 100 square meters per gram in contrast to the only 3 square meters per gram that Li-ion batteries hold. The result of the lithium-titanate nanocrystals with their enlarged surface area is that electrons are able to enter and leave the anode much more rapidly, leading to fast recharging and enhanced lifetimes of the battery.
7	**Lithium Nickel Manganese Spinel (LNMO)**	• LNMO battery is termed as next-gen battery that is said to provide longer range for electric vehicles. This battery is currently at R&D stage[15].

[14] Battery University (access here)
[15] Process Worldwide (access here)

Key technical characteristics of Li-ion chemistries is presented in the below figure:

Figure 4: Key technical characteristics of Li-ion chemistries

	Li-ion chemistries					
	LFP	NMC	LCO	NCA	LMO	LTO
	Lithium Iron Phosphate	Lithium Nickel Manganese Cobalt Oxide	Lithium Cobalt Oxide	Lithium Nickel Cobalt Aluminium Oxide	Lithium Manganese Oxide	Lithium Titanate
ANODE	Graphite ✓	Graphite + Silicon ✓	Graphite ✓	Graphite ✓	Graphite ✓	LTO
ENERGY DENSITY (Wh/Kg)	90–120Wh/kg	150–220Wh/kg	150–200Wh/kg.	200-260Wh/kg	100–150Wh/kg	70–80Wh/kg
CHARGE (C-rate)	1C typical (3h charge time typical)	0.7–1C (3h charge typical)	0.7–1C (3h charge typical)	0.7–1C (3h charge typical) fast charge Possible	0.7–1C (3C maximum)	1C typical (5C maximum)
DISCHARGE (C-rate)	1C; 25C possible	1C; 2C possible	1C	1C typical	1C; 10C possible	10C possible
CYCLE LIFE	1000 – 2000	1000 – 2000	500 – 1000	500	300 – 700	3000 – 7000
Thermal runaway limit (°C)	195-219° C	170-204° C	185-195° C	220-230° C	130-200° C	-
Maximum temperature during runaway(°C)	455°	436°	485°	615°	581°	-
EV COMPATIBLE	✓	✓	X	✓	✓	X
EV BATTERY MANUFACTURER	CATL, BYD, Guoxuan High-Tech	LG Chem, Samsung SDI, SKI, CATL, AESC	-	Panasonic, Samsung SDI, LG Chem	AESC, LG Chem, Panasonic, Samsung SDI, LEJ	-
REMARKS	Very flat voltage discharge curve but low capacity; Safe; Elevated Self-discharge	Provides high capacity and high power; Most preferred chemistry for many applications	Very high specific energy, limited specific power; Cobalt is expensive; Serves as Energy Cell	Shares similarities with Li-cobalt; Serves as Energy Cell	High power but less capacity; safer than Li-cobalt; commonly mixed with NMC to improve performance	Long life, fast charge, wide temperature range, low specific energy and expensive. Safe

Source: HSBC, MDPI (access here), Deloitte analysis

Flow battery

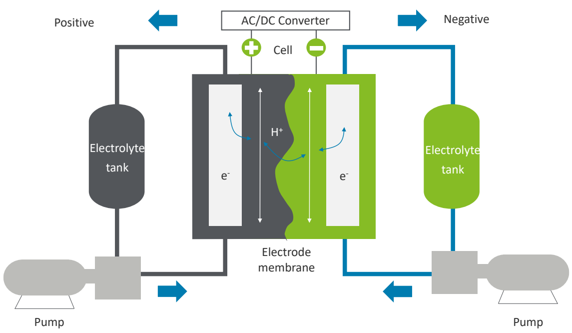
Flow batteries are rechargeable batteries characterized by the presence of two liquid electrolytes in place of electrolyte plates. These liquid electrolytes are separated by an ion selective membrane which allow ions to pass through and react chemically under charging and discharging conditions. They are considered as a better substitute for the lead-acid, solid state batteries and lithium-ion batteries owing to the easy replaceability of electrolytes.

Inside the flow batteries, there are two separate tanks of electrolyte (mostly vanadium) with different charges connected to a centrally located fuel cell stack. The electrolyte is then pumped through the fuel cell stack, where a process of ion exchange occurs across a membrane. During this exchange, a reversible electrochemical reaction takes place as well, which allows the electrical energy to be stored.

They too have a long cycle life due to the absence of phase transitions from one solid to another. With the expected increase in the share of renewables in the overall global primary energy mix in the coming years, the demand and application of flow batteries is expected to witness a similar increase.

The key applications and performance characteristics of flow batteries are given below:

Figure 5: Flow Battery schematic



Key applications of flow batteries are:

Grid Service	Renewable Integration	Backup power and UPS

Key performance characteristics[16] of flow batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
10-70 Wh/Kg	0.5-2 W/kg	12000-14000 cycles	60-85%	N/A

Pros and cons of flow batteries are highlighted below:

PROS

- **Lower levelized cost of storage:** These batteries easily offer a service life of 25 years. Their capital expense is similar to that of lithium-ion batteries but have much lower operating cost than lithium-ion batteries. Hence the cost of ownership could be less by a margin of 40%
- **Flow batteries can operate in ambient conditions** (-10 to $60^{o}C$) without heating / air conditioning as compared to utility scale lithium-ion batteries which always required ventilation
- **Do not need voltage equalization:** Lithium-ion batteries need voltage equalization to maximize capacity of the whole battery pack and keep the cells away from over charging and over- discharging. Flow batteries on the other hand do not need it.
- Flow batterie are nonflammable, nontoxic, and have no risks of explosion unlike lithium-ion batteries

CONS

- **Requirement of larger tanks:** to store large amounts of energy. Larger tanks increase the overall weight of these batteries as well
- **Complex battery systems:** Flow battery systems are complex as they require pumps, sensors, secondary containment vessels, flow, and power management for its operation. These components make the battery system larger and more complex as compared to other battery technologies

Categories of flow batteries are:

#	Type	Details
1	**Redox Flow Battery**	• Redox batteries are rechargeable batteries in which electrochemical components are dissolved in the electrolyte. The electrolytes which contain the active redox species are stored externally in tanks. The cells are then arranged in stacks (bipolar) through which the electrolytes are circulated during the processes of charging and discharging. • The storage capacity can be further determined by the size of the tanks which contain the electrolytes and the reactants' concentration. The power can further be determined by configuration and number of cell stacks and choice of components. The most used type of redox battery is Vanadium Redox Flow Battery
2	**Vanadium Flow Batteries**	• It is a type of rechargeable flow battery which uses vanadium ions in varying oxidation states to store energy. It exploits the ability of vanadium to exist in four oxidation states and use it in a battery to have just one electroactive element. These batteries can use larger electrolyte tanks to offer unlimited energy tanks. It can be used at a depth of discharge of over 90% and a rapid response time. But these batteries have a low energy to volume ratio and a relatively lower efficiency. • The aqueous electrolyte makes it heavy and thereby fit for stationary applications. Toxicity of vanadium oxides also is a concern. It has a low specific energy of 20 Wh/kg. Using Vanadium as a primary

[16] US Department of energy (OSTI) (Access here), NREL, USAID

#	Type	Details
		component, flow batteries have lifespan of 20-25 years, excellent charge retention up to a year and can discharge 100% without any recorded damage. • These batteries can be used in large power storage systems, uninterruptable power supply systems. They are also preferable in applications where batteries need to be stored for a long duration with little or no maintenance and where a steady state throughout is required to be maintained.
3	**Zinc Bromine Flow Battery**	• A type of hybrid flow battery in which zinc bromide solutions are stored in two tanks. During charging or discharging, the electrolyte solutions are pumped through the reactor stack and back into the tanks. It has a higher energy density as compared to other flow batteries of 60-85 Wh/kg and a charging discharging efficiency of 75.9%. • It can even achieve 100% depth of discharge regularly. Zinc Bromine batteries are non-perishable. But there is a need to discharge these batteries regularly to prevent zinc dendrites from rupturing the separator. There is a high cost of power owing to low areal power. • They are used in remote telecom sites as of now. Zinc Bromine gel battery is lighter, quick to charge, flexible and safer as compared to zinc bromine battery with liquid electrolytes. They offer low ionic conductivity and trigger dendrite growth which can even cause short circuit.

Figure 6: Key Technical Characteristics of Flow Batteries

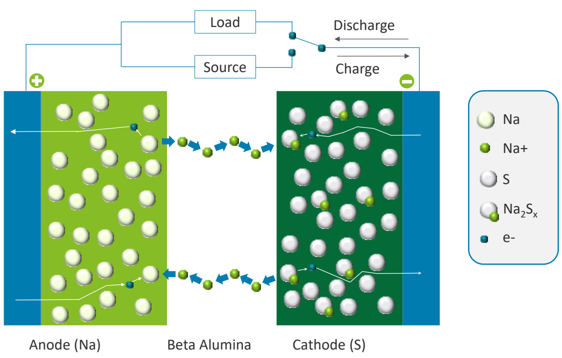
	Redox Flow Chemistries	
	VFB	ZBFB
	Vanadium Flow Battery	Zinc Bromine flow battery
ANODE	Vanadium	Zinc
ENERGY DENSITY (Wh/Kg)	10–20Wh/kg	60-85 Wh/kg
CHARGING TIME	4-10 hours	5-6 hours
CHARGE/DISCHARGE EFFICIENCY	75-80%	75.9%
CYCLE LIFE	>12000 – 14000	>2000 cycles
EV COMPATIBLE	X	X
BATTERY MANUFACTURER	UniEnergy Technologies, Largo Energy, Invinity energy, VoltStorage, Prudent Energy	Primus Power, RedFlow limited, Smart Energy, EnSync, ZBEST
REMARKS	Can offer unlimited energy capacity, more than 90% DoD, very low levelized cost of energy (LCOE)	High energy density, 100% DoD capability daily, No shelf-life limitations, Scalable capacities

Source: Deloitte Research

High temperature battery

These batteries use molten salts as electrolyte and two liquid metals as electrodes. The electrolyte is further segregated into three layers based on immiscibility and density. These batteries have a unique combination of high energy, long life, high power density and low-cost materials to solve grid scale electricity storage problems. The components of these high temperature batteries remain solid at room temperature and can be stored inactive for a long period of time. During activation at high temperatures, the anode, cathode, and electrolyte layers spread due to their immiscibility and relative densities. The electrolyte has high ionic conductivity, and the ionic species travel through the electrolyte as the charging and discharging process takes place.

Figure 7: High Temperature battery schematic



These batteries are expected to further improve the ageing power grid's overall reliability. It might even curb the need to build additional generation, transmission, and distribution capacities. The operating temperatures of these batteries are high which is maintained by self-heating during the cycles of charging and discharging.[17]

The key applications and performance characteristics of high temperature batteries are given below:

Key applications of high temperature batteries are:

Grid Service	Railway	Space

Key performance characteristics[18] of high temperature batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
150-240 Wh/kg	120-160 W/kg	2500-4500 cycles	70-90%	1/6C

Pros and cons of high temperature batteries are highlighted below:

PROS

- **Low cost:** Compared to lithium-ion batteries
- **Higher operating temperatures:** High temperature batteries operate at high temperatures (245°-350° C)
- **They are immune to degradation of microstructural electrode**
- **They have capability to store energy for long hours**

CONS

- Active cell components are highly corrosive
- They have higher possibility of metallic solubility of metal electrodes in molten salt
- **Requirement of a heat source:** These batteries require a heat source for maintaining operational conditions which also drains the battery efficiency as the heat is maintained by using battery's stored energy
- **Immobility**: Presence of a heat source makes this battery less useable to mobile solutions

There are two types of high temperature batteries:

#	Type	Details
1	**Sodium Sulphur (NaS)**	• This uses electrode materials which are cheap and abundantly available. It uses liquid sulfur as the positive electrode. It has a high energy density and a higher charging discharging efficiency. It has a long cycle life and operating temperatures of 300-350°C. • The high operating temperatures and the corrosive nature of sodium polysulfides make them suitable for energy storage applications. Sodium sulfur batteries can be used in applications such as grid standalone systems, space applications and transport and heavy machinery applications.
2	**Sodium Nickel Chloride (ZEBRA)**	• The battery operates at 245°C. and uses molten sodium tetrachloroaluminate as the electrolyte which has a melting point of 157°C. Here the negative electrode is molten sodium. The positive electrode in the discharged state is Nickel and in the charged state is nickel chloride.

[17] Electropaedia (Access here)
[18] US Department of energy (OSTI) (Access here), NREL, USAID

#	Type	• Details
		• As both of them are insoluble in basic metals, contact is allowed which hardly provides resistance to charge transfer. When not in use, this battery is kept molten as it may take up to 12 hours to reheat it. It can be used in EVs, HEV and railway.[19]

Figure 8: Key Technical Characteristics of flow batteries

	High Temperature Chemistries	
	Na-S	ZEBRA
	Sodium Sulphur Battery	Sodium Nickel Chloride
ANODE	Sodium ✓	Sodium Metal ✓
ENERGY DENSITY (Wh/Kg)	150 Wh/kg	90-120 Wh/kg
C-rate	C/6	C/6
CHARGE/DISCHARGE EFFICIENCY	80%	~100%
CYCLE LIFE	4500 cycles	>2000 cycles
EV COMPATIBLE	X	X
REMARKS	High energy density, efficiency and long life cycle. High operating temperatures and corrosive nature of sodium polysulfides make them suitable for stationary applications	High energy density, long life, low maintenance (~0), zero emission and high recyclability of raw materials

Source: Deloitte Analysis

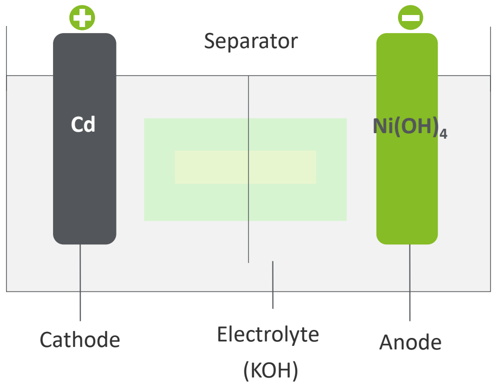
Nickel cadmium

Nickel Cadmium battery is a rechargeable battery which uses Nickel Oxide hydroxide and metallic cadmium as electrodes. Nickel cadmium batteries consist of a metal case and a sealing plate which is further equipped with a self-sealing safety valve.

Cadmium layer acts as the cathode terminal. The separator layers (provide OH ions) are kept above it. It is also soaked with water to provide for the initial reactions. When Nickel combines with water and Cadmium, it forms Cadmium Oxide and Nickel Oxide. This reaction is followed by the flow of electrons causing potential difference between two terminals.

This battery has a jelly roll design wherein the positive and negative electrodes are isolated using the separator and rolled into a spiral shape. This construction helps Ni-Cd batteries to deliver higher maximum current as compared to alkaline batteries of similar size. Modern Ni-Cd batteries are extremely resistant to electric abuse. They are available in the same sizes as that of alkaline batteries.

Figure 9: Nickel Cadmium Battery Schematic



The key applications and performance characteristics of nickel cadmium batteries are given below:

Key applications of Nickel Cadmium batteries are:

Mobile Phones	Standby Power	Aircraft

[19] Electropaedia (Access here)

Key performance characteristics[20] of Nickel Cadmium batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
45-80 Wh/Kg	150 W/Kg	2000 cycles	70%	1 C

Pros and cons of Nickel Cadmium batteries are highlighted below:

PROS

- **Relatively Inexpensive** when compared to newer chemistries
- **Tolerant to overcharging**: Nickel cadmium batteries are less sensitive to overcharging. Hence, this reduces the requirements for the charging regimes
- **Can be fully discharged:** Nickel Cadmium batteries can be fully discharged without causing any damage to the battery as compared to other battery chemistries which do not support full discharge
- **Reduced sensitivity to temperature:** As the electrolyte composition does not change during charging and discharging, Nickel Cadmium batteries are not as susceptible to freezing at lower temperatures as lead acid batteries. NiCd batteries can tolerate temperatures up to -50^{o} C

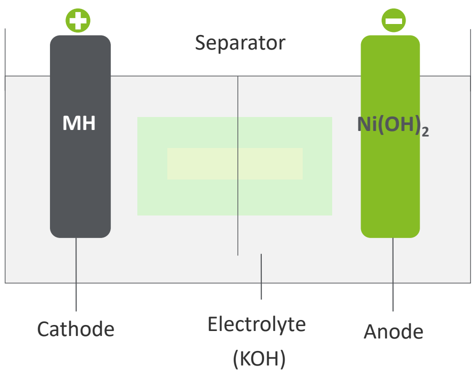
CONS

- **Memory effect:** After repeated charging/ discharging the batteries memorizes the decreased life cycle, hence the next time the battery is charged, it will have a significantly shorter operating life
- **Higher self-discharging rate:** NiCd has a self-discharge rate of 10-20% as compared to lead acid batteries which have a self-discharge rate of 5%
- **Toxic to the environment:** Cadmium is a toxic and heavy metal, hence discarding these batteries will damage the environment

Nickel metal hydride

NiMH is one of the most advanced and commercially available rechargeable battery. It uses Nickel Oxide Hydroxide in its positive electrode and hydrogen absorbing alloy in the negative electrode. The electrodes are separated by a permeable membrane which allows for ionic and electron flow between them. The membrane is made up of aqueous potassium hydroxide and is immersed in the electrolyte. There is no significant change to this membrane during the battery operation. They are used as substitutes for alkaline batteries due to their compact size, compatible cell voltage, leak, and explosion resistant.

Figure 10: Nickel Metal Hydride Battery Schematic



The battery has a resettable fuse which breaks the circuit if the current or the temperature is too high. They are much safer as compared to NiCad and give a higher output. However, their performance is not superior when compared to Lithium-Ion battery.[21]

The key applications and performance characteristics of nickel metal hydride batteries are given below:

Key applications of Nickel metal hydride batteries are:

[20] US Department of energy (OSTI) (Access here), NREL
[21] Electropaedia (Access here)

		
Mobile Phones	**Digital camera**	**Electric Vehicles (e-4w)**

Key performance characteristics[22] of Nickel metal hydride batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
60-120 Wh/Kg	250-1000 W/Kg	700-1000 cycles	66-92%	0.5 C

Pros and cons of Nickel metal hydride batteries are highlighted below:

PROS

- **Higher energy density** as compared to Nickel Cadmium batteries by a margin of 30-40%
- Lesser requirement of periodic exercise cycles
- Environment friendly as no cadmium, lead or mercury is used in these batteries.
- Resistant to leakage and explosion
- **Easier to store and transport** as compared to battery technologies like lead acid, flow batteries, etc.

CONS

- **Expensive**, as compared to NiCad
- **Higher self-discharging rate:** Higher self-discharging rate (10-15% in first 24 hours, then 10-15% per month) as compared to lead acid or lithium-ion batteries
- **Complex charging algorithm:** NiMH batteries use a dT/dt charge system which is more expensive as compared to the charging methods of NiCd or Li Ion batteries. Also, extended trickle charging can damage a NiMH battery, hence a timer should be used to regulate the recommended total charging time

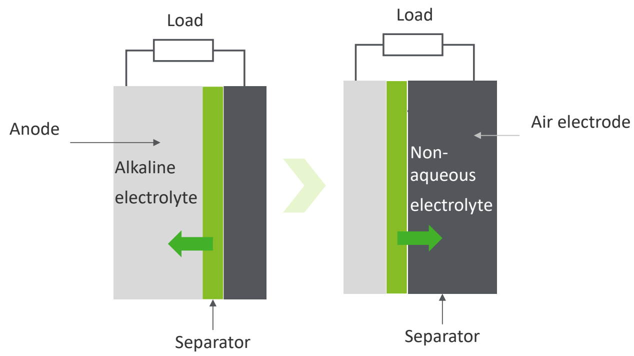
Metal-air battery

Metal air batteries have metal anodes with aqueous or non-aqueous electrolyte. It creates voltage from the availability of oxygen molecules (O_2) at cathode which reacts with positively charged metal ions to form oxide and generate electric energy. These batteries hold great potential to resolve future energy and environmental issues.

In these batteries, the electrolyte can be aqueous or non-aqueous depending on the nature of the anode employed; the air breathing cathode often has an open porous architecture that permits continuous oxygen supply from surrounding air.

Metal-air batteries holds great potential to resolve future energy and environmental issues. It creates voltage from the availability of oxygen molecules (O_2) at cathode which reacts with positively charged lithium ions to form Li_2O_2 and generate electric energy[23]. During discharge, metal is oxidized at the anode; O_2 from the surrounding air is reduced.

Figure 11: Metal-air battery Schematic



[22] US Department of energy (OSTI) (Access here), NREL
[23] IFLS (access here)

The metal air batteries use different metals such as Zinc (Zn), Lithium (Li), Aluminium (Al), Manganese (Mn), Sodium (Na), Iron (Fe) etc.

Box 1: NTT R&D on lithium-air secondary battery technology

NTT (Japan) is currently conducting research on producing lithium-air secondary batteries. As per the institute, Li-air secondary batteries can charge and discharge with larger energy densities per weight and volume than lead-acid or lithium-ion batteries. The theoretical capacity of Li-air batteries is 5-8 times higher than conventional Li-ion batteries and can be an ideal substitute for use in EVs.

Source: NTT - Lithium-air secondary battery technology (access here)

The key applications and performance characteristics of metal air batteries are given below:

Key applications of metal air batteries are:

	
Grid Service	**Electric Vehicles**

Key performance characteristics[24] of metal air batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
350-500 Wh/Kg	100 W/Kg	>1000 cycles	<60%	N/A

Pros and cons of metal air batteries are highlighted below:

PROS

- **Less charging time:** Metal air batteries take lower time to charge (10 mins) as compared to lithium-ion battery or any other chemistry
- **Higher energy density**: Metal air batteries have a higher energy density (350-500 Wh/Kg) as compared to lithium-ion batteries (100-325 Wh/Kg)

CONS

- **Dendrite Formation:** During the charging cycle, the chemical and electrochemical processes drive a complex reaction resulting in the deposition of dendrites inside the battery

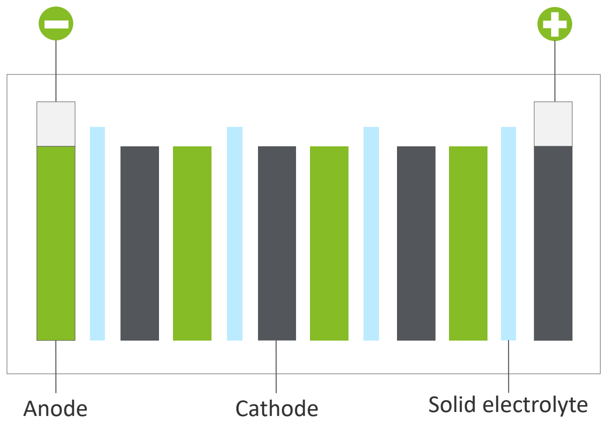
[24] US Department of energy (OSTI) (click here)

Solid state batteries

A Solid-state battery uses both solid electrodes and electrolytes instead of the liquid or polymer gel electrolytes used in other Li-ion batteries. Solid state batteries are futuristic, highly advanced, next-gen battery that delivers high performance and safety. The Solid-state battery has high energy density (since cells are thinner by 80-90%), safety, non-flammability, lesser self-discharge and thermal stability (electrolyte does not get heated much and hence it suits fat charging).

On the counter side, the Solid-state batteries are expensive to manufacture. Their conductivity also reduces at low temperature as it uses solid electrolytes. In addition to this, Li dendrites tend to form at the Lithium metal anode due to uneven deposition of Lithium during the charge-discharge process. These dendrites penetrate the separator and can cause short circuits.

Figure 12: Solid state battery schematic



Box 2: Volkswagen QuantumScape partnership

In 2019, Volkswagen (VW) established a joint venture with QuantumScape Corporation to advance the research, production and marketing of Solid-State (SS) batteries. Both the companies are working towards creating a solid-state battery production line which is targeted to commence in year 2024. VW intends to use the solid-state batteries in its EVs; with the integration of SS batteries, the range of VW EVs are expected to improve to 450-500 miles. The solid-state batteries are expected to be much safer and lighter than conventional Li-ion batteries. The recharging duration of these batteries are estimated to be 15 mins.

Source: Volkswagen QuantumScape partnership (access here)

The key applications and performance characteristics of solid-state batteries are given below:

Key applications of solid-state batteries are:

		
Consumer Electronics	**Grid Service**	**Electric Vehicles**

Key performance characteristics[25] of solid-state batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
>1000 Wh/kg	n/a	Up to 10 years	n/a	0.2C-100C

Chemistry

#	Type	Details
1	**Solid state lithium batteries**	• In these batteries, lithium metal is used as anode. The solid electrolytes can include ceramics. The cathode also can be lithium based. When lithium metal is used as anode, the challenge faced is the

[25] US Department of energy (OSTI) (Access here), NREL

#	Type	• Details
		growth of dendrites on the anode surface which could short circuit the battery. Researchers are increasingly working towards a multilayer battery design to overcome this.

Pros and cons of solid-state batteries are highlighted below:

PROS

- **Non-toxic** as compared to other battery technologies
- **Very low self-discharge rate:** of 1.5-2% as compared to lithium-ion batteries which have a self-discharge rate of less than 5%
- **Safety:** Solid state batteries are safer and more stable as compared to lithium-ion batteries with liquid electrolytes

CONS

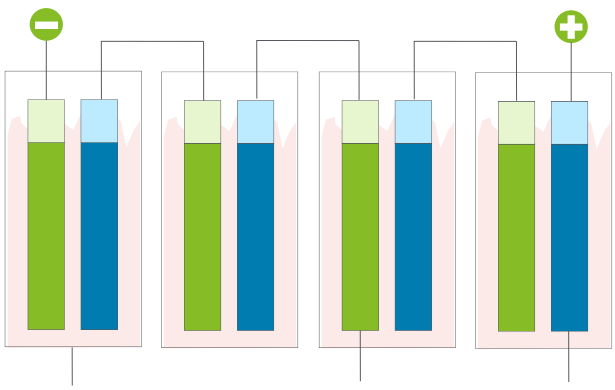
- **Expensive:** Mass production and manufacturing methods are quite expensive and complex as compared to other battery chemistries
- They have less conductivity at low temperature
- **Dendrite formation:** Dendrites commonly form during electrodeposition during the charging and discharging cycle causing degradation in their performance

Sodium-ion

Sodium-ion battery (SiB) utilizes the same principle as Lithium-ion batteries in which Sodium ions shuffle between cathode and anode for energy charge and discharge. Compared to Lithium, Sodium ions have larger ionic radius than Lithium resulting in different battery materials. Graphite which is the dominant anode used in Limbs cannot be used in SiBs due to which Hard Carbon is the anode choice for SiBs. Aluminum foil is known to be the better current collector in SiBs than copper foil. The major electrolytes used in SiBs are sodium based $NaFP_6$ rather than the $LiFP_6$ used in Lithium-ion batteries.

Sodium-ion batteries don't involve rare metals and are low-cost battery solutions by their very nature. Sodium-ion batteries share multiple constituents with Lithium-ion batteries like Aluminum, Iron, Potassium, Magnesium, Titanium, Zinc, Copper etc. which are highly abundant as compared to Nickel, Cobalt, and Lithium.

Figure 13: Sodium-ion battery schematic



CATL is developing a solution (AB Battery Solution) that enables the integration of a SiB and LiB into one Battery pack. It purports to be able take advantage of the low-temperature performance of the SiB or the high energy density of LiB, depending on the need. When temperatures fall sharply, it will utilize the SiB to provide more driving range and rely on the LiB for a more powerful performance.

Box 3: Faradion acquisition by Reliance New Energy Solar Limited (RNESL) for Sodium-ion batteries

In December 2021, Reliance New Energy Solar Limited (RNESL), a wholly owned subsidiary of Reliance Industries, has entered into an agreement with UK's Faradion Limited to acquire sodium ion battery for £100 million. Faradion is one of the leading global battery technology companies, based out of Oxford in UK, with extensive IP portfolios covering several aspects of sodium-ion technologies. Reliance is expected to use the technology from Faradion in its upcoming fully integrated energy storage gigafactory at the Dhirubhai Ambani Green Energy Giga Complex in Jamnagar. The acquisition is directed towards commercializing the technology for usage in grid scale storage, back-up power, mobility and transport sector.

Source: RIL Press Release (access here)

The key applications and performance characteristics of sodium-ion batteries are given below:

Key applications of Sodium-ion batteries are:

Grid Service	**Electric Vehicles**

Key performance characteristics of Sodium-ion batteries are:

Energy Density	Power Density	Cycle Life	Round-trip Efficiency	C-rate
160 Wh/kg[26]	n/a	~3000 cycles	92%	0.1C-2C[27]

Pros and cons of Sodium-ion batteries are highlighted below:

PROS

- **Low battery BOM cost** compared to LFP batteries (-25%[28])
- **Abundance of raw materials** in comparison to Lithium-ion batteries
- **Broader Operating temperature** range with more than 90% capacity retention at -20°C
- **Capability to be transported at zero volts** relatively to Li-ion batteries which need to retain 40% of charge to preserve performance

CONS

- **Lower Energy density** in comparison to Li-ion batteries leading to higher weight limiting application in Grid storage

Based on their suitability – lithium-ion & sodium-ion technologies are identified as the most promising technology for electric vehicle application; lead-acid and nickel metal batteries are not suitable for e-4 BEV, whereas technologies such as metal-air or solid-state are yet to achieve commercial viability.

[26] CATL (Samsung Securities Analyst Report)
[27] OSTI (access here)
[28] AMTE Power

Lookup table for current EV batteries:

Table 1 Lookup table – EV category, OEM & battery details

Sl. No.	Vehicle	EV category	Battery Type & Chemistry	Manufacturer	Battery Capacity (kWh)	Range per charge (km)*	Cycle Life	Battery Cost (USD/kWh)
1.	TVS iQube Electric		Li-ion	24M	2.25	75	650-750	300-400
2.	Ola S1		Li-ion	StoreDot	2.98	121	-	150-250
3.	Revolt RV 400		Li-ion	Candra	3.24	150	650-750	150-250
4.	Ather 450X		Li-ion-NMC 622	In house	2.6	116	-	200-300
5.	Bajaj Chetak		Li-ion-NCA	Lithium Sun	2.89	85	800-900	150-250
6.	Simple Energy One		Li-ion	C4V	6.4	236	300-400	100-200
7.	Bounce Infinity E1		Li-ion	BattRE	2	85	550-650	140-250
8.	Hero Electric Optima		Li-ion-LFP	AMCO, Log9, Gogoro	1.87	125	900-1000	150-250
9.	Oben Rorr		Li-ion - LFP	-	4.4	200	250-350	100-200
10.	Hero Electric Atria		Li-ion - LFP	AMCO, Log9, Gogoro	1.53	85	900-1000	200-300
11.	Hero Electric Photon		Li-ion - LFP	AMCO, Log9, Gogoro	1.28	108	900-1000	300-400
12.	Ampere Magnus		Li-ion - NMC	Greaves Cotton	2.8	84	450-550	100-200
13.	Tork Kratos		Li-ion	In house	4	180	200-300	100-200
14.	Okinawa PraisePro		Li-ion-LFP	In house	2	88	300-400	200-300
15.	Okinawa Okhi90		Li-ion-LFP	In house	3.6	160	150-250	200-300
16.	Hero Electric NYX		Li-ion - LFP	AMCO, Log9, Gogoro	1.536	165	900-1000	200-300
17.	Komaki Ranger		Li-ion	In house	4	200	900-1000	200-300
18.	Hero Electric Flash		Li-ion - LFP	AMCO, Log9, Gogoro	0.96	85	900-1000	250-350
19.	PURE EV Epluto		Li-ion-NMC	In house/CK Motors	2.5	80	450-500	150-160
20.	Odysse Electric Evoqis		Li-ion	-	4.32	140	650-750	190-200

Sl. No.	Vehicle	EV category	Battery Type & Chemistry	Manufacturer	Battery Capacity (kWh)	Range per charge (km)*	Cycle Life	Battery Cost (USD/kWh)
21.	Mahindra Treo Zor		Li-ion - LFP	Exide/Amara raja	7.4	125	600-700	250-350
22.	Piaggio Ape E-Xtra FX		Li-ion-NMC	Sun Mobility	8.5	142	700-800	150-250
23.	Euler HiLoad DV		Li-ion - NCA	Assembled inhouse	12.4	150	500-600	100-200
24.	ETO Bulke		Li-ion-LFP	BYD	9.8	148	500-600	150-250
25.	GMW Taskman SmartAuto		Li-ion	Leoch Battery Shenzhen Corp	7	110	-	150-250
26.	Kinetic Safar Star MSV 400		Li-ion	Exicom/JV with Sharda Motors	4.5	65	-	250-350
27.	Kalinga Ventures / Vidhyut C1 L5		Li-ion	-	6.6	70	-	100-200
28.	Omega Seiki Rage+		Li-ion - LFP	Amara raja / exicom /log 9 materials	7.5	100	750-800	150-250
29.	Altigreen Propulsion Labs		Li-ion - LFP	Inhouse	11	151	650-750	150-250
30.	Atul Elite E-rickshaw		Li-ion/Lead acid	Honda	12	60	650-750	50-150
31.	Renault Twingo ZE		Li-ion NMC 712	LG Chem	21.3	104	1500 – 1600	450 – 500
32.	Renault Zoe (ZE 40 battery)		Li-ion NMC 622	LG Chem	41	204	700 – 800	300 – 350
33.	Renault Zoe (ZE 50 battery)		Li-ion NMC 712	LG Chem	52	248	600 – 700	250 – 300
34.	VW E-Golf		Li-ion NCM 111	Samsung SDI	32	152	1500 – 1600	350 – 400
35.	Skoda CITIGOe iv		Li-ion NMC 622	LG Chem	32.3	164	900 – 1000	300 – 350
36.	BMW i3		Li-ion NMC 622	Samsung SDI	37.9	184	800 – 900	350 – 400
37.	Peugeot e-208		Li-ion NMC	CATL	46	228	700 – 800	250 – 300
38.	Nissan LEAF		Li-ion NMC 523	Envision AESC	56	272	500 – 700	250 – 300
39.	Chevrolet Bolt EV		Li-ion NMC	LG Chem	64	334	400 – 500	200 – 250
40.	Hyundai Kona Electric		Li-ion NMC 622	LG Chem	64	316	500 – 600	200 – 250
41.	Hyundai Ioniq		Li-ion NMC 622	LG Chem	38.3	200	700 – 900	350 – 400
42.	Kia e-soul/Kia e-Niro		Li-ion NMC 622	SK Innovation	64	296	500 – 700	200 – 250
43.	Jaguar I-PACE		Li-ion NMC 622	LG Chem	84.7	304	500 – 600	300 – 350
44.	Mercedes Benz EQC		Li-ion NMC 622	LG Chem/SK Innovation	80	296	500 – 600	350 – 450
45.	Audi e-tron 55 quattro		Li-ion NMC 622	LG Chem	86.5	292	500 – 600	300 – 400

Sl. No.	Vehicle	EV category	Battery Type & Chemistry	Manufacturer	Battery Capacity (kWh)	Range per charge (km)*	Cycle Life	Battery Cost (USD/kWh)
46.	Porsche Taycan Turbo S		Li-ion NMC 622	LG Chem	83.7	320	400 – 600	700 – 900
47.	Tesla Model X		Li-ion NCA	Panasonic	98.4	392	400 – 600	400 – 500
48.	Tesla Model 3		Li-ion NCA	Panasonic	76	304	400 – 600	200 – 300
49.	Tesla Model 3		Li-ion LFP	CATL	52.5	388	400 – 600	400 – 500
50.	Tesla Model Y		Li-ion LFP	CATL	57.5	348	400 – 600	300 – 400
51.	Tata Motors Nexon EV		Li-ion NMC	Tata Autocomp	30.2	250	400 – 600	150 – 200
52.	Mahindra eVerito		Li-ion NMC	LG Chem	21.2	88	400 – 600	100 – 150
53.	Tata Tigor		Li-ion NMC	Tata Autocomp	26	145	800 – 1000	100 – 200
54.	Toyota PROACE Verso M		Li-ion NMC	Prime Planet Energy & Solutions	64	200	700 – 900	200 – 300
55.	Honda e		Li-ion NMC	SES Holdings	28.5	136	1000 – 1200	300 – 400
56.	Fiat 500e Hatchbatch		Li-ion NMC	Bosch	37.3	188	800 – 1000	150 – 250
57.	Volvo C40 Recharge Twin Pure Electric		Li-ion NMC	LG Chem	75	280	500 – 700	150 – 250

Source: Company websites, Deloitte analysis

*Note: *range per charge is the 80% of the maximum range delivered by the EV under testing environment; cycle life is calculated using battery range (per charge) and warranty provided by the EV OEM*

Within lithium-ion, LFP, NMC and NCA are the preferred battery chemistries by the global EV OEMs

Box 4: Battery technology – Suitability w.r.t Indian tropical conditions

Due to its technical characteristics (such as energy density, power density, efficiency, cycle life etc.) Li-ion has been the preferred choice of battery technology for traction applications. However, within Li-ion, there are three fundamental chemistries which have been widely adopted by EV OEMs globally – LFP, NMC and NCA (for e.g. BYD primarily uses LFP chemistry for its EVs; Ford, Volkswagen, GM use NMC chemistry; NCA is mostly used by Tesla).

Of all the three chemistries, NMC and NCA holds higher energy density compared to LFP, and therefore provides higher drive range. However, for Indian conditions, LFP batteries are better suited chemistry than NMC or NCA.

1. **Comparison vis-à-vis Safety:**

LFP battery storage systems have **superior thermal and chemical stability** than those based on cell technologies made with other cathode materials. The LFP offers efficient heat dissipation for better thermal stability especially during long rides and quick acceleration. They provide better safety characteristics, especially concerning potential fire hazards caused by improper overcharging or short circuit conditions.

LFP battery enters a thermal runaway condition at 270^{o}C and release minimal energy during thermal runaway. A typical NMC/LCO battery can enter thermal runaway condition as low as 150^{o}C.

During thermal runaway, LCO and NCA battery chemistries have a temperature rise of 470°C per minute, whereas NMC chemistries witness a temperature increase of 200°C per minute. Compared to these, LFP batteries witness only a temperature rise **of 1.5°C per minute** during thermal runaway. Hence, the thermal runaway of an LFP technology is intrinsically impossible in normal operation, and even almost impossible to artificially trigger.

LFP batteries have Aluminum which makes them more stable as compared to NMC batteries. LFP batteries also have other advantages such as: **better slope climbing ability, better acceleration experience**, and **improved stability** of electronic components. In comparison to other lithium-ion battery technologies, LFP batteries are **less stressed** if subjected to high voltage over a prolonged period of time and more tolerant to conditions of deep cycle.

2. **Comparison vis-à-vis environmental impact:**

Lithium iron phosphate batteries are one of the few **cobalt-free lithium-ion batteries**; they also do not contain other **toxic heavy metals like lead and nickel** which are commonly used in other batteries. Lithium iron phosphate, in contrast, is a substance that is in its chemical composition a naturally occurring mineral. These batteries are considered to be safe, not toxic, and of low environmental impact.

1.2 Battery comparison – traction v/s stationary applications

Batteries are used for multiple applications such as electronics, medical devices, aerospace etc. however, their use in two applications is far critical – mobility/ traction and stationary storage. This section will deep dive into the basic difference between the batteries for traction application and stationary storage application.

Application	Details
 Traction	• Traction batteries are used in Battery Electric Vehicles or Hybrid Electric Vehicles to power the electric motors. They are rechargeable and differ from SLI batteries as they are deep cycle batteries and are designed to give power over longer periods of time.

Application	Details
 **Stationary storage**	• Stationary batteries are used in applications where power is needed on a standby or emergency basis. These batteries are not discharged frequently. On demand use require stationary batteries to be continuously remain on float charge. They are used for load levelling during peak demand, backup emergency power, UPS, and telecommunications equipment. Traction batteries need to be compact and require high power density and volumetric energy. But these factors are not as critical for grid storage systems as size, shape, weight, etc. are not limiting criterions. If more storage capability is required additional batteries could be installed to meet the purpose.

Converting traction batteries into secondary batteries

EV batteries are subjected to extreme operating temperatures, changing discharge rates and hundreds of partial cycles in any given year during their life. The traction batteries are mostly designed to have a useful life of 10 years. After a decade, these batteries do not meet the performance standards of EV (maintaining 80% of total usable capacity and a self-discharge rate of 5% over 24 hours). But these batteries can have a second life. After remanufacturing/ refurbishing / repurposing, such batteries can be used in less demanding stationary applications.

After acquiring and testing the used batteries for second use, they need to be reconfigured. Stationary applications have varying energy and power requirements. Small commercial systems have power and energy requirement of 25 KW and 100 kWh respectively. Utility systems on the other hand will require power of 100 MW and energy requirement of over tens of megawatt hour.

Many of the applications are likely to be unique requiring a different battery configuration. Some applications need larger battery systems which are equivalent to 100 full EV packs. If it is fully reassembled at the refurbishing facility, shipping and handling will be cumbersome. Also, assembling hundreds of battery modules at the application site will lead to significant increase in the installation cost. So, EV modules need to be assembled at the refurbishing facility such that they are small enough for convenient shipping and handling and it is large enough to reduce the installation cost.

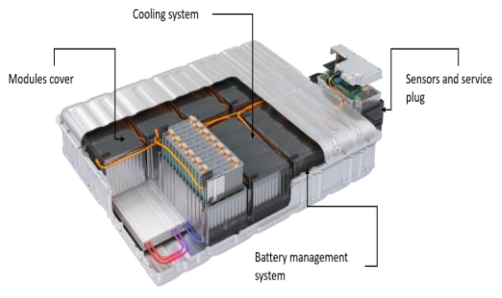
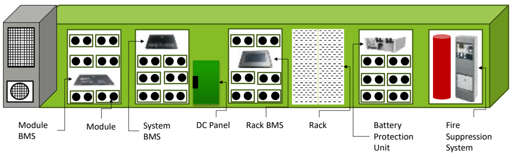
25 kWh is considered as a convenient building block to meet the performance standards and requirements of smaller applications. Moreover, this size would be similar to that of an EV battery pack, hence this could lead to efficient estimation of assembly costs and materials.

The traction batteries first go through screening wherein the degraded and damaged cells are identified in the battery pack. Critical information such as State of health is retrieved in this step. The battery pack is then disassembled where in the battery is opened and all mechanical and electric components are removed along with auxiliary electronic parts. The defective and degraded cells are replaced followed by refilling of the electrical components such as connector, power cables and control wiring. The cell is then reassembled which depends on the application for which the battery is being repurposed. Based on that, a specific master BMS must be developed.

For different applications, the design for Battery pack, BMS, equalization management system and thermal management system will undergo changes in design. Post reassembly, the battery pack performance will also be tested. Also, the battery pack is connected in parallel as it is not possible to connect the battery pack in series. A DC/DC converter should be added which shall elevate the voltage (DC) to the working level of the power conditioning system. Alternatively, efforts can be made to oversize the power conditioning system due to high currents which will further increase the system cost.

Structural comparison of traction and stationary battery

The traction and stationary batteries differ in their physical form. In the below section, we will provide details on key physical appearance and key components of batteries for both the applications.

Particulars	Traction battery	Stationary Battery
Illustration		
Modules	• Battery assembly built by combining fixed number of cells. • Protects the battery cells from heat, vibrations, and external shocks	• Connects multiple battery cells to appropriate current and voltage
Battery Management System	• Monitors the voltage produced by individual battery cells in the stack. It communicates with the vehicle outside the battery pack as well	• Protects the cell to achieve reliable and safe operation. It even balances the state of charge of cells within a serial connection
Battery Protection Unit	• A battery protection unit in EV has three safety monitors to guard against hazardous conditions: o Voltage measurement to aid in monitoring and balancing battery cells o Current measurement to monitor battery stack's current o Isolators which bring the measurement signals from high voltage batteries to low voltage BMS	• BMS is equipped with a low voltage disconnect unit which disconnects the battery from the load or the charger under critical conditions preventing failure of batteries and damage to the batteries
Battery Thermal Management System	• The BTMS ensures controlled surrounding where temperature is controlled and there is no risk of thermal runaway. This ensures battery pack safety, increased lifespan, and performance. The BTMS should be equipped with cooling, heating, insulation, and ventilation functions to maintain the right operating conditions of the battery pack	• Based on the specifications of the cells in terms of temperature gradients and absolute values, the BTMS controls the temperatures of the cells based on their specifications in terms of temperature gradients and absolute value in the pack. Air cooling systems is the preferred method for BTM in stationary batteries.
Other Components	• **Service Plug**: Splits the battery stack into two halves which are electrically isolated from each other when the service plug is removed	• **Rack**: Used to keep the battery modules in an enclosed structure
	• **Relays or contractors**: Controls the distribution of electric power of the battery pack to the output terminals	• **DC Panel**: A switch or quick disconnect method to isolate the battery electrically from the rest of the system
	• **Sensors**: Collects data regarding temperature, voltage and current which Is further collected by BMS to ensure the smooth functioning of the battery pack	• **Fire suppression system**: Fire protection and alarm units with supervisory control and data acquisition

Performance comparison of Traction and stationary batteries:

Table 2: Performance comparison of Traction and stationary batteries

Characteristics	Traction application	Stationary application
Energy Density	**(High)** These batteries discharge continuously over extended periods of time. A higher run time or mileage is desired in these applications. Since for electric mobility, weight and size of the battery becomes a limiting factor, batteries with a smaller footprint and high performance are preferred. As lithium ion has the highest energy density amongst the current commercial battery technologies, it is preferred for such applications.	**(Low to medium)** For stationary applications, weight and size of the battery is not a limiting factor. For grid and utility scale storage, bigger battery systems are preferred which can lost longer.
Power density	**(High)** Batteries need higher power density to be able to release larger amounts of energy quickly based on their mass. This is to meet the acceleration requirements of the vehicle.	**(Medium to high)** Focus is on energy storage for long periods of time and discharge during peak conditions. Hence, there is no requirement for releasing large amount of energy quickly. Weight and size are not a concern as well.
Efficiency	**(High)** Round trip efficiency influences the overall vehicle efficiency. Charge retention should be higher for the vehicle and loss of energy is low for EVs. Hence, EV can travel more distance until it discharges.	**(Low to medium)** Roundtrip efficiency is a key determinant for cost effectiveness of the battery system. It takes into consideration energy losses due to parasitic loads or power conversions as well, which could be frequent in stationary batteries, thereby marking a low to medium efficiency. For stationary batteries, efficiency of **less than 75%** are not likely to be cost effective
Lifecycles	**(High life cycle)** For these applications the battery should be able to undergo high number of charging-discharging cycles before reduced performance. This directly influences the lifetime of the battery.	**(High life cycle)** The operational lifetime directly affects the cost-effectiveness of energy storage for stationary batteries. The cycling requirement might reduce if the percentage of power spikes tolerated without intervention is increased. Furthermore, there is demand for longer duration of energy storage. For residential and commercial applications these batteries need to have lifetime cycles in the range: **7300-22000**

Characteristics	Traction application	Stationary application
C-rate	**(High)** The speed of the charge and discharge currents can be identified through the C-rate of a battery. For traction applications, higher C ratings deliver more energy and have higher performance levels.	**(High)** For stationary applications, battery with higher C ratings suffer less from voltage drops under load. It reduces charging time as well and can maintain higher and consistent voltage
Depth of discharge	**(Deep discharge)** Traction batteries are will have one deep discharge per day. Hence these batteries need to be capable of withstanding regular deep discharge (80% DOD). It maximizes energy and delivers full power output even during deep discharge to ensure long range operation.	**(Low to medium)** For stationary applications, it is not a good practice to discharge batteries at its full capacity. This could lead to increase in internal resistance which could cause trouble during recharging. Hence the depth of discharge is kept low to medium.
Discharge rate	**(Low)** Typically, traction batteries need to have a high cycle life and lifetime which will depend on the discharge rate as well. Lower discharge rates signify lesser number of charging discharging cycles and ultimately higher cycle life	**(Low to medium)** The cut off voltage for these applications need to be high post which the load will be disconnected. The cut off rate depends on the discharge rate of the battery. To maintain a high cut off rate the discharge rate shall be kept low
Operational temperature	**(High)** The traction batteries might need to operate in harsh operating environments. To endure that it should be able to withstand wide temperature changes	**(Low)** These batteries tend to heat up during discharging. Since their operating temperatures are low, there needs to be a thermal management system to prevent overheating of those systems.

1.3 Research and development in traction batteries

Recent developments in battery research and developments are enabled by collaboration between EV manufacturers and research institutes. Majority of the research is focused on lithium-ion batteries due to their overall application in Electric mobility. Definitive research is being carried out on solid state batteries which can be a long-term replacement of lithium-ion batteries. Further research is being carried out in order to achieve sustainability and restrict the use of toxic and hazardous materials.

Research by international laboratories

Advanced lead acid battery

Majority of the research on advanced lead acid batteries is carried out by the Consortium for Battery Innovation in US by collaborating with institutes like the Pacific Northwest National Laboratory. The research work is focused on improving performance bipolar lead acid batteries and fast charging EVs.

Table 3: List of ongoing R&D in advanced lead acid batteries (non-exhaustive)

Sl. No.	Ongoing Research	Institute	Details
1.	Novel testing and evaluation for EV fast charging	National Renewable Energy Laboratory (NREL) (Colorado, USA)	• NREL is testing and evaluating five different lead acid battery systems in behind the meter storage (BTMS) for fast charging of EVs

Lithium-ion battery

The research areas for lithium-ion batteries include manufacturing improvements, safety, improvement in material properties, reducing cobalt content, stability, and cell design. The research and development work done by various institutes are captured below:

Table 4: List of ongoing R&D in lithium-ion batteries (non-exhaustive)

Sl. No.	Ongoing Research	Institute	Details
1.	Nickel-rich Cathode and Ionic Liquid Electrolyte enable good stability and high energy density	Helmholtz Institute of Ulm (HIU) (Baden-Wurttemberg, Germany)	• New combination of materials: Cobalt poor Nickel rich cathode (NCM88) and nonvolatile, poorly flammable dual anion Ionic Liquid Electrolyte (ILE) • High energy density:560 Wh/kg based on the total weight of active materials. • Capacity Retention after 1000 cycles: 88%
2.	Developed cathodes in Li ion battery using a new class of materials	Berkeley National Laboratory (California, USA)	• Developed cathodes using disordered rock salts with excess lithium (DRX) made from inexpensive and abundant metals. • Energy density: Same if not higher than current models • DRX cathodes can use any metal in place of nickel and cobalt
3.	Improved the safety of lithium-ion batteries operating with gas electrodes by developing a new separator which keeps the gas-based electrolytes from vaporizing	University of California San Diego (California, USA)	• The battery separator was built out of a metal-organic framework which is a porous, crystalline material. It is filed with tiny pores that can trap the molecules of fluoromethane and condense them at relatively lower pressures. • Tested in a lithium-ion battery at a pressure of 70 psi which is far lower than what is required to liquefy fluoromethane and the cells could retain 57% charge at -40°C. • Cathode: Carbon fluoride • Anode: Lithium metal
4.	Extensive search for Cation substitution in lithium-ion batteries to improve discharge capacity	Japan Advanced Institute of Science and Technology (Nomi, Japan)	• Relatively inexpensive techniques were used such as density functional theory and cluster expansion for cation replacement. SCAN functional was further applied to test the reliability and accuracy in voltage predictions.

Sl. No.	Ongoing Research	Institute	Details
			• Nickel partially substituted with Platinum and Palladium in a nickel-based lithium-ion battery had the highest discharge capacity
5.	Organosilicon Electrolyte in Li-ion Batteries	University of Wisconsin Madison (Wisconsin, USA)	• Electrolyte used: OS3. It is an advanced electrolyte solvent which stabilizes lithium salt and carbonate cosolvents in solution preventing their decomposition during the fast charge operation • It showed a lower gas generation, lower impedance, and a higher capacity in the fast charge test protocol
6.	NanoBolt lithium tungsten batteries (Fast recharging)	N1 technologies (Belize, Central America)	• Researchers at N1 technologies, Inc. added tungsten and multilayered nanotubes of carbon which bond to the copper anode substrate and build a web like structure. Hence more ions get attached during recharging and discharging cycles due to a huge surface • This makes recharging faster and stores more energy as well.
7.	Preventing oxygen release leads to safer and high-density Lithium-ion batteries	Tohoku University and Japan Synchroton Radiation Research Institute (Sendai, Japan)	• Oxygen release from cathode is a thermal runaway trigger. Researchers further investigated the oxygen release behavior and the structural changes in the cathode materials due to this. • Based on the research, it was proposed that the high valent transition metals in oxide-based battery materials destabilize lattice oxygen
8.	Lead as an alternative to graphite for the anode material	US Department of Energy Argonne National Laboratory (Illinois, USA)	• Graphite anode was replaced by lead nanoparticles embedded in a carbon matrix and further enclosed by a shell of thin lead oxide. • After 100 cycles of charge-discharge, the new anode of lead-based nano composite attained double energy storage capacity as compared to that of graphite anodes.
9.	Gold nanowire gel electrolyte batteries	University of California, Irvine (California, USA)	• Researchers tried coating gold nano wires with Manganese dioxide and covered them up with electrolyte gel. • On charging them, it was discovered that it held charge up to 200000 cycles as compared to 6000 cycles in a conventional battery.

Other batteries

Amongst other batteries, most of the research is restricted to solid state batteries and Nickel Metal Hydride batteries are these two batteries are good alternatives to lithium-ion batteries. While Nickel Metal Hydrides are still used in EVs, solid state batteries can replace lithium-ion batteries in the long run. The research on these batteries have been capture below:

Table 5: Current status of R&D in solid state and NiMH batteries (non-exhaustive)

Sl. No.	Ongoing Research	Institute	Details
1.	Long lasting stable solid-state lithium battery	Harvard John A Paulson School of Engineering and Applied Sciences (Boston, USA)	• A stable lithium-ion solid state battery has been designed by researchers which can be charged and discharged at least 10000 times and at a high current density. This could increase the lifetime of EVs up to 10-15 years (similar to gasoline batteries). With its high current density, it is a pathway to the future for fully charging EVs in 10-20 minutes • To enhance stability, a multilayer battery was designed with anode followed by a coating of graphite followed by two electrolytes and then the cathode. The first electrolyte is more stable to lithium but is not immune to dendrite penetration. The second electrolyte is less stable with lithium but immune to dendrite penetration.

Sl. No.	Ongoing Research	Institute	Details
2.	Development of Lithium Sulfur Solid State Battery in Multi-layer pouch cells	Fraunhofer Institute for Material and Beam Technology IWS (Dresden, Germany)	• This research focused on working on a promising concept and driving it towards industrial application. Low material costs of sulfur and high storage capabilities of Lithium-Sulfur solid-state batteries enables the construction of cost-effective and very light weight batteries. The research focuses on developing batteries with multiple electrode layers and then evaluating them in an application-oriented manner.
3.	Improving ionic conductivity using the electrostatic interface of polymer electrolytes	Pohang University of Science & Technology (Pohang, South Korea)	• Researchers have found a way to solve lower mobility of ions in the dead zone existing in two dimensional morphologies by developing a novel block copolymer electrolyte. A new nanostructured electrolyte was developed by controlling the electrostatic interactions in the polymer electrolyte. • The new electrolyte showed enhanced conductivity as compared to other two-dimensional structures. This could lead to production of safe solid-state batteries and their commercialization.
4.	Using a solvent assisted process to alter the microstructure of the electrode for improvement in organic solid-state batteries	University of Houston (Houston, Texas)	• Researchers improved the electrode level energy density in OBEM cathodes by ensuring improved ion transfer within the cathode and thus optimizing the cathode microstructure. Further solid electrolyte or ethanol solvent was used in combination with lithium anodes to improve energy density, prevent short-circuit and enable fast charging • Utilization rates of active materials improved to 98% as compared to 50% previously. The energy density of the dry-mixed microstructure was 180 Wh/Kg as compared to 300 Wh/Kg by solvent assisted microstructure.
5.	Spreadable interlayer improves the current density by ten-fold while also improving performance and safety	Chalmers University of technology (Gothenburg, Sweden)	• Researchers are working on a soft, spreadable, "butter like" interlayer, which is made of nanoparticles of ceramic electrolyte, LAGP and further mixed with an ionic liquid which encapsulates the LAGP particles, thereby making the interlayer soft and protective. • The interlayer ensures stability and can withstand much higher current density. The stability is important as solid-state batteries are not stable enough at high current densities. This research could pave a way for improving the stability at higher current density.
6.	Controlling the atomic alignment of solid materials to improve the interface of cathode-solid electrolyte and stability in solid state batteries	University of Illinois (Illinois, USA)	• The research is focused on improving the cathode-solid electrolyte interface and stability in solid-state batteries by demonstrating control over the atomic alignment of solid materials. Electrodes containing sodium and lithium ions were built with specific atomic arrangements. Further research showed correlations between the battery performance and the interface atomic arrangements of sodium and lithium-based batteries.
7.	New method for recycling old batteries can provide better performing and cheaper rechargeable NiMH batteries	Stockholm University (Stockholm, Sweden)	• The new method of recycling older NiMH batteries focuses on directly using upcycled materials in new battery productions. The new method consists of mechanical washing followed by separating corrosion products and reusable electrode materials.

Research by Indian laboratories

In India, most of the research developments in EV battery technology is around lithium-ion technology. Institutions such as Centre for Automotive Energy Materials (CAEM), IIT Bombay, etc. are currently researching on improving the overall performance of the lithium-ion batteries used for mobility application.

Table 6: List of ongoing R&D in EV batteries in India (non-exhaustive)

Sl. No.	Ongoing Research	Institute	Details
1.	Development of Li-ion batteries for EV application	Centre for Automotive Energy Materials (CAEM)	• The core objective of this research is to establish the Li-ion technology using standard materials and demonstrate off-line/on-board vehicle testing. • CAEM is also working on developing high voltage/new materials will be developed indigenously. The promising materials will be optimized and scale-up for process technology.
2.	In-situ carbon coating technique for layered oxide cathode materials for Li-ion battery	Centre for Automotive Energy Materials (CAEM)	• CAEM is working on using uniform carbon coating on electrode materials for Li-ion battery to increase the cyclic stability of lithium-ion cells.
3.	High voltage carbon encapsulated-graded LiNi1-x-yMnxCoyO2 and LiNi1-x-yCoxAlyO2 cathode for rechargeable Li-ion pouch cells	Centre for Automotive Energy Materials (CAEM)	• The practical achievable capacity of LiNi1-x-yMnxCoyO2 and LiNi1-x-yCoxAlyO2 cathode materials is restricted to 150-200 mAh/g; CAEM is working on improving the reversible capacity of up to 250 mAh/g.
4.	Electrochemical energy storage materials for powering electric vehicles	IIT Bombay	• In order to overcome the safety and performance barriers (poor power density, energy density, cyclic stability, and safety) in existing electrochemical technologies, IITB is in the process of developing nanostructured electrode materials in order to build electrodes having improved energy density, rate capability and safety.
5.	State of the art Hybrid Energy Storage System (HESS) based high-power high-speed Electric Vehicle (EV) drive train for a Multi Utility Vehicle (MUV)	NIT Rourkela	• Sponsored by SERB (Science and Engineering Research Board), DST (Department of Science and Technology) • Design, development and prototyping of state-of-the-art Hybrid Energy Storage System (HESS) based high power high speed Electric Vehicle (EV) drive train for a Multi Utility Vehicle (MUV)
6.	Indigenous technology for synthesizing LTO anode for fast charging EV vehicles	International Advanced Research Center for Powder Metallurgy and New Materials (ARCI)	• ARCI team used TiO_2 and Li_2CO_3 as precursors to improve electronic conductivity of LTO anode through a simple, energy efficient and economically scalable production method. The high energy milling method has a few advantages such as: low contamination, short processing time, short processing time, high energy input and high relative velocity of balls. The performance was validated in half cell and has high specific capacity and long cyclic stability.
7.	Supercapacitor based battery technology	Log 9 materials	• Log 9 materials used it core competence of graphene and know-how of supercapacitor technology to develop this battery. It claims that the battery can be fully charged in 15 minutes and has a lifetime of 15 years. This battery also provides five times the power of a conventional lithium-ion batteries. It is five times safer in terms of impact resistance and fire resistance as well. The range for electric 2 wheelers and 3 wheelers promised is 70 kms and 60-80 kms respectively. Log 9 materials have commenced partnership with logistics, e-commerce, and mobility-based companies to target the last mile delivery in B2B segment. Trial runs of these batteries are going on as well in several cities of India. These batteries also provide peak performance across a broad range of temperatures: -30°C to +60°C.
8.	Graphene Battery	Samsung SDI	• Samsung has developed graphene balls which boost the capacity of its lithium-ion battery by 45%. It recharges five times faster as compared to current batteries. Samsung claims that these batteries can be recharged in 12 minutes. It is currently used in smartphones, but Samsung claims that its wide operating temperature range and its ability to withstand temperatures over 60° C could make it useful for electric vehicles as well.

Sl. No.	Ongoing Research	Institute	Details
9.	Smart swappable batteries	Ipower Batteries Pvt ltd	• Ipower is using smart technology solutions to promote the battery swapping ecosystems in India. The lithium-ion batteries developed are modular, lightweight, tamper and theft-proof. They can be operated across multiple vehicle platforms. It also supports live monitoring through its computing power, built in GPRS and SIM. Other features include geo fencing, remote monitoring and control features, battery immobilization and advanced tracking.
10.	Technology using advanced nanomaterial composites	Gegadyne Energy	• This technology using advanced nanomaterial composites will offer longer lifecycles and higher energy density while maintaining high safety standards. It also enables the ultra-fast recharging of batteries: 0-100% in 15 minutes. Unlike lithium-ion batteries, the raw materials for this technology can be sourced domestically as well thereby reducing import dependencies.
11.	Indigenously designed Lithium batteries	Inverted Energy	• Inverted Energy has developed a new range of lithium batteries which are designed and engineered indigenously. These batteries are 20% more efficient as compares to current commercial traction batteries. This battery can be used in EVs, utility power, solar plants and home storage applications. The manufacturing will be carried out in the company facility in Okhla. This battery technology will be one of the first lithium-ion batteries to be used in home storage applications.
12.	Transfer of lithium-ion cell technology developed by VSSC to industries	ISRP	• ISRO's VSSC has succeeded in developing and qualifying lithium-ion cells with capacities ranging from 1.5 Ah to 1000 Ah to be used in satellites and launch vehicles. VSSC is now planning to transfer technology to industries to set up production facilities and foster production of lithium-ion cells to meet the power storage requirements of India. VSSC has tested this technology in various applications. VSSC has also mentioned the successful application of 50 Ah VSSC li-ion cells in an electric scooter

1.4 Battery technology outlook

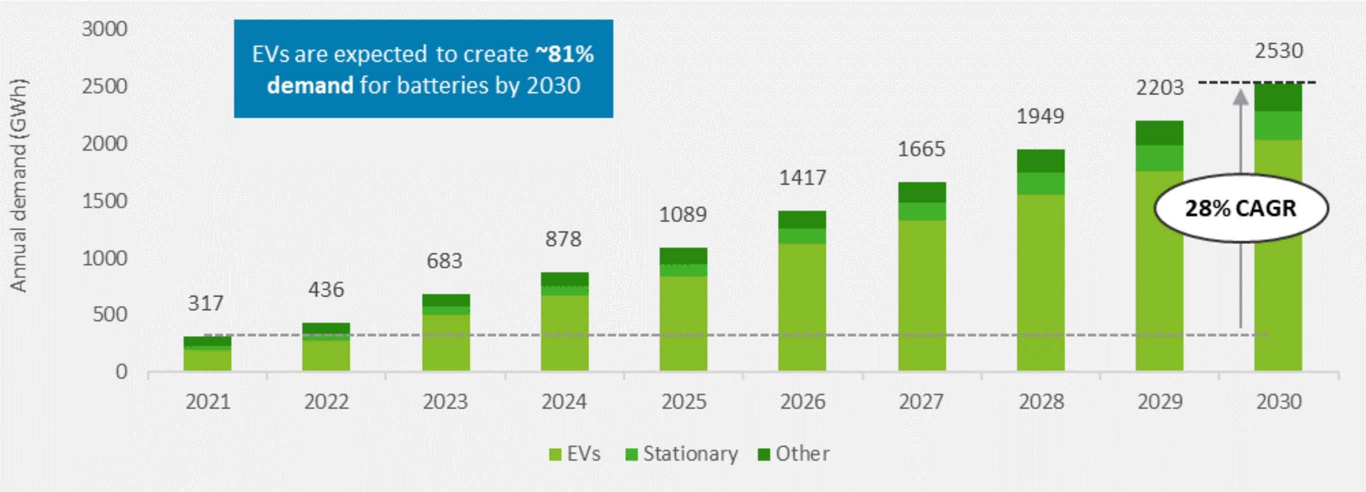
Electric vehicle has emerged as a promising technology to attain global decarbonization goals. Instead of fossil fuel, these vehicles run on charged batteries. Their large-scale adoption has also infused growth in battery industry in the last decade. As reported by World Economic Forum[29], in 2018, 77% of the global battery demand was accounted by electric vehicles (142 GWh out of 184 GWh).

The growth in adoption of electric vehicles is anticipated to continue in the current decade as well. Bloomberg in its Electric Vehicle Outlook 2021[30] report, projects that passenger EV sales will reach 14 million by 2025 from 3.1 million in 2020. With the positive EV outlook, battery demand by 2030 is also expected to be largely influenced by electric vehicles.

CES (Customized Energy Solutions) estimates that the global demand for batteries will exceed 2,500 GWh per annum by 2030. Year on year trend of the demand is provided in figure below.

[29] Source: WEF – A Vision for a Sustainable Battery Value Chain in 2030 (access here)
[30] Source: Bnef – Electric Vehicle Outlook 2021 (access here)

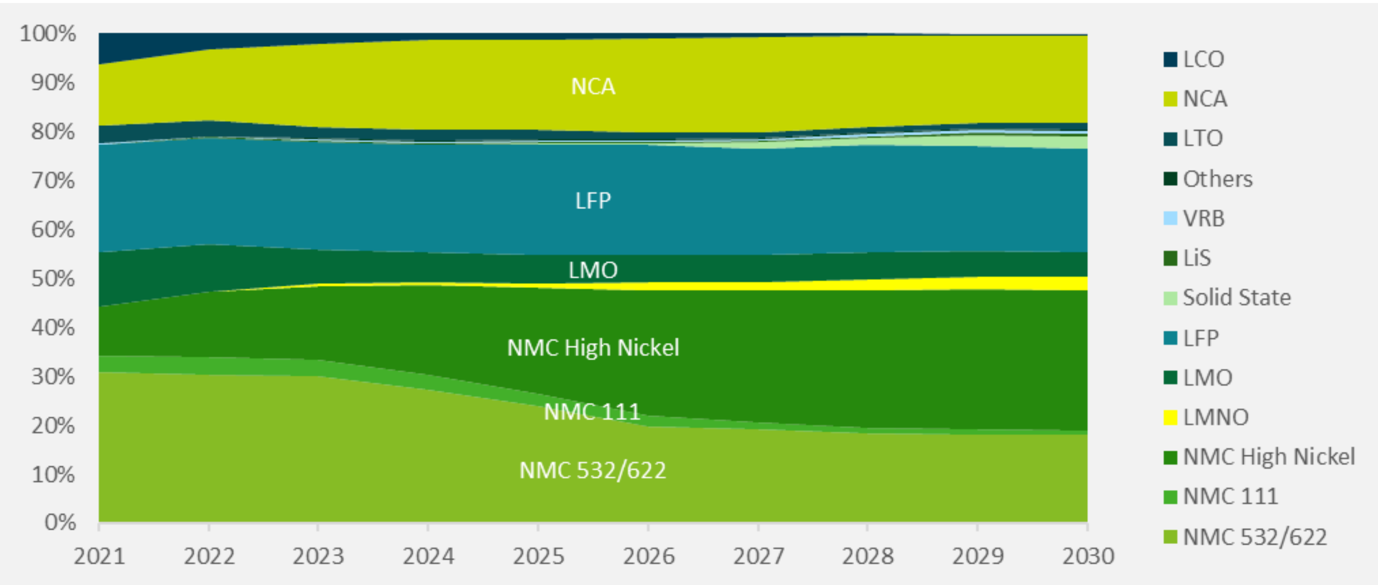
Figure 14: Global annual battery demand (GWh) - application-wise



Source: Customized Energy Solution (CES)

Lithium-ion chemistries are expected to have the greater share by 2030 with technologies such as sodium-sulfur and solid-state slowly getting adopted at the later end of the decade. Higher rate of adoption of lithium-ion batteries can be accounted due to possible decrease in lithium-ion battery prices which are expected to reach US$58/kWh by 2030 as per Bloomberg[31].

Figure 15: Technology-wise share in overall battery demand

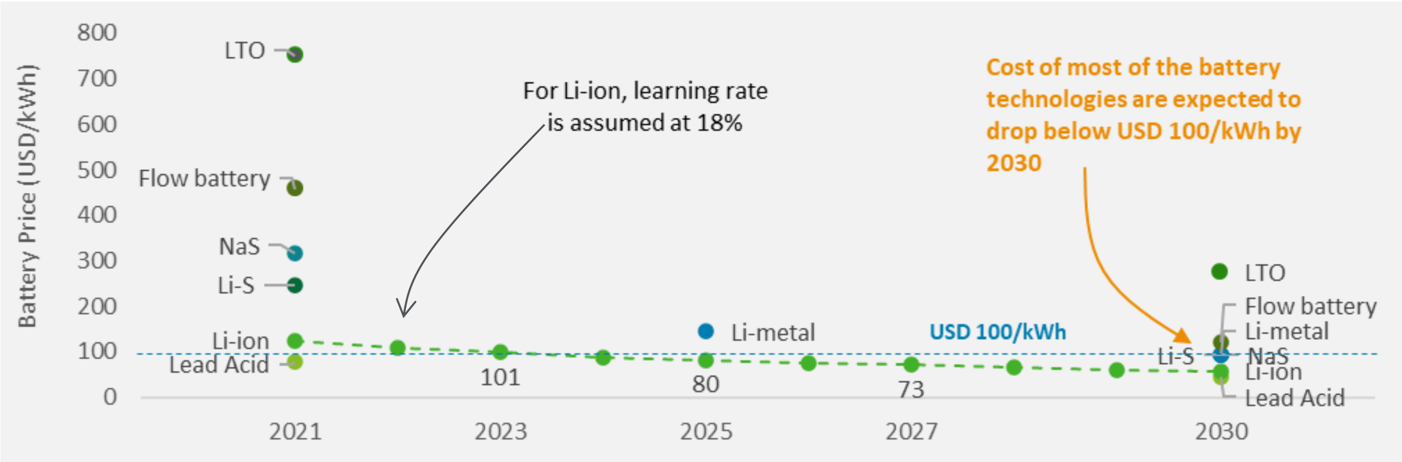


Source: Customized Energy Solution (CES)

As far as the cost projections of the battery technology goes, Li-ion technology is expected to fall below the USD 100/kWh mark in this decade. Also, technologies such as flow batteries, lithium-sulfur are expected to witness massive drop in their prices. Average drop across all the technologies is expected to be ~10% CAGR from 2021 to 2030. Detailed figure charting out the projected decline in battery prices is presented below.

[31] Bnef – Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh (access here)

Figure 16: Outlook on battery technology prices (USD/kWh) by 2030



Note: Battery prices highlighted in the figure are the average prices of all the chemistries under the given technology.
Source: Bnef, Deloitte analysis

Lithium-ion technology is expected to dominate the global EV battery industry for the next decade with next gen NMC, NCA and LFP chemistries leading the way; however, considering the competitiveness in the EV industry, cost will play a crucial role in their individual share of the market.

1.5 Battery demand from EVs in India

At present, EV sales penetration in India is ~1%; however, with the supporting schemes and policies such as FAME II and PLI, large scale adoption of EVs can be seen happening in medium to long term. The FAME II scheme is supporting uptake of electric vehicle by providing upfront subsidy to the consumers for purchase of electric vehicles. The PLI Scheme for Automobile and Auto components was launched to establish a manufacturing ecosystem for electric vehicles and associated components in the country.

Indigenous manufacturing supported with PLI subsidy will help reduce the cost of electric vehicles in India and help EVs attain parity with conventional ICE vehicles. Low cost of electric vehicles coupled with upfront subsidy on purchase will make EVs an attractive buying decision for the consumers.

Considering the impact of PLI and FAME II scheme, we created three possible scenarios to estimate the yearly sales of EVs in India by 2030.

Overall EV Sales Penetration (%)

Low growth

	2025	2030
Overall EV Sales Penetration	6%	20%

Medium growth

	2025	2030
Overall EV Sales Penetration	7%	30%

High growth

	2025	2030
Overall EV Sales Penetration	9%	40%

Note: Growth rate in automobile industry is referred from last decade's growth rate (2011-2020)

Further breaking down the overall sales penetration to segment level, we believe that the sales of e-2W and e-3Ws will outpace all other EV categories. This is because these categories will not be reliant on deployment of public EV charging stations which is currently one of the biggest hinderance in the adoption of electric vehicles. Category-wise breakup of EV adoption rate is provided in the below image:

EV adoption rate (% of total sales)

Low growth

	2025	2030
Passenger Vehicle	1.3%	10.0%
Commercial Vehicle (w/o bus)	0.8%	6.5%
Buses	0.8%	8.5%
Three wheeler	12.5%	32.5%
Two wheeler	6.5%	21.0%

Medium growth

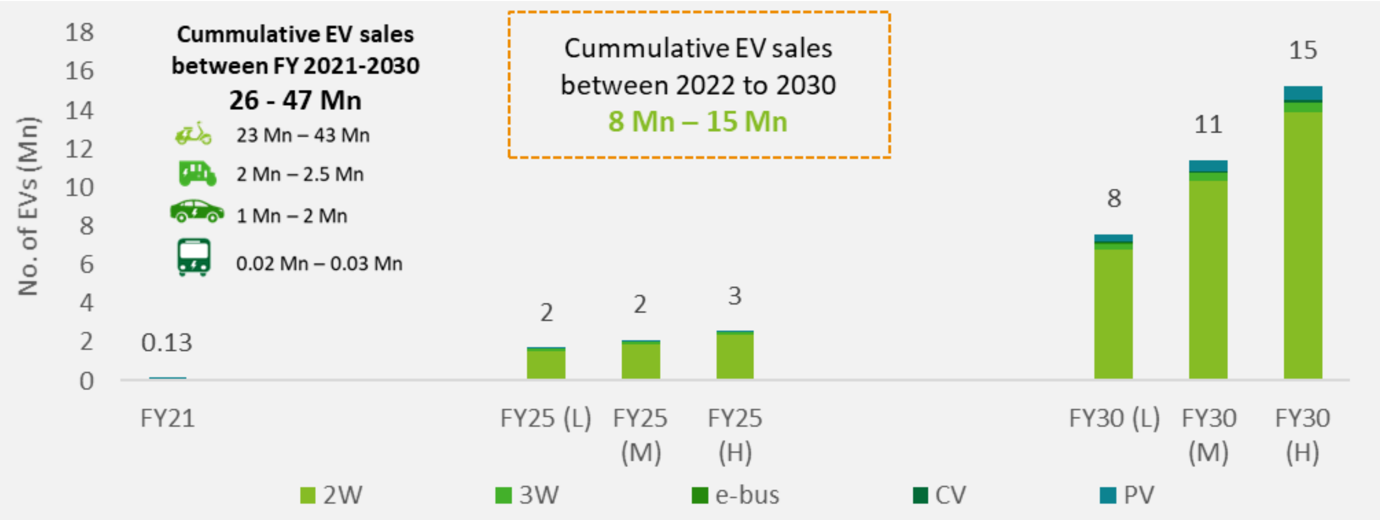
	2025	2030
Passenger Vehicle	1.4%	15.0%
Commercial Vehicle (w/o bus)	0.9%	8.0%
Buses	0.9%	10.0%
Three wheeler	13.5%	40.0%
Two wheeler	8.0%	32.0%

High growth

	2025	2030
Passenger Vehicle	1.5%	20.0%
Commercial Vehicle (w/o bus)	1.0%	10.0%
Buses	1.0%	12.0%
Three wheeler	15.0%	50.0%
Two wheeler	10.0%	43.0%

Using the EV adoption assumptions, the yearly sales of EVs are calculated for each scenario which is highlighted in the below figure:

Figure 17: Yearly EV sales in FY2025 and FY2030



Note: CV – Commercial Vehicle; PV – Passenger Vehicle; L: Low growth scenario; M: Medium growth scenario; H: High growth scenario
Source: Deloitte analysis

From the estimation, it can be seen that, by 2030, E-2W segment will dominate India's EV market contributing 87-89% in overall sales. The E-4W segment is likely to become the second biggest market vis-à-vis sales after E-2W. The growth of E-4W largely depends upon the availability of charging infrastructure and demand is expected to pick as the deployment of charging infrastructure across the country increase.

Each EV category uses a different battery size. We have assumed range for each vehicle category to determine the overall market size for batteries from EVs. Assumed battery size ranges are provided in the table below.

Battery size assumption

Category	2W	3W	4W (Passenger)	4W (Commercial)	Buses
Battery size (kWh)	2.5 (Low) – 4.5 (High)	4.5 (Low) – 10 (High)	20 (Low) – 45 (High)	35 (Low) – 75 (High)	150 (Low) – 250 (High)

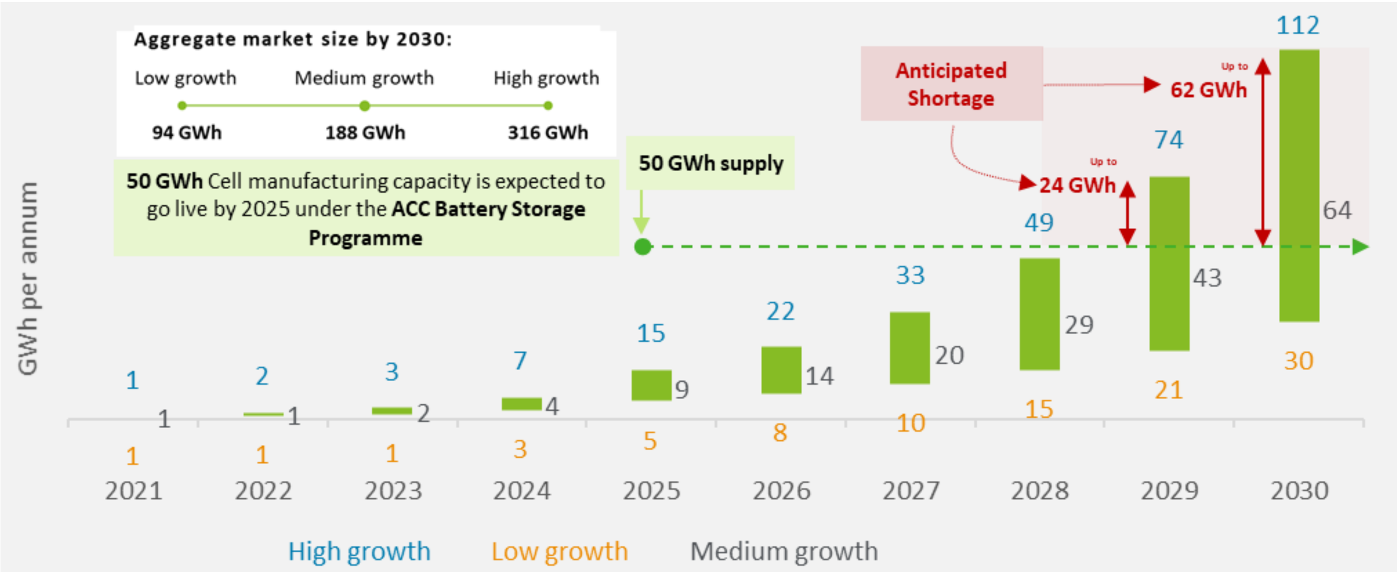
Taking the estimated battery size, it is observed that, by 2025, overall battery demand from EVs will be between 5-15 GWh which will further increase to 30-112 GWh by 2030. By 2025, the EVs are expected to achieve parity with the ICE vehicles thereby faster adoption of EVs post 2025 is expected.

From the supply side, India is targeting 50 GWh of domestic battery cell manufacturing capability by 2025[32]. Assuming that India successfully commissions 50 GWh of battery cell manufacturing industry by 2025 and there are no further battery manufacturing

[32] National Programme on Advanced Chemistry Cell Battery Storage (access here)

establishment in the country, the industry is expected to experience battery shortage after 2029. By 2030, the expected shortage in battery supply may reach up to 62 GWh. Figure 18 below represents the yearly battery demand from EVs and supply scenario:

Figure 18: Yearly battery demand from EV sales and supply scenario (GWh/annum)



Note: Best case scenario is considered assuming complete 50GWh capacity allocated under the ACC Battery Storage Programme go-live by 2025 itself; It is also assumed that there will be no additional battery manufacturing setup in India beyond 50GWh under ACC PLI scheme

Considering the anticipated size of the market for batteries in India from EV application, more announcements for setting-up battery/ cell manufacturing in the country by domestic as well as global players can be expected in the near- to medium-term

1.6 Battery ecosystem players

The typical ecosystem of battery industry can be presented in three levels: 1. Ecosystem enablers; 2. Supply players; and, 3. Demand players.

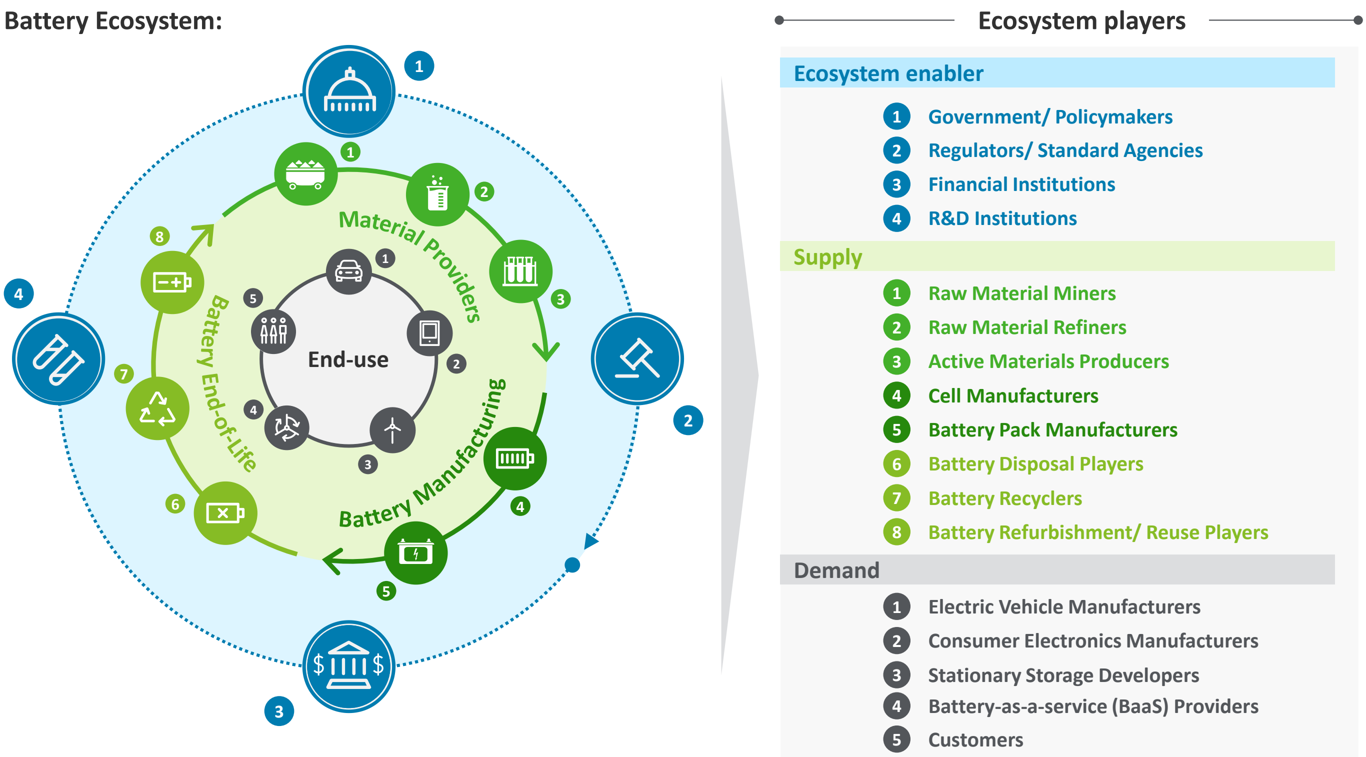
The **ecosystem enablers** have influence over the entire battery value chain – be it the policymakers, regulators or the financial institutions. R&D players are also ecosystem enablers as they play vital role in improving the technology, performance and cost of battery technologies.

The **supply players** are responsible for meeting the battery demand. These players play a direct or indirect role in battery production/ supply. This category has the maximum number of stakeholders starting from raw mineral miners to battery pack manufacturers to battery refurbishment/ reuse players.

The **demand players** are at the extreme end of the ecosystem. These players are responsible for creating the demand for battery storage in the market. These players can be classified into three key categories: EV manufacturers, consumer electronics manufacturer and stationary storage solution providers (such as grid service, RE integration, power backup etc.).

An illustration of the battery ecosystem along with associated players in presented in the figure provided below:

Figure 19: Illustration of a battery ecosystem and associated players



Source: Deloitte analysis

Indicative roles and responsibilities of ecosystem players is provided in the table below:

Table 7 Roles and responsibilities of battery ecosystem players

Sl. No	Stakeholders	Roles and Responsibilities
a.	Ecosystem enabler	
1.	**Government/ Policymaker**	• Develop/ promote battery ecosystem by designing supportive policies to promote battery value chain participation and end-use demand.
2.	**Regulators/ Standard agencies**	• Responsible for regulating both supply and demand ends of battery storage market. Standard agencies formulate standards to guide on safety, handling, usage etc. of battery technologies.
3.	**Financial Institutions**	• Helps in providing the necessary financial impetus to the value chain players in allowing higher investments in the battery value chain.
4.	**R&D Institutes**	• Responsible for conducting continued research on the battery technologies, material, chemistries etc. and improving the overall capability/ performance of batteries.
b.	Supply players	
5.	**Raw material miners**	• Responsible for mining the critical battery minerals such as lithium, nickel, cobalt, manganese, graphite etc.
6.	**Raw material refiners**	• Responsible for removing the unwanted impurities from the mined ore and increasing the concentration of the core mineral.
7.	**Active materials producers**	• Responsible for creating the active materials for cathode (such as LFP, NMC, NCA etc.) and anode (coated spherical graphite, synthetic graphite etc.)

Sl. No	Stakeholders	Roles and Responsibilities
8.	**Cell manufacturers**	• Responsible for manufacturing battery cells using the active materials and other components.
9.	**Battery pack manufacturers**	• Responsible for grouping the modules along with control or protection systems including a BMS, cooling system etc. to prepare battery pack.
10.	**Battery disposal players**	• Responsible for disposing unwanted components of a spent battery safely.
11.	**Battery recyclers**	• Responsible for smelting the spent battery and recovering essential battery minerals.
12.	**Battery refurbishment/ reuse players**	• Repurposing the battery to suit fewer demanding applications after reaching the end of useful life in EVs. Responsible for converting the spent batteries into in usable state and reuse the same for second-life applications (such as grid service, power backup etc.)
c.	**Demand players**	
13.	**Electric vehicle manufacturers**	• Purchase batteries to manufacture electric vehicles.
14.	**Consumer electronics manufacturers**	• Purchase battery to manufacture electronic device (such as mobile phone, laptop etc.)
15.	**Stationary storage developers**	• Purchase battery packs and creates integration solutions for battery with renewables or grid.
16.	**Battery-as-a-service (BaaS) Providers**	• Helps end-use consumers in bearing the upfront cost of battery by providing services such as battery leasing, battery swapping etc.
17.	**Customers**	• The end use stakeholders who purchase & use batteries for various applications such as power backup, consumer electronics etc.

Battery Standards

Chapter 2. Traction batteries Standards – Global & India

The last decade has experienced critical innovations in the field of battery technology. Lead-acid batteries, which are essentially the most commercialized technology so far, is gradually being replaced by Lithium-ion batteries (Lithium Iron Phosphate-LFP, Nickel Cobalt Manganese-NMC, Lithium Cobalt Oxide-LCO etc.) in most applications. The advanced batteries are not only superior in energy density (Wh/kg), but they also have longer cycle life and are suitable for multiple applications.

The chemical composition in a battery determines the efficiency, energy density and suitability of applications. While most of the battery technologies are commercialized currently, many of the chemistries are still under R&D stage. For instance, lead acid, Lithium-ion batteries, Nickel cadmium batteries, etc. have been use for quite some time now and have been matured.

Technologies like NMC, NCA, LMO, LTO, etc. belonging to the Lithium-ion family, although commercialized, are still under R&D for improving their performance, energy densities and other specifications. Finally, there are technologies like Metal Sulphur, Lithium metal, Metal-air, Solid state batteries and some chemistries from the Lithium-ion family, etc. that are presently in R&D only and not entirely proven.

In the wake of the evolving landscape of cell chemistries, automotive OEMs have been exploring how to ensure advanced chemistries make way for application in electric vehicles. A key aspect of such evaluation is to ensure standardized methods to measure performance, safety and extent of abuse tolerance of such batteries & cells. This is because traction applications make the battery subject to extreme climatic, environmental and stress factors.

To ensure customer confidence in such chemistries, it is essential to ensure such battery chemistries can perform well in Indian conditions. With regards to the above, it is necessary to carry out a review of the existing Indian standards and international standards for traction related applications and understand their coverage.

Bureau of Indian standards is the designated authority for formulating / adopting standards for electric vehicle batteries in India. Globally, the major organizations who specify standards include:

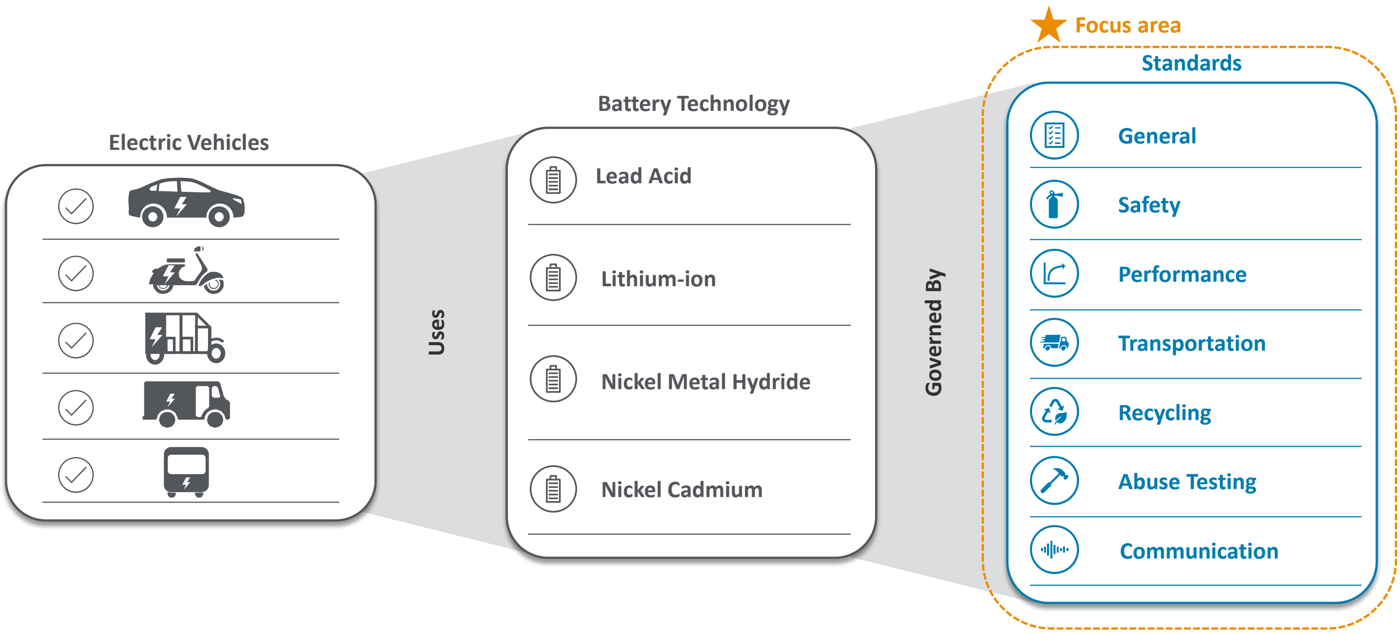
1. International Electro-technical Commission
2. Underwriters Laboratories
3. International Standards Organization
4. CENELEC (European Committee for Electrotechnical Standardization)
5. Institute of Electrical and Electronics Engineers
6. Society of Automotive Engineers

Development of standards have been instrumental in the uptake of various battery technologies around the world. These standards provide much needed reference points and guidance for R&D, safety, performance, testing of various battery chemistries. With the increasing adoption of EV envisaged across the world and in India, the need for harmonized acceptance of standards is necessary to keep the EV revolution on track as more and more advanced battery technologies with higher performance characteristics enter the market. This is also essential because presence of adequate methodology for testing the performance and safety features of batteries instils consumer confidence in such technologies.

2.1 Categorization of battery standards for EVs

For the purpose of better understanding, battery standards have been categorized into various buckets viz. general, performance, safety, transportation, abuse testing and recycling standards. Standards for communication of battery with external systems have also been covered.

Figure 20 Approach for standards review



General standards cover basic requirements for batteries such as dimensions, necessary markings for identification, specifying the intended application of the batteries and the vehicle segment the battery can be used for, if necessary. In a nutshell, these standards specify the general requirements for any battery to be used for electric vehicle traction applications.

Performance standards help in determining whether the products meet the minimum performance specifications declared by the manufacturers. These standards mention a wide spectrum of tests to measure energy density, capacity, power density, internal resistance, storage or charge retention capacity, cycle life, energy efficiency, etc. Procedure for measuring these parameters vary based on the chemistry of the cell.

Safety assessment involves a myriad of tests that a battery must pass to certify that it will not be hazardous to the users. These outline various test procedures to demonstrate that the batteries are electrically and mechanically safe for the intended application. A variety of tests are specified in these standards to ensure that there is no fire, explosion, rupture, leakage, etc. which might result in unforeseen and dangerous consequences.

Tests such as short-circuit tests have associated timings with them to assess the variability of battery parameters such as voltage, current, and temperature across the time period. The timings vary from organization to organization based on the limiting ranges set by them in their standards. Similarly, the frequencies in vibration test are so defined to mimic the vibrations during vehicle operations which are subject to the standards organization preferences.

Abuse testing standards are an extension of safety standards which test the battery cells and packs in abusive conditions such as overcharging, short circuit, physical deformation. Such abusive conditions generally are efforts to replicate the instance of a vehicle crash which may trigger exothermic reactions in cells leading to thermal runaway and fire hazards and other failures.

Recycling standards specifies how the recyclers should utilize batteries, which have achieved their end-of-life, for second life applications. Moreover, batteries of any chemistry are hazardous in nature. It is necessary to have proper guidelines and regulations for transportation or shipping of batteries. **Transportation standards** serve this purpose as they help in guiding various manufacturers, recyclers, users in proper handling of batteries.

Reuse standards specifies the requirements for repurposing battery systems, battery packs, modules, and secondary cells. These standards also specify the procedure to evaluate performance and safety parameters for battery reuse along with providing a general guidance for reusing batteries and secondary cells

In the subsequent section, we cover the various international and India standards associated with lead acid, lithium-ion and nickel metal hydride chemistries. Detailed operational parameters have been provided for some of the standards to provide a like to like comparison amongst standards and their applicability in Indian conditions.

2.2 International and Indian battery standards

Standards for Lead Acid chemistry

A brief overview of global and Indian standards for lead acid chemistry is shown below:

Table 8: Snapshot of Lead Acid traction battery Standards

	General	Performance and Lifecycle	Safety	Transportation	Recycling
Global	IEC 60254-2:2008, IEC 62902:2019, EN 60254-2:2008, QC/T 989-2014, QC/T 1023-2015	IEC 61982:2012, J1798, J2758, J1634, J2288, IEC 60254-1:2005, IEC 63193:2020	IEC 62485-3:2014, EN 61982-4:2016, J2289, J1495, QC/T 989-2014, ISO 6469-1:2019, J2289, J1495, UL 2271	QC/T 989-2014, SAE J2289	EN 61429:1996, IEC 61429:1995, J3071, J2984
Indian	IS 5154-2:2013	IS 13514: 2015, IS 5154: Part 1: 2013	AIS 048, IS 16894: Part 3: 2018	IS 16894: Part 2: 2018	-

General standards

The table below captures the scope and coverage of multiple global and Indian standards.

Table 9: General Standards for Lead Acid Traction Batteries

Sl. No	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC, CENELEC**	**IEC 60254-2:2008**	**Global**	• The objective of the standard is to provide guidance on: ○ the maximum external (overall) dimensions of traction battery cells ○ the form of the marking of traction battery cell polarity and dimensions of corresponding symbols ○ the basic dimensions of some commonly used traction battery terminals designed to connect output cables to the battery ○ the dimensions of cells commonly used in Asia and North America
2.	**IEC**	**IEC 62902:2019**	**Global**	• This standard specifies methods for the clear identification of secondary cells, batteries, battery modules and monoblocs according to their chemistry (electrochemical storage technology). • This standard is applicable for secondary cells, batteries, battery modules and monoblocs with a volume of more than 900 cm^3. The standard covers the application of markings on the batteries, markings with and without recycling symbols, background colors, durability markings.

Sl. No	Organization	Standard	Type	Standard Description and Coverage
				• The standard covers all the relevant electric vehicle traction battery chemistries namely lead acid, nickel cadmium, nickel metal hydride, lithium-ion, and lithium metal.
3.	**QC/T**	**QC/T 989-2014**	**Global**	• This standard specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification marks for transportation, storage and package of battery enclosure in the traction battery system of electric vehicles. • This is applicable to vehicle charging battery enclosure and swapping battery enclosure.
4.	**QC/T**	**QC/T 1023-2015**	**Global**	• The standard covers general requirement of traction battery system for electric vehicles. It also stresses upon the assembly of traction battery system, its component interfaces, identification markings, transportation and storage of lithium-ion batteries used in electric vehicles.
5.	**BIS**	**IS 5154: Part 2: 2013**	**Indian**	• The standard follows the IEC 60254-2: 2008 standard. The objective of the standard is to provide: • maximum external dimensions of traction battery cells • the form of marking the battery cell polarity and dimensions of symbols • the basic dimensions of some commonly used traction battery terminals designed to connect output cables to the battery • the dimensions of cells commonly used in Asia and North America.

Source: IEC, CENELEC, QC/T, BIS

The Indian standards for the general requirements of lead acid batteries have been referenced from IEC. The standards referenced viz. IEC 60254-2 cover necessary aspects for the battery specifications such as capacity, charge retention along with markings for batteries. Batteries need to be light-weight and compact so that they can be easily utilized in electric vehicles. Such standards are essential to ensure that batteries conform to physical characteristics suitable for traction related applications.

However, on closer inspection it can be observed that international standards such as QC/T cover requirements related to mechanical strength, environmental resistance and assembly. QC/T standards also include requirements for further components viz. vehicle charging battery enclosure and swapping battery enclosure which may be relevant for uptake of swapping business in India.

Performance standards

The standards for performance of traction batteries are covered by IEC, CENELEC and SAE. The Indian standards organization BIS has also covered the performance aspect of batteries by adopting relevant IEC standards.

IEC 61982 is one of the most widely accepted standards for assessing the performance of lead acid batteries used in electric vehicles propulsion. Overview of the standard is given below.

Standard: IEC 61982:2012[33]	
Scope and Coverage	• This defines the performance and endurance tests for secondary batteries (such as lead acid, nickel cadmium, nickel metal hydride and sodium-based chemistries) used in electric vehicles, including hybrid electric vehicles.

[33] Ruiz V., Standards for the performance and durability assessment of electric vehicle batteries - Possible performance criteria for an Ecodesign Regulation

Standard: IEC 61982:2012[33]

Key Operational Parameters	• An overview of the test requirements is given below. • **Energy and Capacity measurement**: At predetermined voltage and current for discharge, the batteries are discharged at one-third of the rated current i.e., C/3 at a temperature of 25 °C. To ensure that such measurement is done in actual driving conditions, the battery is put through power profiles (varying current profiles) until the battery gets discharged. • **Storage Capacity**: Battery is charge to 100% soc level and kept at rest for 30 days. This is done at different temperatures viz. 40, 25, and -20 °C. Once the resting period ends, the state of charge losses are observed to determine the storage capacity. • **Energy efficiency**: The round-trip efficiency is measured by discharging from a state of charge of 100% to 20% and again charging back to 100%. The charging and discharging rates for the test are specified by the manufacturer. The efficiency value is calculated as the ratio of the net energy delivered by the battery during a discharge test to the total energy required to restore the initial SoC. • **Cycle Life**: After determining the initial performance parameters stated above, the battery is put through continuous charge / discharge cycles. Discharging is done till 80% DoD. Once 80% level is reached, the battery is recharged within 1 hour and then discharged within 1 hour. After each 50 charge / discharge cycles, the state-of-health of the battery is determined. Test is terminated once the energy delivered reaches less than 80% of benchmark energy. Cycle life demonstrated till this state are calculated.

Other than IEC, SAE too has specified two standards applicable for performance and cycle-life testing of EV traction batteries. SAE J2288 as mentioned below covers all kinds of battery chemistries used in electric vehicles.

Standard: SAE J2288[33]

Scope and Coverage	• This standard covers procedures to determine the expected service life, in cycles, of electric vehicle battery modules based on a set of nominal or baseline operating conditions.
Key Operational Parameters	• The **performance characteristics** viz. rated energy capacity, efficiency, etc. are measured in a temperature range of 25 °C ± 2 °C. Battery module is discharged at C/3 till the specified discharge voltage or other cut off limits. The battery module is then charged as per the rated current and open circuit voltage specified by the manufacturer. The steps mentioned (from discharging to charging) are repeated until similar levels of capacity are measured with tolerance of 2%. • **Cycle Life**: Cycle life is determined after determining initial performance parameters such as energy capacity, efficiency, etc. At a temperature range of 25 °C ± 2 °C, the battery module is discharged to 80% depth of discharge (DoD) with multiple discharge rates. After 80% DoD is reached, the battery is fully recharged. The steps are repeated for 28 days. After 28 days, the initial performance parameters are once again determined, and the tests are terminated if the measured capacity drops to 80% of rated capacity or the peak power capability goes below 80% of its rated value at 80% depth of discharge.

Other than SAE J2288, SAE has a standard specific to lead acid (and Nickel metal hydride battery) modules. The details of the standard are mentioned under.

Standard: SAE J1798[33]

Scope and Coverage	• This standard specifies necessary tests to determine basic performance of EV battery modules • Coverage includes lead acid and nickel metal hydride batteries.
Key Operational Parameters	• **Energy capacity**: The standard specifies test parameters to determine static and dynamic capacity of battery modules. To determine static capacity, the modules are subjected to temperatures of 45, 25, 0, and -20 °C with discharge rates of 1C, C/2, and C/3. For determining the dynamic capacity, the battery module at a temperature of 25 °C is put through

Standard: SAE J1798[33]	
	a specific power profile (which is a characteristic of driving conditions through which a traction battery is subjected to) repetitively until the device under test is fully discharged. Based on the time taken to discharge, the energy capacity of the battery module is determined. • **Power and internal resistance**: The test requires subjecting the battery to 30 seconds of high-current pulse at 90% state of charge. The battery should be able to deliver sustained power for 30 seconds over its useable discharge capacity. Power is measured as product of the voltage and current magnitude • **Storage capacity loss**: This is measured at a temperature of 25 °C with state of charge adjusted to 100% and discharge at a rate of C/3. Once discharged, battery is subjected to a rest time of 2, 14, and 30 days. Once the resting period ends, the losses in the state of charge of discharged battery are observed to determine the storage capacity.

BIS has provided a standard IS 13514: 2015 dedicated to secondary batteries used for propulsion of electric vehicle focusing mainly on performance and endurance tests. The standard is based on IEC 61982: 2012 and covers all battery chemistries (lead acid, nickel metal hydride, nickel cadmium and sodium based) except lithium batteries. Overview of tests prescribed are mentioned below:

Standard: IS 13514: 2015[34]	
Scope and Coverage	• This standard specifies the general testing requirements (measuring instruments, provisions, test samples and temperatures, etc.), information on dynamic discharge performance test, dynamic endurance test, testing parameters for battery systems. • The standard also specifies various general provisions for the tests viz. current slew rate, temperature, and mechanical support.
Reference Standard	• The standard has been adopted from IEC 61982: 2012
Key Operational Parameters	• **Rated Capacity**: The battery is discharged at a constant current (specified by the manufacturer at a temperature of 25 °C). The discharge is continued till the battery reaches the voltage specified. Basis the time taken, the capacity is measured by taking the product of the current and time taken to reach the voltage. A maximum of 20 cycles are allowed for new batteries to achieve the rated capacity and as per battery type, they may also be tested at temperatures of 45, 0, -20 °C. • **Dynamic discharge test**: Batteries are subjected to repeated micro charging cycles for 60 seconds and three current levels simulating the operating conditions of electric vehicles. This is done under two conditions i.e., with and without regenerative charging. At the end of the cycles, the capacity of the is measured. • **Dynamic endurance test**: At a temperature of 25 °C ± 2 K, discharge cycles are carried out unless and until the actual capacity of the battery falls to 80% of initial capacity when tested. The motive of this test is to determine the number of discharge cycles accumulated until the actual capacity falls below the state range. The test is carried out in two scenarios viz. with and without regenerative charging. • **Charging efficiency test**: The test is carried out for batteries in three kinds of operations viz. charging efficiency during normal operation, rapid charging, and partial discharge. During this test, efficiency is calculated by recording the energy input to the battery and the energy output from the battery during each charge/ discharge cycle. For rapid charging efficiency, the battery is discharged to a state of charge of 40% and then it is rapidly charged to 80% state of charge and then the necessary readings are taken to calculate efficiency.

Batteries of electric vehicles have to withstand stress originating out of the manner in which vehicles are driven. Subjecting the vehicle to sudden acceleration, braking, driving up in an inclined path, frequent starts / stops in the road, etc. are some of the various driving profiles which a battery has to withstand. All these profiles affect the battery performance which can vary from the performance of a battery at normal use conditions. A battery must demonstrate satisfactory performance in all of these conditions.

[34] BIS – IS 13514: 2015 Standard Document

Tests specified by IEC and SAE take into account several of the above conditions to determine how a battery is performing at such driving conditions. Although the Indian standards for the performance requirement of EV traction lead acid batteries are referenced from IEC 61982 and are comprehensive, yet the following points may be looked at:

1) **Rated capacity could be measured at different charge / discharge rates as specified by SAE J1798**
2) **EV battery must be able to deliver rated power during high acceleration periods. Methodology for measurement of this could be adopted from SAE J1798. Storage capacity test specified by SAE J1798 could be utilized.**
3) **Electric vehicles could be subjected to long duration of idling and hence it is important to ensure batteries do not lose energy when kept at rest for long duration.**
4) **During driving conditions, battery should be able to deliver the minimum rated power. SAE J1798 specifies a test procedure for the same which can be adopted.**
5) **There is no methodology to measure cycle life of traction batteries in BIS standards. The same could be adopted from SAE J2288 / IEC 61982.**

Safety standards

The safety standards for lead acid batteries have been covered by the global standards organizations such as IEC, ISO, CENELEC, SAE, QC/T. The Indian standards developers such as ARAI have also incorporated safety standards for traction batteries after taking reference from multiple global standards organizations.

Following is an overview of various global standards for lead-acid batteries:

Table 10: Safety Standards for Lead Acid Traction Batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC**	**IEC 62485-3:2014**	**Global**	• It provides requirements on safety aspects associated with the installation, use, inspection, maintenance, and disposal of batteries. Outlines for battery containers and enclosures, battery peripheral equipment, transportation, storage, disposal, and environmental aspects are provided along with guidelines for: ○ Protection against electric shock by the battery and charger ○ Prevention of short circuits and protection from other effects of current ○ Provisions against explosion hazards by ventilation ○ Provisions against electrolyte hazard
2.	**CENELEC**	**EN 61982-4:2016**	**Global**	• Applies to secondary batteries and battery installations used for electric vehicles, e.g., in electric industrial trucks (including lift trucks, tow trucks, cleaning machines, automatic guided vehicles), in battery powered locomotives, in electric vehicles (e.g., goods vehicles, golf carts, bicycles, wheelchairs). • It provides requirements on safety aspects associated with the installation, use, inspection, maintenance and disposal of batteries
3.	**ISO**	**ISO 6469-1:2019**	**Global**	• Specifies safety requirements for rechargeable energy storage systems (RESS) of electrically propelled road vehicles for the protection of persons. The standard covers various test procedures including mechanical, climatic, simulated vehicle accident, electrical, and functional tests
4.	**SAE**	**J2289**	**Global**	• Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements,

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
				electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. Also covers termination, retention, venting system, thermal management, and other features necessary for battery systems.
5.	**SAE**	**J1495**	**Global**	• The standard details procedures for testing lead-acid SLI (starting, lighting, and ignition), heavy-duty, EV (electric vehicle), and RV (recreational vehicle) batteries
6.	**QC/T**	**QC/T 989-2014**	**Global**	• The standard specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles. Applicable to vehicle charging battery enclosure and swapping battery enclosure.
7.	**UL**	**UL 2271**	**Global**	• This standard covers electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in **light electric-powered vehicles** (LEVs) as defined in this standard. • • To be compliant with the standard, the batteries must withstand overcharging, over-discharging, short circuit, imbalanced charging, and operation at maximum specified temperature in addition to withstand vibration, shock, crushing, drops, and roll overs. The batteries must also pass environmental tests such as immersion test and exposure test to stated IP67 rating and rapid thermal cycling from extremes of hot to cold and cold to hot.

Source: IEC, CENELEC, ISO, SAE, QC/T, UL

BIS has stated IS 16894-3: 2018 which covers the general safety aspects for lead acid batteries as highlighted below.

Standard: IS 16894-3: 2018[35]	
Scope and Coverage	• The standard provides requirements on safety aspects associated with the installation, use, inspection, maintenance and disposal of batteries.
Standard Reference	• IEC 62485-3: 2014
Key Operational Parameters	• For protection against electric shock, the standard prescribes requirements of insulation, barriers or enclosures, etc. • For prevention of short circuits and protection from other effects of electric current, specifications of cables and cell connectors are provided. • The provisions for ventilation against gas generation and recommended charging practices are provided. • The standard also mentions the requirements for battery containers, enclosures, accommodation for charging/ maintenance, battery peripherals, central filling system, thermal management system, electrolyte agitation system, catalyst vent plugs, and connectors for ensuring overall safety

Apart from BIS, ARAI has also provided a standard AIS-048 which covers the various tests and procedures for assessing the safety aspects of EV traction batteries. Following is an overview of the same.

[35] BIS IS 16894-3: 2018 Standard Document

Standard: AIS-048[36]	
Scope and Coverage	• The standard is applicable for L (two wheelers), M (four wheelers), and N (four wheelers used for carrying goods and also persons) category vehicles[37].
Key Operational Parameters	• **Short circuit test**: A hard short (i.e., a conductor connecting the positive and negative terminals) is applied to a battery at a temperature of 30 °C. The resistance of the short should be less than or equal to 5 mΩ and it should be applied for 10 minutes. The batteries are considered to pass the test if there is no physical damage to the casing, melting of components, fire & explosions. • **Overcharge test**: Battery is overcharged at a constant rate of 0.1 A for a duration of 10 hours after the battery has reached 100% state of charge. The ambient temperature is maintained at 27 ± 5 °C. The battery is considered to pass the test if there is no physical damage to the casing, melting of components, no fire & no explosions. • **Vibration test**: This test is carried out at 30 °C wherein the cells are subjected to sinusoidal vibrations in the vertical and horizontal axis with an acceleration of 3 g, frequency ranging from 30 to 150 Hz & a sweep rate of 1 octave per minute. On each of the axis, the test is carried out for 2 hours. The battery is considered to pass the test if no electrolyte loss is witnessed, no physical damage to the casing is observed and no fire or explosion happens. Moreover, the deterioration of battery rated capacity should not be more than 10% when the battery is discharged at a rate of 20% of its capacity after the vibration test. • **Shock Test**: At 100% state of charge, a battery is subjected to 10 shocks in each axis with half-sine wave of 30 g amplitude and 15 ms duration. After the test, the battery is discharged at temperature not exceeding 30 °C at C/5 rate. The battery is considered to pass the test if the rated capacity deterioration is less than 10% and there is no explosion or fire damage due to these shocks. • **Roll-over test**: The battery module is subjected to one complete rotation in one direction. This rotation is done a continuous, slow-roll fashion within a 1 min time. The battery is observed for any potential leakage. The module is then rotated 360° in 90° increments in same direction. At each position, the battery is held for one hour. The battery module is considered to pass the test if the volume of electrolyte spilled in each position shall not be more than 25 ml per module. • **Penetration test**: Battery module is penetrated with a mild steel pointed rod (3 mm diameter for cells and 20mm for modules) at a rate of 8cm/s. This mild steel rod should be electrically insulated from a test fixture. The rod is kept in that stage for a period of 1 hour and the battery is physically observed. The battery module is considered to pass the test if the battery shows no melting of components and fire or explosion. • Apart from the tests mentioned above, the standard also provides guidelines for declaration by the manufacturer in relation to parameters of the battery such as rated capacity and charge retention.

Note: Some other standards covering the safety of lead acid traction batteries are mentioned in annexure.

Electric vehicles may be subjected to different terrains such as hills, troughs, inclines, etc. Moreover, vehicles have a tendency to roll over during accidents or unintended shocks and are subjected to various mechanical stresses during driving. During unintended physical impacts, the vehicles / batteries could be physically crushed / penetrated by external objects. In all such situations, it must be ensured that batteries do not cause any harm to passengers due to leakage, explosion, short-circuits, etc. These standards hence prescribe a wide variety of tests to ensure all of the above conditions are complied to.

Traction batteries should be tested for all such scenarios since driving in Indian conditions, where traffic density is high, requires that OEMs must maintain adequate mechanism for ensuring safety of passengers. An assurance that batteries would be safe in all such conditions would be instrumental in instilling the consumer confidence in such technologies and large uptake of electric vehicles in India.

IS 16894 and AIS-048 combinedly provide a good reference point for assessing the safety standard of lead acid batteries. The standards take reference from multiple international standards and cover the necessary tests and requirements for safety of batteries.

AIS 048 in many ways can be considered as an abuse testing and reliability standard due to its large array of tests but at the same time, the standard lacks in certain aspects such as thermal shock test, thermal cycling, fire test, emissions and

[36] AIS – 048 (access here)
[37] Homologation (access here)

flammability. These aspects could be derived from UL and SAE standards appropriately provided in other sections to make lead acid batteries safer for mobility applications.

Transportation standards

The transportation standards for lead acid batteries have been specified by Chinese standards QC/T, BIS, and SAE as highlighted in the table below.

Table 11: Transportation standards for Lead Acid Traction Batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**QC/T**	**QC/T 989-2014**	**Global**	• This specifies the **transportation** and storage and package of battery enclosure in the traction battery system of electric vehicles. This is applicable to vehicle charging battery enclosure and swapping battery enclosure.
2.	**BIS**	**IS 16894: Part 2: 2018**	**Indian**	• The standard covers lead-acid and NiCd/NiMH batteries and describes the principal measures for protections against hazards generated from electricity, gas emission or electrolytes. • **The clause on "Transportation, storage, disposal and environmental aspects"** specifies the following international regulations for transport, safe packing and carriage of dangerous goods depending on the geographic area and mode of transport as highlighted below: ○ **By road:** European Agreement for the International Carriage of Dangerous Goods by Road (ADR) ○ **By rail (international):** International Convention concerning the Carriage of Goods by Rail (CIM) ○ **By sea:** International Maritime Organisation, Dangerous Goods Code IMDG Code 8 Class 8 corrosives ○ **By Air:** International Air Transport Association (IATA), Dangerous Goods Regulations
3.	**SAE**	**J2289**	**Global**	• This describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. This includes **storage and shipment characteristics** and labeling requirements. • This also covers termination, retention, venting system, thermal management, and other features

Source: SAE, QC/T, BIS

Recycling standards

International organizations such as IEC, CENELEC and SAE have specified recycling standards for lead acid only. BIS, at present, does not have any standard related to recycling of lead acid batteries. However, India has formulated the battery waste management rules which govern the recycling of lead acid batteries in particular.

Recycling standards prescribed by IEC and SAE are highlighted below:

Table 12: Recycling standards for Lead Acid Traction Batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**SAE**	**J3071**	**Global**	• The standard provides information applicable to chemistries such as lead acid, lithium-ion, nickel cadmium, etc. It focuses on segregation, identification of battery system and subsystem chemistries which could be adopted globally.

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
2.	**SAE**	**J2984**	**Global**	• This standard specifies identification of Transportation Battery Systems for recycling. The procedure is intended to support the proper and efficient recycling of rechargeable battery systems used in transportation applications with a maximum voltage greater than 12V (including SLI batteries).

Source: SAE

IEC, CENELEC and SAE have comprehensive standards for recycling of lead acid batteries. India presently has Battery Waste Management Rules which covers lead acid batteries in particular but necessary standards for recycling for each chemistry would be required in the future.

Standards for lithium-ion chemistry

The table below gives a snapshot of the various standards for Lithium-ion chemistries for traction applications.

Table 13: Snapshot of Lithium-ion traction battery Standards

Type	General	Performance and Lifecycle	Safety	Reliability and Abuse Testing	Transportation	Recycling
Global	IEC 62902:2019, ISO/IEC PAS 16898:2012, ISO 18300:2016, SAE J2289, SAE J3124, QC/T 1023-2015, QC/T 743-2006, QC/T 840-2010, QC/T 989-2014	IEC 62660-1:2018, ISO 12405-4:2018, J2288, J2758, J1634	IEC 62485-3:2014, IEC 62485-6:2021, IEC TR 62660-4: 2017, IEC 62281:2019, ISO 18243:2017, EN 50604-1:2016/A1:2021, EN 62485-3:2014, EN IEC 62485-6:2021, IEC 62660-3:2021, J2289, J2929, QC/T 989-2014, UL 2271	UN Manual (Section 38.3), IEC 62660-2:2018, J2464, UL 2580, IS 16893-2: 2018,	QC/T 989-2014, J2950, IEC 62281:2019, UN Manual (Section 38.3), J2289, QC/T 1023-2015, QC/T 743-2006	J3071, J2984
Indian	IS 16827: 2018	IS 16893: Part 1: 2018	AIS 048, IS 16894: Part 3: 2018, IS 16893: Part 3: 2018		-	-

General standards

BIS has come up with IS 16827: 2018[38] standard which has been adopted from ISO/IEC PAS 16898:2012. Overview of the same is given below:

Standard: IS 16827: 2018[39]	
Scope and Coverage	• Specifies a method to designate the shape (cylindrical or prismatic or pouch) and dimensions of secondary lithium-ion cells for integration into battery packs and systems used in electrically propelled road vehicles. • The standard does not apply to cells specifically used for mopeds, motorcycles, and vehicles not primarily defined as road vehicles.
Reference Standard	• ISO/IEC PAS 16898:2012

[38] BIS IS 16827: 2018 Standard Document
[39] BIS IS 16827: 2018 Standard Document

Standard: IS 16827: 2018[39]	
Key Operational Parameters	• Over-pressure safety device (OPSD) needs to be available in the outer geometry of the cell. • The temperature for the measurement of the cell dimensions is specified at 25 ± 2°C in accordance with the tolerance as per IEC 62660-1.

The global standards for lithium-ion traction batteries are mentioned in the table below.

Table 14: General standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC**	**IEC 62902:2019**	**Global**	• The standard specifies methods for the clear identification of secondary cells, batteries, battery modules and monoblocs, with a volume of more than 900 cm^3, according to their chemistry (electrochemical storage technology).
2.	**IEC**	**ISO/IEC PAS 16898:2012**	**Global**	• It specifies a designation system as well as procedure for measuring shapes and dimensions for secondary lithium-ion cells for integration into battery packs and systems used in electrically propelled road vehicles including the position of the terminals and any over-pressure safety device (**OPSD**). It is applicable to cylindrical, prismatic and pouch cells used in the EV traction batteries.
3.	**ISO**	**ISO 18300:2016**	**Global**	• The standard provides test specifications for lithium-ion battery systems combined with lead acid battery or capacitor. It specifies configurations for lithium-ion batteries with lead acid batteries or double layer capacitor. Test procedures for pre-conditioning, rated capacity, micro-cycle and cycle life are defined in this standard
4.	**SAE**	**J2289**	**Global**	• Describes practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. This Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. This also covers termination, retention, venting system, thermal management, and other features for lithium-ion traction batteries.
5.	**QC/T**	**QC/T 1023-2015**	**Global**	• The standard covers general requirement of traction battery system for electric vehicles. It also stresses upon the assembly of traction battery system, its component interfaces, identification markings, transportation and storage of lithium-ion batteries used in electric vehicles.
6.	**QC/T**	**QC/T 743-2006**	**Global**	• The standard specifies the requirements, testing methods, inspection rules, symbols, package, transport and storage of Li-ion battery used in electric vehicles. This is applicable to Lithium-ion batteries for electric vehicles of nominal voltage of monomer of 3.6V
7.	**QC/T**	**QC/T 840-2010**	**Global**	• The standard provides specification and dimension of monomer and module of metal hydride nickel traction batteries and lithium-ion traction battery for electric vehicles.
8.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles.

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
				This is applicable to vehicle charging battery enclosure and swapping battery enclosure.

Source: IEC, ISO, SAE, QC/T

Such standards give adequate information on the appropriate physical characteristics of batteries for electric mobility related applications as well as ways of identification of the relevant chemistry. In addition, it also provides guidance for appropriate dimensioning of batteries, optimal shapes and design for integration with EVs, and optimal ways to assemble the product for ease of operation in electric mobility related applications.

Performance standards

Following are the details of various international standards which specify methodology for performance assessment of lithium-ion batteries:

Standard: IEC 62660-1:2018[33]	
Scope and Coverage	• The standard specifies test procedures to measure various performance parameters viz. energy capacity, power density, energy density, cycle life, etc.
Key Operational Parameters	• **Energy capacity measurement**: Cells are discharged at rates of C/3 and 1C for BEV and HEV respectively (C being the 1-hour discharge rate as specified by the manufacturer) at a temperature of 25 °C. Based on the discharge time taken to drain out the cell, the energy capacity of the cell is determined. Capacity measurements are carried out at the same discharging rates at two more temperature points i.e., at 0 °C and 45 °C. • **Power and Internal Resistance**: At temperatures of 40 °C, 25 °C, 0 °C, and -20 °C, cells are adjusted to varying state of charge (80%, 50%, and 20%) and are subject to varying discharge rates (C/3, 1C, 2C, 5C) and maximum charge rate (as specified by the manufacturer). In each of the scenarios, the voltage is measured at the end of a 10 second pulses having at least 10 minutes rest between steps. Based on the voltage measurement and the current pulse value, the power delivered by the cell is calculated. The internal resistance on the other hand is determined by dividing the voltage by the current. • **Storage Capacity**: Cells with state of charge 100% (for BEVs) and 50% (for HEVs) at a temperature of 45 °C are left idle for 42 days for 3 cycles (aggregating to 126 days). At the end of each cycle, the state of charge of the battery is measured to determine losses from previous state. This is used to determine the storage capacity during idling stages. • **Energy efficiency**: This is measured at temperatures of 45 °C, 0 °C, and -20 °C under state of charge of 100% and 70%. Discharge rate for BEVs is C/3 whereas for HEVs it is 1C where C is the 1 hour charging rate specified by the manufacturer. The efficiency value is determined by the ratio of the net energy delivered by a battery during a discharge test (from specified SOC to zero SOC) to the total energy required to restore the initial SoC. • **Cycle life**: After determining the initial performance parameters stated above, the cells are put through different charge and discharge cycles using different current profiles in line with standard operating conditions of an electric vehicle. • For the charge and discharge cycles, the cells are kept at a temperature range of 45 °C ± 2 °C with a state of charge of 80%. After adjusting the SOC, the cells are put through discharge rich and charge rich profiles for 22 hours and are rested for 2 hours. The SOC of the cells in these cycles swings between 30% to 80% which are akin to the operating conditions in electric vehicles. The power is measured after 7 days for HEV cells and after 28 days for BEV cells. The cells are rejected if the capacity or power is below 80% of initial value.

Similar to IEC 62660-1, ISO has provided performance standards for lithium-ion cells. This standard is an amalgamation of two previous standards ISO 12405-1: 2011 and ISO 12405-2:2012.

Standard: ISO 12405-4:2018[33]	
Scope and Coverage	• The standard specifies test procedures to measure various performance parameters viz. energy capacity, power density, energy density, cycle life, etc. The standard covers the batteries used in BEVs and HEVs and the tests performed for the standard are done on a *cell level*.
Key Operational Parameters	• **Energy and Capacity Measurement**: The temperature range to be maintained for these tests vary from -18 °C to 40 °C with the discharging rates such as C/3, 10 C, and maximum C-rate (C being the charging rate specified by the manufacturer). Based on the discharge time taken to drain out the cell, the energy capacity of the cell is determined. • **Power and Internal resistance**: Temperature requirement for these tests vary from -18 °C to 40 °C. Multiple state of charge can be considered for HEVs and BEVs applications. The cells are subjected to a discharge rate of C/3, for BEVs, and 1C for HEVs. Based on the voltage output, the power delivered is computed by multiplying it with the current used. The internal resistance of the battery pack and system are computed by dividing the voltage output by the current in the system. • **Storage Capacity**: This is determined using two conditions viz. no load and with load. During no load test, HEV and BEV batteries are taken to a state of charge of 80% and 100% respectively with resting times ranging from 1 day to 30 days. During a load test, the HEV and BEV systems are taken to a state of charge of 50% and discharged at 1C and C/3 (C being the one hour charging rate) respectively with resting time of 30 days. Based on the assessment of state of charge after the resting period, losses are measured to understand the storage capacity of the device when not in use. • **Cranking Power**: This is measured only for HEV systems where the cell is subjected to temperatures (°C) of 50, 25, -18, -30 and to the lowest state of charge possible or 20% SoC. The battery packs are discharged at varying C rates ranging from 1 C to 20 C (C being the 1 hour charging rate). Based on the voltage output of the battery pack, the cranking power is measured. This test is aimed to measure the cranking power which the battery can provide to start the engine at its lowest state of charge and varied temperature ranges. • **Cycle life assessment**: After the initial performance assessment, the cell is subjected to different charge and discharge cycles using different current / voltage profiles such that the state of charge of the cell varies between 20% and 100%. Power is measured after 7 days for HEV cells and after 28 days for BEV cells. The test is terminated if the capacity or power is below 80% (for HEVs cells) and if any performance value is below 80% of initial value for (BEVs cells).

SAE J2288 defines a standardized test method to determine the expected service life of electric vehicle battery modules. The various tests under this standard are mentioned in performance stanadards of lead acid batteries.

IS 16893-1: 2018 governs the performance assessment of lithium-ion traction batteries. Details of the standard are mentioned below:

Standard: IS 16893-1:2018[40]	
Scope and Coverage	• This standard specifies method to test performance of secondary lithium-ion cells used for propulsion of electric vehicles including both BEVs and HEVs.
Reference standard	• IEC 62660
Key Operational Parameters	• **Capacity measurement**: Charging is carried out at constant current in room temperature (25 °C) after which it is discharged at 1/3 I_t (I_t being the reference current) for BEV and at I_t for HEV applications. Based on the discharge duration taken by the cell to reach the specified end of discharge voltage, the energy capacity is calculated. • **Power Measurement**: Firstly, the mass and dimensions of cells are measured. The cells are set at multiple state of charges viz. 20%, 50% and 80% and temperatures 40 °C, 25 °C, 0 °C and -20 °C. Based on the level of charge and discharge current specified by the manufacturer, the cell is charged or discharged. At each charge / discharge current level, a 10 second pulse is applied, and the voltage is measured at the end. Based on the voltage and the current, power delivered is measured.

[40] BIS IS 16893-1: 2018 Standard Document

Standard: IS 16893-1:2018[40]
• **Energy Measurement**: A fully charged cell is discharged and the value of the average voltage during the discharging is calculated by measuring the voltage at specific time intervals, integrating the discharge voltage over time and dividing the result by the discharge duration. Based on the voltage measurements, the energy is measured. • **Charge retention test**: The SoC of the cells is adjusted to 50% and the cells are taken to the end of discharge voltage at a discharge current of 1/3 I_t for BEV applications and at It for HEV applications. After taking the cell back to 50% state of charge, it is stored for 28 days at an ambient temperature of 45 °C ± 2 K. The cells are then again discharged to measure their capacity loss, if any. • **Storage life test**: Cells are adjusted to a SOC of 100% and 50% for BEV and HEV applications respectively. The cells are then made to rest in idle condition for 42 days at an ambient temperature of 45 °C ± 2 K. Following the resting time, the cell is kept at room temperature and discharged at constant current of 1/3 I_t (I_t being the reference current) for BEV and at I_t for HEV applications down to the discharge voltage specified by the manufacturer. The discharge capacity so obtained is the retained capacity after idle conditions. The above stated steps are repeated 3 times to reach at a conclusive value. • **Cycle life test**: The cells are put through charge and discharge cycles which will imitate real life operating conditions of traction batteries. The cycles are repeated for 28 days and the performance of the cells is then measured. The test is terminated after all the steps have been repeated 6 times or when any performance decreases to less than 80% of initial value or the temperature of the cell reaches the upper limit agreed between manufacturer and customer.

Note: Other standards for Lithium-ion performance and lifecycle assessment are provided in the annexure.

Batteries of electric vehicles have to withstand stress originating out of the manner in which vehicles are driven. Subjecting the vehicle to sudden acceleration, braking, driving up in an inclined path, frequent starts / stops in the road, etc. are some of the various driving profiles which a battery has to withstand. All these profiles affect the battery performance which can vary from the performance of a battery at normal use conditions. A battery must demonstrate satisfactory performance in all of these conditions.

The following points may be looked at:

1) **ISO 12405-4:20181 specifies that energy capacity of a cell should also be measured at 10C. This is because electric vehicle batteries tend to be exposed to variety of driving conditions. At present, Indian standards specifies measurement of energy capacity at C and C/3 only.**

2) **Battery should be able to deliver a proper cranking power is in case the vehicle is idle for a long time. Moreover, losses during charging and discharging should also be kept minimum since traction batteries are always subjected to frequent charge and discharges. At present, Indian standard does not mention any test for determining energy efficiency and cranking power. Reference from the same can be taken from IEC and ISO standards**

Safety standards

Following are the details of various international standards covering safety related aspects of Lithium-ion chemistries:

Standard: ISO 18243:2017[33]	
Scope and Coverage	• This standard specifies safety requirements for lithium-ion battery systems used in electrically propelled mopeds and motorcycles.
Key Operational Parameters	• The standard is very similar to ISO 12405-2:2012 which is currently versioned as ISO 12405-4:2018 and dedicated for high-energy applications (BEVs and PHEVs) with only minor changes. • The **changes** can be observed in test parameters where lower temperatures are used for measurement of energy and capacity measurements (40, 25, 0, -10 °C). This is justified in a sense that batteries in LEV applications are subjected to less strict environmental conditions compared to those used in four wheelers. • The standard specifies tests for ensuring that batteries are safe from vibration, mechanical shock, drop, thermal shock, water immersion, fire, overtemperature, short circuits, overcharge, over discharge, dewing and salt spray.

Standard: SAE J2929	
Scope and Coverage	• Overall objective of the standard is to specify safety standards for battery operation in EV propulsion systems.
Key Operational Parameters	• **Mechanical shock test**: This is performed at cell, pack and module level. The test needs to be performed in positive and negative direction in longitudinal and lateral axes traversing all possible shock directions. A peak acceleration of 150 g (g being acceleration due to gravity) for a duration of 6 milliseconds is applied. If cell weighs more than 0.5 kg, and module weighs more than 12 kgs, peak acceleration of 50 g is applied for a duration of 11 milliseconds. At vehicle level, collision is carried out at speeds of 48, 54, and 80km/hr. • **Drop test**: The battery pack is dropped on a flat surface from a height greater than 1 meter or maximum distance to ground or maximum possible drop distance that battery systems experience when serviced at a state of charge of 95-100% of maximum normal vehicle operation. • **Immersion test**: This is carried out at the pack level wherein the pack is immersed in 5% NaCl at a temperature range of 25±5 °C. the pack is kept immersed for at least 2 hours or until such duration of time till any visible reactions have stopped. The battery is kept at a state of charge of 95-100%. • **Crush test**: At a pack level, the test uses a crush speed of 5-10 mm/min, force of 100 kN or expected intrusion types specified as per Federal Motor Vehicle Safety Standards 305. The pack is adjusted to a SoC of 95-100% of normal operation. • **Rollover test**: The battery pack is rotated with incremental revolution of 90^o (within 60-180 seconds) and is held for 5 minutes per increment. For the test, the packs are adjusted to SoC of 95-100% of normal operation. • **Vibration test**: The vibration test under the standard is carried out at cell, pack and module level. There are two types of vibration profile that the device under test (DUT) are put through viz. random profile (10-190 Hz; vibration along vertical, longitudinal and lateral axes; SoC 95-100%) and sine wave (7-200 Hz; three mutually perpendicular mounting positions; SoC 95-100%) • **Short-circuit test**: The battery pack is kept at a state of charge of 95-100%. It is put through this test with a cooling medium, if necessary. A resistance less than 5 milli ohms is used for a hard short and a resistance greater than 10 milli ohms is used for a soft short. • **Overcharge test**: The pack is charged at the maximum possible rate with disabled non-passive protective device until the charge device voltage is reached or the connection interface disconnects battery from charge device. • **Over discharge test**: The battery pack is discharged at 1C (for HEV/PHEV) and at C/3 (for BEV) where C is the charging rate of the pack. The discharge is ended until the connection interface disconnects battery from discharge load or when the voltage of the pack reaches 0 ± 0.2 V. • **Thermal shock test**: Cells, packs and modules with their active thermal controls disabled are put through temperature range of 72±2 °C to -40 ±2 °C. The device under test is held at the temperature for a specified duration. • The device under test is considered to pass if there is no fire, explosion, or battery enclosure rupture after any of the above tests.

Amongst the Indian standards, BIS has come out with **IS 16893-3: 2018** that specifies battery safety test for secondary lithium-ion cells and cell blocks used for propulsion of electric vehicles (EV) including battery electric vehicles (BEV) and hybrid electric vehicles (HEV)[41]. The details of the tests under the standard are mentioned below:

Standard: IS 16893-3:2018	
Scope and Coverage	• This covers the safety requirements for Lithium-ion cells used for the propulsion of electric road vehicles including battery electric vehicles and hybrid electric vehicles.

[41] BIS IS 16893-3: 2018 Standard Document

Standard: IS 16893-3:2018

Key Operational Parameters	• **Mechanical shock test**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. They are then subjected to a half-sinusoidal pulse at an acceleration of 500 m/s^2 for a duration of 6 milliseconds. 10 shocks are given per direction of the cells. • **Temperature cycling test**: The test is performed in two conditions i.e., with or without electrical operation. Without electrical operation, the cells are put through the cycling for a time period of 4 hours with the temperature change between 25 °C, T_{min}, T_{max} of the cells for 30 cycles. With electrical operation, for a cumulative time of 4 hours, the cells are cycled between temperatures ranging from 65 to -20°C. • **External short-circuit test**: The cells are taken to a state of charge of 100% and then short-circuited with external resistance of equal to or less than 5 mΩ for a time period of 10 mins. Multiple cell parameters are recorded to assess the response of the cells to the short-circuit. • **Vibration test**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. The cells are then subjected to maximum frequency of vibration of 2000 Hz and acceleration value of 27.8 m/s^2. The condition of the cells is monitored after the test which continues for 8 hours. • **Crush test**: This is performed for prismatic and cylindrical cells with hemispherical and semicircular bar crushing tools respectively. The force shall be released if there is more than 15% deformation from initial dimension or if an abrupt voltage drops of 1/3rd of the original cell voltage occurs or if a force of 1000 times the weight of the cell is applied. The cells are kept under observation for 24 hours or until the time the cell temperature declines by 80% of the maximum temperature rise during the test. • **High temperature endurance test**: At a 100% state of charge, cells are stabilized at room temperature. Cells are then kept in an oven and the oven temperature is set to 130 °C ± 2 K for 30 minutes. The oven is then turned off and the cell is observed for 1 hour in the oven. If there is no fire or explosion, the cell is considered to pass the test. • **Overcharge test**: The cell is adjusted to a state of charge of 100% and the charging is continued at a charge rate of 1 I_t for BEV and 5 I_t for HEV applications. The test is discontinued when the cell reaches 120 % of the maximum voltage specified by the manufacturer, or the quantity of electricity applied to the cell reaches the equivalent of 130 % SOC, whichever comes first. • **Forced discharge**: The tests are carried out after taking the cells to 0% state of charge and then discharging is continued until the cell goes beyond 0% state of charge with 1 I_t discharging current at room temperature. The forced discharge is continued until the voltage reaches 25 % or less of the nominal voltage specified by the manufacturer, or the cell is discharged for 30 min, whichever is sooner. • **The device under test is considered to pass if it doesn't exhibit any leakage, venting, rupture or explosion.**

Note: Some of the other safety standards for lithium-ion EV traction batteries are mentioned in Annexure

AIS-048 is focused on the safety requirements of traction batteries. The standard is applicable for L (two wheelers), M (four wheelers), and N (four wheelers used for carrying goods and also persons) category vehicles. The various requirements under the standard are mentioned in safety standards for lead acid batteries.

IS 16893-3 and AIS-048 combined provide a good reference point for assessing the safety standard of lithium-ion batteries. The standards take reference from multiple international standards and cover the necessary tests and requirements for safety of batteries. AIS 048 in many ways can be considered as an abuse testing and reliability standard due to its large array of tests but at the same time, the standard lacks in certain aspects such as thermal shock test, drop test, immersion test, fire test, emissions and flammability. Apart from the tests mentioned, ISO 18243 can also be referred to include dewing and salt spray tests which are very relevant for Indian conditions to make batteries safer.

Reliability and abuse testing standards

These tests are designed to examine if the batteries can tolerate extreme abuse conditions. It has to be noted that the abuse and reliability standards would be similar to safety standards.

UNECE in its Manual of Tests and Criteria has specified certain test methods and procedures as highlighted below:

Standard: UN Manual Section 38.3	
Key Operational Parameters	• **Altitude Simulation test**: The test simulates air transport under low-pressure conditions. Test cells and batteries shall be stored at a pressure of 11.6 kPa or less for at least 6 hours at ambient temperature (20±5 °C). • **Thermal test**: Test cells and batteries are to be stored for at least 6 hours at high temperature of 72 ± 2°C followed by storage for at least 6 hours at low temperature of -40 ± 2°C with a maximum interval between test temperature extremes of 30 minutes with 10 repetitive cycles after which batteries are stored at ambient temperature of (20±5°C). • **Vibration test**: Cells and batteries are subjected to sinusoidal waveform of vibrations with a logarithmic sweep between 7-200 Hz and back to 7Hz traversed in 15 minutes. Such cycles are repeated 12 times for a total of 3 hours for each of mutually perpendicular mounting position of cells. The frequency differs for cells and batteries with gross mass less than 12 kgs and more than 12 kgs. • **Shock test**: Each cell and battery shall be subjected to a half sine shock of peak acceleration of 150 g with a pulse duration 6 ms, large cells are subjected to peak acceleration of 50 g and pulse duration of 11 ms. • **External short-circuit test**: The cell or battery shall be heated for a period of time necessary to reach a homogenous stabilized temperature of 57 ± 4 °C. The time period shall be at least 6 hours for small cells, batteries and 12 hours for large cells and batteries. Then the cell and battery shall be then subjected to one short circuit condition with a total external resistance of less than 0.1 ohm. • **Impact/ crash test**: The cell or component cell is crushed between two flat surfaces at a speed of 1.5 cm/s at the first point of contact. Crushing is continued until applied force reaches 13 kN ± 0.78 kN or voltage of the cell drops by at least 100 mV or cell is deformed by 50% or more of its original thickness. Cells and components meet the requirement if their external temperature does not exceed 170 °C and there is no disassembly and no fire during the test and within six hours after this test. • **Overcharge**: The charge current shall be twice the manufacturer's recommended maximum continuous current. The maximum voltage of the test shall be as follows: • When the manufacturer's recommended charge voltage is not more than 18 V, minimum voltage of the test shall be lesser of two times of the maximum voltage of the battery or 22 V. • When the manufacturer's recommended charge voltage is more than 18 V, the minimum voltage of the test shall be 1.2 times the maximum charge voltage. • **Forced discharge**: Each cell shall be forced discharged at ambient temperature by connecting it in series with a 12 V DC power supply at an initial current equal to the maximum discharge current specified by the manufacturer.

For the altitude simulation, thermal, vibration, shock, and external short-circuit test, cells and batteries are considered to pass the tests if there is no leakage, no venting, no disassembly, no rupture and no fire and open circuit voltage of each test cell or battery after testing is not less than 90% of voltage prior to the procedure. For the overcharge and over discharge tests, batteries are considered to pass the test if there is no disassembly and fire during & within seven days after the test.

Standard **IEC 62660-2:2018** specifies reliability and abuse testing procedures for Lithium-ion cells used for the propulsion of electric road vehicles[42]. Unlike UN Manual section 38.3, the standard doesn't cover altitude simulation test.

Standard: IEC 62660-2:2018	
Scope and Coverage	• This includes test procedures to observe the reliability and abuse behavior of secondary lithium-ion cells and cell blocks used for propulsion of electric vehicles including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).
Key Operational Parameter	• **Mechanical shock test**: Carried out in the same direction of acceleration of shock that occurs in the vehicle with a peak acceleration of 51g with shock duration of 6ms. The cells are adjusted to state of charge of 80% for HEVs and 100% for BEVs. • **Crush test**: This is done by crushing the batteries with a crush force of less than / equal to 1000 times the device under test (DUT) weight. The cells are adjusted to state of charge of 80% for HEVs and 100% for BEVs prior to the test. • **Vibration test**: This is done with a random frequency profile within a range of 10 to 2000 Hz and with a power spectral density (PSD) random wave with 0.14 to 20 $(m/s^2)2/Hz$.

[42] Ruiz et al., A review of international abuse testing standards and regulations for lithium ion batteries in electric and hybrid electric vehicles (access here)

Standard: IEC 62660-2:2018	
	• **Short-circuit test**: This is done with a resistance less than or equal to 5 ohms and with an adjustment of state of charge to 100%. • **Over-charge test**: This is carried out with a charge rate of 5 I_t for HEVs and 1 I_t for BEVs (I_t is the current with rated capacity of the cells). The charging is stopped when the voltage reaches 2 V_{max} (V_{max} is the maximum voltage specified by the manufacturer). • **Over-discharge test**: This is done at a discharge rate of 1 I_t for 90 minutes. The cells are discharged until the device interrupts or limits the discharging of the cells. • **Thermal stability test**: This is done by subjecting the device to a heating rate of 5 C/min and is terminated at a temperature of 130 ± 2 C with a holding time of 30 minutes. In case of self-heating (an instance when temperature increase at a rate higher than 1°C/min), repetition is carried out with state of charge 80% and 100% of rated capacity for HEV and BEV cells respectively. • **Thermal shock test**: This is done with and without electrical operation with 30 repetitions with holding time of 1.5 hours at minimum temperature and 1.83 hours at maximum temperature. A repetition here refers to subjecting the device to minimum or maximum temperature, holding it for certain time period and then subjecting it to other temperature limit and holding it there for the mentioned time period. • Without electrical operation, the cells are put through maximum temperature of 85 ± 1 °C and minimum temperature of -40 ± 1 °C with state of charge 80% for HEVs and 100% for BEVs. • With electrical operation, the cells are put through maximum temperature of 85 ± 2 °C and minimum temperature of -40 ± 2 °C with state of charge 80% for HEVs and 100% for BEVs. • The passing criteria for the above tests are that the device under test should not explode or catch fire.

SAE has come out with J2464 covering the safety, reliability and abuse testing aspects of lithium-ion batteries. Overview of the standard is mentioned below:

Standard: SAE J2464	
Key Operational Parameters	• **Mechanical shock test**: The pack is subjected to an acceleration of 25g for a duration of 15 milliseconds with half sine pulse form shock. 18 such shocks are given with 3 repeats on three axes in both positive and negative directions. The pack is observed for a minimum of 1 hour after the test. • **Drop test**: The device under test is dropped from a height of 1 meter or at any other suitable height replicating actual field use procedures whichever is larger. For the test, it is acceptable if the device undergoes a horizontal impact into a hard surface with suitable velocity and deceleration. After the drop, the DUT is observed for a minimum of 1 hour after the test. • **Penetration test**: A rod of diameter 3mm, for cell, and 20mm, for module/ pack with tapered end is penetrated at a rate of 8 cm/s or greater. • **Rollover test**: This is done at a pack and module level, the device under test (DUT) is rotated for one complete revolution in 1 minute in a continuous slow roll fashion and it is observed if any material leaks from it. The DUT is then rotated in 90° increments for one full revolution. The DUT is observed for 1 hour at each position and for a minimum of 1 hour after the test. • **Overcharge test**: Carried out with a charge rate of 5 I_t for HEVs and 1 I_t for BEVs (I_t is the current with rated capacity of the cells). The end of charge is done at 2 V_{max} (V_{max} is the maximum voltage specified by the manufacturer) or at 200% of state of charge. • **Immersion test**: The module or battery packs in their normal operating orientation and temperature are immersed in salt water (5% by weight NaCl in water) for a minimum of 2 hours until any visible reactions have stopped. • **Crush test**: The DUT shall be crushed between a fixed surface and a crush fixture that results in sufficient localized deformation to cause shorting. The DUT is crushed up to 85% of initial dimensions and is held for 5 minutes. The crush force shall be limited to 1000 times the weight of the DUT and the crush speed shall be between 0.5 cm/min and 1 cm/min for packs and between 0.5 mm/min and 1 mm/min for cells). • **High temperature hazard test**: A thermal chamber is used for the test in which the radiating surfaces are at a temperature of 590 ± 5 °C. The DUT is put through the test with 100% state of charge for a period of 20 minutes. This test is carried out at levels of module and above

Standard: SAE J2464	
	• **Thermal Stability Test**: This test is conducted at a cell level, where the cell is fully charged at a temperature of 25oC. The temperature is ramped up at a minimum rate of 5oC/min up to a temperature of 300oC. The temperature till which the DUT is stable is observed. • **Cycling without thermal management**: This is performed at a module and pack level, after fully charging the DUT, contained in a static air and active thermal controls disabled. It is charged with manufacturer defined charge algorithm followed by discharge at a rate comparable to intended application. 20 full charge/ discharge cycles shall be performed with no resting period in between. • **Thermal shock cycling**: The test is applicable for cells and systems above it. The DUT at maximum operating state of charge with active thermal controls disabled is thermally cycled with ambient air cycling between -40 to 70ºC. The DUT shall remain at the temperature extremes for a minimum of 1 hour at cell level and 6 hours at module level or as required to reach uniform temperature at pack level. Total 5 cycles are performed. • **Short circuit test**: The battery pack or module or cells are put through this test with a cooling medium, if necessary, for operation with a state of charge of 95-100% of normal vehicle operation. The DUT is put through the test with resistance less than 5 milli ohms for a hard short and with a resistance greater than 10 milli ohms for a soft short. • **Overcharge test**: The DUT (cell and module or pack) shall be fully charged for this test. • Cells shall be charged at two rates viz. 1 C-rate constant current and high-rate overcharge at the maximum current. Charging continues until at least 150% of maximum charge voltage or 200% SOC has been reached. • Modules and packs shall be charged at 1 C-rate constant current until pack voltage is under 400 V, 150%/ 120% of maximum charge voltage or 200% SOC has been reached or the test is terminated by some other factor. • The passing criteria for the tests are that the device under test should not explode or catch fire.

UL has prescribed UL 2580 for abuse testing of lithium-ion batteries which is followed extensively in North America. The specifications of the standard are mentioned below:

Standard: UL 2580[42]	
Scope and Coverage	• Covers electrical energy storage assemblies such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in electric-powered vehicles.
Key Operational Parameters	• **Mechanical shock test**: This is carried out on a cell, module and pack level. The shock is given in both positive and negative directions with 3 repeats on 3 axes making a total of 18 shocks. The peak acceleration for the cells is 51g whereas for the module and pack it is at 25g. The duration of the shock varies from 6 milliseconds for cells to 15 milliseconds for module and packs. The state of charge for module and packs is the maximum operating SOC and for cells it is 80% for HEVs and 100% for BEVs. • **Drop test**: This is done at a cell and pack level at maximum state of charge. The object is dropped on a flat concrete surface at a drop height of 1 meter. • **Immersion test**: At maximum state of charge, module and packs are immersed in 5 wt% NaCl at a temperature range of 25±5 °C for a time period greater than 1 hour until visible reactions have stopped. • **Crush test**: Crush test is carried out at cell, module and pack levels at pre-determined crush speed and force. The modules and packs are kept at maximum state of charge for the test whereas the cells are kept at a SOC of 80% (HEVs) and 100% (BEVs) • **Rollover test**: This test is carried at a pack level where they are rotated at a speed of 360º per minutes in three mutually perpendicular directions at maximum state of charge. • **Vibration test**: This is carried out on all three levels of cell, pack and module with a random profile. The frequency range used is 10-2000 HZ and 10-190 Hz for cells and modules, packs respectively. For cells the state of charge is 80% for HEVs and 100% for BEVs; modules and packs are tested at 100% state of charge. • **Short-circuit test**: This is carried out at cell, pack and module level with maximum operating state of charge with a resistance of 5 mΩ for cells and 20 mΩ for modules and packs.

Standard: UL 2580[42]	
	• **<u>Charge tests</u>**: <u>Overcharge:</u> Cells are charged at charging rate 5 times the current at rated capacity (I_t) for HEVs and at I_t for BEVs. Modules and packs are charged at maximum specified charge rate by manufacturer. Charging is continued till they reach twice the maximum voltage or 200% of state of charge (for cells) or manufacturer specified limit or device fails through explosion or fire.

As far as Indian standards are concerned, BIS has published IS 16893: Part 2: 2018. The specifications of the standard are mentioned below:

Standard: IS 16893-2: 2018[43]	
Scope and Coverage	• Specifies reliability and abuse testing procedures for Lithium-ion cells used for the propulsion of electric road vehicles. Electric vehicles stated in the standard include battery electric vehicles (BEV) and hybrid electric vehicles (HEV). The tests are used to observe reliability and abuse behavior of secondary lithium-ion cells and cell blocks.
Reference Standard	• IEC 62550-2: 2010
Key Operational Parameters	• **<u>Mechanical shock test</u>**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. They are then subjected to a half-sinusoidal pulse at an acceleration of 500 m/s^2 for a duration of 6 milliseconds. 10 shocks are given per direction of the cells. • **<u>Crush test</u>**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. Based on the cell type, the crushing tool is selected (semicircular bar or hemispherical) with 150 mm diameter. Crushing continues till voltage drops to one-third of its original value or the cells deform more than 15% or the crushing force exceeds 1000 times the cell weight, whichever occurs first. The cells remain on test for 24 hours or until the case temperature declines by 20% of maximum temperature rise. • **<u>Vibration test</u>**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. The cells are then subjected to maximum frequency of vibration of 2000 Hz and acceleration value of 27.8 m/s^2. The condition of the cells is monitored after the test which continues for 8 hours. • **<u>High temperature endurance test</u>**: The cells are adjusted to a SOC of 100% for BEV applications and 80% for HEV applications. After stabilizing the cells at room temperature, they are put in an oven and the temperature is raised at a rate of 5 K/min to a temperature of 130 °C ± 2 K where it is kept for 30 minutes. • **<u>Temperature cycling test</u>**: The test is performed in two conditions as per the agreement with the manufacturer i.e. with or without electrical operation. Without electrical operation, the cells are put through the cycling for a time period of 4 hours with the temperature change between 25 °C, T_{min}, T_{max} of the cells for 30 cycles. With electrical operation, for a cumulative time of 4 hours, the cells are cycled between temperatures ranging from 65 to -20°C. • **<u>External short-circuit test</u>**: The cells are taken to a state of charge of 100% and then short-circuited with external resistance of equal to or less than 5 mΩ for a time period of 10 mins. Multiple cell parameters are recorded to assess the response of the cells to the short-circuit. • **<u>Overcharge</u>**: After adjusting the cells to a state of charge of 100%, they are continued to be charged with a current I_t (reference test current) for BEV and 5 I_t for HEVs. The test is discontinued when voltage reaches twice the maximum voltage, or 200% SOC. Multiple cell parameters are recorded to assess the response of the cells to the short-circuit. • The passing criteria for the tests are that the device under test should not explode or catch fire.

The abuse testing and reliability standards for Lithium-ion batteries draw multiple parallels with the safety standards described for the chemistry. As per a review carried out for abuse testing standards and regulations for lithium-ion batteries in electric and hybrid vehicles by Ruiz et al[42], AIS-048 can also be considered as one of the abuse testing standards. AIS-048 covers

[43] BIS IS 16893: Part 2: 2018 Standard Document

mechanical and electrical tests but lacks any tests for environmental (thermal tests, temperature related tests) and chemical tests (flammability and emission tests). Such aspects for new standards can be derived from SAE J2929 and SAE J2464 which have complete array of tests when it comes to abuse and reliability tests.

At the same time, IS 16893: Part 2 covers the reliability and abuse testing procedures for lithium-ion chemistry cells. But because of the derived nature of the standard, it also carries the shortcomings of IEC 62660-2. The standard lacks some basic mechanical tests for drop, penetration, and immersion.

If new standards were to be developed, they must address these shortcomings. The important aspects such as flammability and emissions should also be considered given Indian climate conditions. Stricter safety standards for lithium-ion chemistry batteries can help in addressing the shortcomings in the current standards and give a holistic standards framework for manufacturers and OEMs.

Transportation standards

The transportation standards for Lithium-ion batteries have been spelt out by QC/T (Chinese standards), SAE, UN, and IEC. In India, there are no standards related to transportation of Lithium-ion batteries. Following is a brief overview of the various standards prevalent internationally.

Table 15: Transportation standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, **transportation** and storage and package of battery enclosure in the traction battery system of electric vehicles. Applicable to vehicle charging battery enclosure and swapping battery enclosure.
2.	**SAE**	**J2950**	**Global**	• The standard aids in the identification, handling, and shipping of lithium batteries to and from specified locations. The standard utilizes the existing U.S. and international hazardous materials (dangerous goods) transportation regulations, which are the only methodologies to be used to establish transportability.
3.	**IEC**	**IEC 62281:2019+AMD1:2021**	**Global**	• The standard specifies test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal.
4.	**UN**	**UN Manual (Section 38.3)**	**Global**	• According to the provisions of the "United Nations Recommendations on the transport of dangerous goods, Model Regulations", Lithium-ion batteries fall under the hazard classes section in the manual. The tests specify altitude simulation, thermal, vibration, shock, external-short circuit, impact, overcharge, and forced discharge tests.
5.	**SAE**	**J2289**	**Global**	• Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • Also covers termination, retention, venting system, thermal management, and other features
6.	**QC/T**	**QC/T 1023-2015**	**Global**	• The standard covers general requirement of traction battery system for electric vehicles. It also stresses upon the assembly of traction battery system, its component interfaces, identification markings, **transportation** and storage of lithium-ion batteries used in electric vehicles.
7.	**QC/T**	**QC/T 743-2006**	**Global**	• The standard specifies the requirements, testing methods, inspection rules, symbols, package, **transport** and storage of Li-ion battery used in electric vehicles.

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
				This is applicable to Lithium-ion batteries for electric vehicles of nominal voltage of monomer of 3.6V

Source: IEC, SAE, QC/T, UN

At present, there are no standards developed by Indian authorities for the transportation of lithium-ion electric vehicle traction batteries. Even though Hazardous and other Wastes (Management and Transboundary Movement) Rules 2016 by Central Pollution Control Board state the necessary transportation guidelines, BIS standards for transportation are yet to be published. Since most of the batteries deployed in electric vehicles would be imported in the country, OEMs need to adhere to these standards. The QC/T, SAE, and IEC standards mentioned above can be referred to in this context.

Recycling standards

Global organizations such as IEC, CENELEC, SAE, etc. have developed recycling standards for lithium-ion batteries. The Indian organizations are yet to develop standards for recycling of lithium-ion batteries. Going forward as more lithium-ion batteries enter the market and reach their end of life, recycling will be of paramount importance. This would pave a sound ecosystem for ensuring a circular economy for batteries and ensure that the raw materials are not wasted.

Following are the various international standards for recycling of lithium-ion batteries in traction applications:

Table 16: Recycling standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**SAE**	**J3071**	**Global**	• Illustrates automotive battery recycling identification and cross contamination prevention guidelines. The standard provides information applicable to chemistries such as lead acid, lithium-ion, nickel cadmium, etc. It focuses on segregation, identification of battery system and subsystem chemistries which could be adopted globally.
2.	**SAE**	**J2984**	**Global**	• The standard recommends practices for transportation of battery systems for recycling. The chemistry identification system is intended to support the proper and efficient recycling of rechargeable battery systems used in transportation applications with a maximum voltage greater than 12V (including SLI batteries).

Source: SAE

At present, there are no standards related to recycling in India covering lithium-ion traction batteries. India's target of electrifying its vehicle fleet will generate a substantial need to recycle the batteries used in its electric fleet. Unless suitable standards are adopted for recycling, the strive towards electrification will not be sustainable. Suitable standards need to be defined for recycling. Reference can be taken from IEC, CENELEC, and SAE.

Reuse standards

The standards mentioned in this section cover the major EV markets in the world namely Europe, USA, etc. Standards specified by organizations such as IEC (International Electrochemical Commission), ISO (International Organization for Standardization), CENELEC (European Committee for Electrotechnical Standardization), QC/T (Chinese standards), UL (Underwriters Laboratory) have been considered. It is important to note that the IEC standards are currently under preparation and will be completed in the upcoming years.

Following are the various international standards for reuse of lithium-ion batteries:

Table 17: Reuse standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC**	**IEC 63330**	**Global**	• This standard lists down the requirements for repurposing battery systems, battery packs, modules, and secondary cells manufactured for use in applications such as mobility. It also specifies the procedure to evaluate performance and safety parameters of batteries for repurposing. It does not cover redox flow batteries.
2.	**IEC**	**IEC 63338**	**Global**	• This standard gives a general guidance regarding the reuse of batteries and secondary cells
3	**UL**	**UL 1974**	**Global**	• This standard specifies how to evaluate batteries for repurposing based on BMS measurements. This standard also covers the processes for sorting and grading of battery packs, modules, cells and electrochemical capacitors which were originally configured for EV propulsion.

Source: IEC, UL

At present, there are no standards related to battery reuse in India covering lithium-ion traction batteries. India's quest of electrifying its vehicles will generate huge amounts of spent batteries in the upcoming years which could still be used for various applications such as mobility, energy storage, and other less demanding application. Hence, suitable standards need to be defined for reuse. Reference can be taken from IEC and UL standards.

Standards for Nickel Metal Hydride chemistry

NiMH is one of the most advanced and commercially available rechargeable chemistries around the world. The table below gives a snapshot of the various standards defined in India as well as by various international agencies.

Table 18: Snapshot of Nickel metal hydride traction battery Standards

Type	General	Performance and Lifecycle	Safety	Transportation	Recycling
Global	IEC 62902:2019, QC/T 1023-2015, QC/T 840-2010	IEC 61982: 2012, J2288, J1798, J2758, J1634	IEC 62485-3:2014, J2289, QC/T 989-2014, UL 2271	QC/T 989-2014, J2289	EN 61429:1996, IEC 61429:1995, J3071, J2984
Indian	-	IS 13514: 2015	IS 13514-4:2018, AIS 048, IS 16894: Part 3: 2018	IS 16894: Part 2: 2018	-

General standards

General standards of NiMH chemistry have been covered by IEC and QC/T. Following table lists out the key standards pertaining to NiMH chemistry for electric vehicle applications:

Table 19: General standards for Nickel Metal Hydride Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC**	**IEC 62902:2019**	**Global**	• This standard specifies methods for the clear identification of secondary cells, batteries, battery modules and monoblocs according to their chemistry (electrochemical storage technology). This is applicable for secondary cells, batteries, battery modules and monoblocs with a volume of more than 900 cm^3.
2.	**QC/T**	**QC/T 1023-2015**	**Global**	• The standard covers general requirement of traction battery system for electric vehicles. It also stresses upon the assembly of traction battery system, its component interfaces, identification markings, transportation and storage of lithium-ion batteries used in electric vehicles.
3.	**QC/T**	**QC/T 840-2010**	**Global**	• This standard covers the specification and dimensions of monomer and module of metal hydride nickel traction batteries and lithium-ion traction battery for electric vehicles

Source: IEC, QC/T

Performance standards

SAE and IEC have developed performance standards for NiMH based chemistries

IEC 61982: 2012 is a standard applicable to lead acid, nickel metal hydride, nickel cadmium and sodium-based batteries used in electric vehicles. The standard is applicable for all EVs (HEV/ BEV/ PHEV). The tests that are carried out are covered in performance standards for lead-acid batteries.

SAE J2288 defines a standardized test method to determine the expected service life, in cycles, of electric vehicle battery modules. The various tests under this standard are mentioned in performance standards for lead-acid batteries, as it is applicable across lead acid chemistry and nickel metal hydride as well.

SAE 1798 covers recommended practice for performance rating of nickel metal hydride and lead acid electric vehicle battery modules. The test conditions for multiple functional parameters specified in the standard are captured in performance standards for lead-acid batteries.

IS 13514: 2015 specifies the general test requirements (measuring instruments, provisions, test samples and temperatures, etc.), information on dynamic discharge performance test, dynamic endurance test, testing parameters for battery systems. The standard specifies various general provisions for the tests viz. current slew rate, temperature, and mechanical support. The specifics of the standard are mentioned in performance standards for lead-acid batteries.

In addition to the above, following additional standards relevant for performance assessment of NiMH batteries are stated below:

Table 20: Performance standards for Nickel Metal Hydride Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**SAE**	**J2758**	**Global**	• Lays down procedure for determination of the Maximum Available Power from a Rechargeable Energy Storage System on a Hybrid Electric Vehicle
2.	**SAE**	**J1634**	**Global**	• The standard looks forward to determining energy consumption and range of light duty vehicles (LDVs) based on federal emission test procedure (FTP). An urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) are used to provide a flexible testing methodology that is capable of accommodating additional test cycles as needed.

Source: SAE

The standards for measuring performance of Nickel Metal Hydride chemistries are identical to that of Lead acid. The reference standard is very comprehensive and has all the necessary tests required to assess the performance parameters for batteries and the standard also defines method for cycle life assessment which is in line with the Indian operating conditions.

Batteries of electric vehicles have to withstand stress originating out of the manner in which vehicles are driven. Subjecting the vehicle to sudden acceleration, braking, driving up in an inclined path, frequent starts / stops in the road, etc. are some of the various driving profiles which a battery has to withstand. All these profiles affect the battery performance which can vary from the performance of a battery at normal use conditions. A battery must demonstrate satisfactory performance in all of these conditions.

Tests specified by IEC and SAE take into account several of the above conditions to determine how a battery is performing at such driving conditions. Although the Indian standards for the performance requirement of EV traction lead acid batteries are referenced from IEC 61982 and are comprehensive, yet the following points may be looked at:

1) **Measuring rated capacity at -20 °C may not be relevant for a large geography within Indian.**

2) **Rated capacity could be measured at different charge / discharge rates as specified by SAE J1798**

3) **EV battery must be able to deliver rated power during high acceleration periods. Methodology for measurement of this could be adopted from SAE J1798. Storage capacity test specified by SAE J1798 could be utilized.**

4) **Electric vehicles could be subjected to long duration of idling and hence it is important to ensure batteries do not lose energy when kept at rest for long duration.**

5) **There is no methodology specified by BIS to measure cycle life. The same could be adopted from SAE J2288 / IEC 61982.**

Safety standards

Safety requirements for NiMH batteries have been adequately covered in International and Indian standards. In addition, both BIS and ARAI have developed safety standards for NiMH.

IS 13514-4:2018 follows the test procedures from IEC 61982-4:2015. The standard defines multiple safety requirements for NiMH cells and modules used in Electric vehicles. The array of tests in the standard are mentioned below.

Standard: IS 13514-4: 2018[44]	
Scope and Coverage	• This covers safety requirements for NiMH cells and modules used in Electric vehicles for propulsion.
Reference Standard	• IEC 61982-4: 2015
Key Operational Parameters	• <u>**Mechanical shock test**</u>: The cells are adjusted to a SoC of 100% for BEV and 80% for HEV applications respectively. A half-sine shock is applied with a peak acceleration of 50g having pulse duration of 11 milliseconds. Three such shocks are applied in the positive direction followed by three shocks in the negative direction for each of the three mutually perpendicular axes, totaling to 18 shocks. • <u>**Crush test**</u>: The cells are adjusted to SoC of 100% for BEV and 80% for BEV applications respectively. A semicircular bar for cylindrical cells and a hemispherical crushing tool for prismatic cells is used to crush the cells at a speed of 6 mm/min. The force is released if the battery undergoes deformation by more than 15% from initial dimension or the voltage drops by more than 1/3rd of initial value. The cells are then kept under observation for 24 hours or until cell temperature declines to 80% of maximum temperature rise. • <u>**Vibration test**</u>: The cells are adjusted to SoC of 100% for BEV and 80% for BEV applications respectively. The cells are then subjected to a vibration having sinusoidal waveform with logarithmic sweep between 7Hz and 50Hz and back to 7

[44] BIS IS 13514-4:2018 Standard Document

Standard: IS 13514-4: 2018[44]

Hz traversed in 15 min. The cycle is repeated 12 times for a total of 3 hours in the vertical direction of mounting orientation of the cell as specified by manufacturer.

- **High temperature endurance test**: The cells are adjusted to SoC of 100% for BEV and 80% for BEV applications respectively. Then, the cells are placed in a circulating air convention oven maintained at a temperature of 60°C ± 2K for a period of 2 hours. Then the cell is placed in ambient temperature of 25 °C ± 2K for 1 hour in the oven.
- **Temperature cycling test**: The cells are subjected to a temperature of 60°C ± 2K or higher (if requested by manufacturer) for 6 hours followed by storage at -40°C ± 2K or lower if requested by manufacturer. The process is repeated for at least 5 such cycles after which the cells are stored for 24 hours at ambient temperatures.
- **External short circuit test**: This test is carried out on fully charged cells. A short-circuit is applied by connecting the positive and negative terminals with an external resistance of equal to or less than 5 mΩ for 10 minutes. The cell is then observed for 1 hour at ambient temperature for evidence of fire or explosion.
- **Overcharge test**: The cell is adjusted to 100% state of charge and charged beyond rated capacity with charging current as specified by the manufacturer. When the cell reaches 3 times its rated voltage, charging is continued until 200% of rated capacity is reached. Then the cell is observed for 1 hour at ambient temperature.
- **Forced discharge test**: The cell is fully discharged at 1 I_t (rated current at rated capacity) for 90 mins till it reaches -3 V. Then the cell is continued to be discharged to 150% of the rated capacity while maintaining the -3V voltage.
- **In all of the above tests, the cells should not exhibit evidence of fire or explosion for the test to be considered successful**.

IS 16894-3: 2018 is based on IEC 62485. The standard provides requirements on safety aspects associated with the installation, use, inspection, maintenance and disposal of batteries. The various aspects of the standard are mentioned in safety standards for lead acid batteries.

AIS-048 is focused on the safety requirements of traction batteries. The standard is applicable for L (two wheelers), M (four wheelers), and N (four wheelers used for carrying goods and also persons) category vehicles. The various requirements under the standard are mentioned in safety standards for lead acid batteries.

Electric vehicles may be subjected to different terrains such as hills, troughs, inclines, etc. Moreover, vehicles have a tendency to roll over during accidents or unintended shocks. During unintended physical impacts, the vehicles / batteries could be physically crushed / penetrated by external objects. Moreover, the batteries could be subjected to extreme ambient conditions while driving and intrusion by foreign substances. In all such situations, it must be ensured that batteries do not cause any harm to passengers due to leakage, explosion, short-circuits, etc.

These standards hence prescribe a wide variety of tests to ensure all of the above. Traction batteries should be tested for all such scenarios since driving in Indian conditions, where traffic density is high, requires that OEMs must maintain adequate mechanism for ensuring safety of passengers. An assurance that batteries would be safe in all such conditions would be instrumental in instilling the consumer confidence in such technologies and large uptake of electric vehicles in India.

IS 16894 provides a good reference point for assessing the safety standard of NiMH batteries. The standards take reference from multiple international standards and cover the necessary tests and requirements for safety of batteries.

AIS 048 in many ways can be considered as an abuse testing and reliability standard due to its large array of tests but at the same time, the standard lacks in certain aspects such as thermal shock test, thermal cycling, fire test, emissions and flammability. These aspects could be derived from UL 2580 to make lead acid batteries safer for mobility applications in the future.

Transportation standards

QC/T, BIS, and SAE have developed transportation standards for NiMH chemistries. No other international and Indian standards organizations have transportation standards for NiMH batteries.

Table 21: Transportation standards for Nickel Metal Hydride Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, **transportation** and storage and package of battery enclosure in the traction battery system of electric vehicles. • This is applicable to vehicle charging battery enclosure and swapping battery enclosure.
2.	**BIS**	**IS 16894: Part 2: 2018**	**Indian**	• The standard covers lead-acid and NiCd/NiMH batteries and describes the principal measures for protections against hazards generated from electricity, gas emission or electrolytes. • **Transportation, storage, disposal, and environmental aspects** • The clause specifies the following international regulations for transport, safe packing and carriage of dangerous goods depending on the geographic area and mode of transport: ○ **By road:** European Agreement for the International Carriage of Dangerous Goods by Road (ADR) ○ **By rail (international):** International Convention concerning the Carriage of Goods by Rail (CIM) ○ **By sea:** International Maritime Organisation, Dangerous Goods Code IMDG Code 8 Class 8 corrosives ○ **By Air:** International Air Transport Association (IATA), Dangerous Goods Regulations
3.	**SAE**	**J2289**	**Global**	• Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • This also covers termination, retention, venting system, thermal management, and other features

Source: SAE, QC/T, BIS

Recycling standards

CENELEC, IEC and SAE have devised recycling standards for NiMH chemistry of traction batteries. The Indian standards organizations are yet to publish standards related to recycling of NiMH batteries. Overview of the international standards is reproduced below:

Table 22: Recycling standards for Nickel metal hydride traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC/ CENELEC**	**IEC 61429**	**Global**	• These standard covers mechanism of marking of secondary cells and batteries with the international recycling symbol ISO 7000-1135. The standard defines the conditions of utilization of the recycling symbol of the International Organization for Standardization (ISO) associated with the chemical symbols indicating the electrochemical system of the battery.
2.	**SAE**	**J3071**	**Global**	• This standard specifies Automotive Battery Recycling Identification and techniques for prevention of cross contamination. The standard is intended to provide

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
				information that may be applicable to all types of Rechargeable Energy Storage System (RESS) devices.
3.	**SAE**	**J2984**	**Global**	• The standard is intended to support the proper and efficient recycling of rechargeable battery systems used in transportation applications with a maximum voltage greater than 12V (including SLI batteries).

Source: IEC, CENELEC, SAE

IEC, CENELEC, ISO, and SAE have comprehensive standards for recycling batteries. ISO, IEC, and CENELEC cover the necessary enablers for recycling through adequate markings and symbols whereas SAE has provided necessary guidelines to prevent contamination and systems to recycle the rechargeable batteries used in electric batteries.

India presently has Battery Waste Management Rules which covers lead acid batteries in particular but necessary standards for recycling for each chemistry would enable additional clarity and demarcation of chemistry-wise requirements for an effective recycling ecosystem.

Standards for Nickel Cadmium Chemistry

The table below gives a snapshot of International and Indian standards for the chemistry.

Table 23: Snapshot of Nickel Cadmium battery Standards

Type	General	Performance and Lifecycle	Safety	Transportation	Recycling
Global	IEC 62902:2019, QC/T 1023-2015	IEC 61982: 2012, J2288, J2578, J1634	IEC 62485-3:2014, J2289, QC/T 989-2014, UL2271	QC/T 989-2014, J2289	EN 61429:1996, IEC 61429:1995, J3071, J2984
Indian	-	IS 13514: 2015	AIS 048, IS 16894: Part 3: 2018	IS 16894: Part 2: 2018	-

General standards

The table below captures the general standards available internationally.

Table 24: General standards for Nickel Cadmium Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC**	**IEC 62902:2019**	**Global**	• This standard specifies methods for the clear identification of secondary cells, batteries, battery modules and monoblocs according to their chemistry (electrochemical storage technology). This is applicable for secondary cells, batteries, battery modules and monoblocs with a volume of more than 900 cm^3.
2.	**QC/T**	**QC/T 1023-2015**	**Global**	• The standard covers general requirement of traction battery system for electric vehicles. It also stresses upon the assembly of traction battery system, its component interfaces, identification markings, transportation and storage of lithium-ion batteries used in electric vehicles.

Source: IEC, QC/T

Performance standards

SAE and IEC have developed performance standards for Nickel Cadmium based chemistries. When it comes to the Indian standards, there aren't any standards covering the performance aspect of Nickel Cadmium batteries used for electric vehicle traction.

IEC 61982: 2012 is a standard applicable to lead acid, nickel metal hydride, nickel cadmium and sodium-based batteries used in electric vehicles to conduct performance and endurance tests. The standard is applicable for all EVs (HEV/ BEV/ PHEV). The tests are carried out system and sub-system level of the batteries as covered in performance standards for lead acid batteries.

SAE J2288 defines a standardized test method to determine the expected service life, in cycles, of electric vehicle battery modules. The various tests under this standard are mentioned in performance standards for lead acid batteries as the standard is applicable across lead acid chemistry and nickel metal hydride as well.

IS 13514: 2015 specifies the general test requirements (measuring instruments, provisions, test samples and temperatures, etc.), information on dynamic discharge performance test, dynamic endurance test, testing parameters for battery systems. The standard specifies various general provisions for the tests viz. current slew rate, temperature, and mechanical support. The specifics of the standard are mentioned in performance standards for lead acid batteries.

Other than the two international standards mentioned above, there are two more standards covering the performance aspect of nickel cadmium batteries as highlighted in the table below.

Table 25: Performance standards for Nickel Cadmium Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**SAE**	**J2758**	**Global**	• This lays down the procedure for determination of the Maximum Available Power from a Rechargeable Energy Storage System on a Hybrid Electric Vehicle
2.	**SAE**	**J1634**	**Global**	• Battery Electric Vehicle Energy Consumption and Range Test Procedure are illustrated in this document. The standard lays out a procedure to determine energy consumption and range of light duty vehicles (LDVs) based on federal emission test procedure (FTP). An urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) are used to provide a flexible testing methodology that is capable of accommodating additional test cycles as needed.

Source: SAE

Tests specified by IEC and SAE take into account several of the above conditions to determine how a battery is performing at such driving conditions. Although the Indian standards for the performance requirement of EV traction lead acid batteries are referenced from IEC 61982 and are comprehensive, yet the following point may be looked at:

1) **There is no methodology to measure cycle life of traction batteries in BIS standards. The same could be adopted from SAE J2288 / IEC 61982**

Safety standards

Safety standards for Nickel Cadmium EV traction batteries have been covered in certain standards which cater to multiple other battery chemistries. One such example is **IS 16894-3: 2018**. The standard has been referenced from IEC 62485 and provides requirements on safety aspects associated with the installation, use, inspection, maintenance and disposal of batteries. The various aspects of the standard are mentioned in safety standards for lead acid batteries.

ARAI has come out with **AIS-048** which is focused on the safety requirements of traction batteries. The standard is applicable for L (two wheelers), M (four wheelers), and N (four wheelers used for carrying goods and also persons) category vehicles. The various requirements under the standard are mentioned in safety standards for lead acid batteries.

Table 26: Safety standards for Nickel Cadmium Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC, CENELEC**	**IEC 62485-3:2014**	**Global**	• This applies to secondary batteries and battery installations used for electric vehicles, e.g. in electric industrial trucks (including lift trucks, tow trucks, cleaning machines, automatic guided vehicles), in battery powered locomotives, in electric vehicles (e.g. goods vehicles, golf carts, bicycles, wheelchairs), and does not cover the design of such vehicles. • It provides requirements on **safety aspects** associated with the **installation, use, inspection, maintenance and disposal** of batteries.
2.	**SAE**	**J2289**	**Global**	• This describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • This also covers termination, retention, venting system, thermal management, and other features
3.	**QC/T**	**QC/T 989-2014**	**Global**	• This specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles. • This is applicable to vehicle charging battery enclosure and swapping battery enclosure.
4.	**UL**	**UL 2271**	**Global**	• This covers electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in light electric-powered vehicles (LEVs) as defined in this standard. • The batteries must withstand overcharging, over-discharging, short circuit, imbalanced charging, and operation at maximum specified temperature in addition to withstand vibration, shock, crushing, drops, and roll overs. The batteries must also pass environmental tests such as immersion test and exposure test to stated IP67 rating and rapid thermal cycling from extremes of hot to cold and cold to hot.

Source: IEC, CENELEC, ISO, SAE, QC/T, UL

Transportation standards

QC/T, BIS and SAE have developed transportation related standard for NiCd batteries as listed in the table below:

Table 27: Transportation standards for Nickel Cadmium Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, **transportation** and storage and package of battery enclosure in the traction battery system of electric vehicles. • This is applicable to vehicle charging battery enclosure and swapping battery enclosure.

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
2.	**BIS**	**IS 16894: Part 2: 2018**	**Indian**	• The standard covers lead-acid and NiCd/NiMH batteries and describes the principal measures for protections against hazards generated from electricity, gas emission or electrolytes. • The standard specifies the following international regulations for transport, safe packing and carriage of dangerous goods depending on the geographic area and mode of transport: ○ **By road:** European Agreement for the International Carriage of Dangerous Goods by Road (ADR) ○ **By rail (international):** International Convention concerning the Carriage of Goods by Rail (CIM) ○ **By sea:** International Maritime Organisation, Dangerous Goods Code IMDG Code 8 Class 8 corrosives ○ **By Air:** International Air Transport Association (IATA), Dangerous Goods Regulations
3.	**SAE**	**J2289**	**Global**	• Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • Also covers termination, retention, venting system, thermal management, and other features.

Source: SAE, QC/T, BIS

Recycling standards

CENELEC, IEC and SAE have devised recycling standards which cater to NiCd chemistry of traction batteries. The Indian standards organizations are yet to publish standards related to recycling of NiCd batteries. Overview of the international standards is reproduced below:

Table 28: Recycling standards for Nickel Cadmium Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC/ CENELEC**	**IEC 61429**	**Global**	• This standard covers mechanism of marking of secondary cells and batteries with the international recycling symbol ISO 7000-1135. The standard defines the conditions of utilization of the recycling symbol of the International Organization for Standardization (ISO) associated with the chemical symbols indicating the electrochemical system of the battery.
2.	**SAE**	**J3071**	**Global**	• This standard specifies Automotive Battery Recycling Identification and techniques for prevention of cross contamination. The standard is intended to provide information that may be applicable to all types of Rechargeable Energy Storage System (RESS) devices.
3.	**SAE**	**J2984**	**Global**	• The standard is intended to support the proper and efficient recycling of rechargeable battery systems used in transportation applications with a maximum voltage greater than 12V (including SLI batteries).

Source: IEC, CENELEC, SAE

BIS standards under preparation

Following are various standards which are under preparation by BIS:

Table 29: Indian Standards under development

Standard Name	Focus Area	Details
TED 27 (12443)	**Safety**	• This covers Electrically propelled road vehicles and contains safety requirements for lithium-ion traction battery packs and systems
TED 27 (12444)	**Safety**	• This covers Electrically propelled mopeds and motorcycles and covers safety requirements for lithium-ion battery systems
TED 27 (12893)	**Safety**	This covers the basic safety and performance requirement of Traction battery (with Battery Management System, Wiring Harness etc.), used for battery operated vehicles. As per BIS, once issued, these standards will replace AIS 048 The draft standard TED 27 (12893) includes Battery Management System, Wiring Harness etc. as parts of battery, which were not defined earlier in AIS 048. Additional tests which are mentioned over and above the ones prescribed in AIS 048 are as follows: - • Electrical Tests o Force discharge o Over temperature • Mechanical Tests o Thermal propagation o Test for mechanical integrity o Test for fire resistance • Environmental Tests o Altitude stimulation test (Low pressure test) o Test for ingress protection Test for electromagnetic compatibility
TED 27 (12893)	**Performance**	This covers the basic safety and performance requirement of Traction battery (with Battery Management System, Wiring Harness etc.), used for battery operated vehicles. As per BIS, once issued, these standards will replace AIS 048 The draft standard TED 27 (12893) includes Battery Management System, Wiring Harness etc. as parts of battery, which were not defined earlier in AIS 048. Additional tests which are mentioned over and above the ones prescribed in AIS 048 are as follows: - • Performance Tests o Test for capacity o Charge retention test o Thermal shock and cycling test
TED 27 (12441 and 12442)	**Performance**	• These standards cater to test specification for lithium-ion traction battery packs and systems for use in electricity propelled road vehicles. It covers high-power and high-energy applications respectively.

Source: BIS

Labs in India undertaking battery standards testing

To carry out the testing as specified by BIS standards, testing laboratories in India need to get accredited by NABL (National Accreditation Board for Testing and Calibration Laboratories). NABL has specified certain technical requirements to be fulfilled by laboratories for getting accredited. For cells and batteries testing, there are 22 labs accredited by NABL as highlighted in the table below.

Table 30: NABL Accredited battery testing labs in India

Sl. No.	Lab Name	Location
1.	Central Power Research Institute	Karnataka
2.	Micro, Small & Medium Enterprises Testing Centre	West Bengal

Sl. No.	Lab Name	Location
3.	Electronics Test and Development Centre	Punjab
4.	Electronics and Quality Development Centre	Gujarat
5.	Testing laboratories, technical services division, BHEL	Madhya Pradesh
6.	Electrical Research and Development Association	Gujarat
7.	Central Electrical Testing Laboratory	Tamil Nadu
8.	National Test House (N.R.)	Uttar Pradesh
9.	National Test House (Southern Region)	Tamil Nadu
10.	National Test House (WR),	Maharashtra
11.	Central Institute of Road Transport	Maharashtra
12.	Bureau Veritas Consumer Products Services (India) Pvt. Ltd.	Uttar Pradesh
13.	Atharva Laboratories Pvt. Ltd.	Uttar Pradesh
14.	TUV Rheinland (India) Private Limited	Karnataka
15.	Bharat Test House Pvt. Ltd.	Haryana
16.	Alpha Test House	Delhi
17.	International Centre for Automotive Technology	Haryana
18.	SGS India Private Limited, Testing Laboratory - Transportation, Consumer and Retail	Maharashtra
19.	Hi Physix Laboratory India Private Limited	Maharashtra
20.	CQAL Laboratories	Karnataka
21.	Transrail Lab, Transrail Lighting Limited	Dadra and Nagar Haveli
22.	Varroc engineering ltd	Maharashtra

While there are adequate number of laboratories carrying out testing, it is understood that Indian standards mainly revolve around lead-acid and nickel-based chemistries. To carry out testing for other advanced chemistries, laboratories may need capacity building and strengthening. Moreover, the additional tests, as suggested above, need to be within the realms of technical competence of these laboratories.

2.3 Global technical regulations for electric vehicle safety

The United Nations Global Technical Regulation (UN GTR) No. 20 specifies safety-related performance of electrically propelled road vehicles and their rechargeable electric energy storage systems. The regulation applies to vehicle of a maximum design speed exceeding 25 km/h, equipped with electric power train containing high voltage bus, excluding vehicles permanently connected to the grid.

The UN GTR requirements are based on available data, research and analysis carried out by industry experts and testing authorities and the Governments of Canada, China, European Union, Japan, Republic of Korea and the United States of America. The regulations state various test procedures to assess the performance for Rechargeable energy storage systems for Electric vehicles when subjected to vibration, thermal shock and cycling, fire, external short circuit, overcharge, over discharge, overtemperature, overcurrent and mechanical shock.

The regulations contain two set of requirements that may be selected by the contracting parties (individual countries or group of countries such as European Union) according to the category and gross vehicle mass (GVM) of the vehicles:

- For all vehicles of Category 1-1 and vehicles of Categories 1-2 and 2 with GVM of 4,536 kg or less
- For vehicles of Category 1-2 and Category 2 with GVM exceeding 3,500 kg

The specific requirements of the regulations with respect to EV batteries are also further studied in this section.

Test procedures for rechargeable electrical energy storage systems

The test procedures initially state the steps for conducting a standard cycle and also for SOC (state of charge) adjustment. Standard cycle starts with a standard discharge followed by a standard charge at an ambient temperature of 20 ± 10 °C. The manufacturer of the battery has to specify the termination criteria for discharge and if not specified, the discharge is done with 1C current for complete battery and battery subsystems. Similarly, the charging rate if not specified by the manufacturer shall be C/3 until the charging normally terminates.

State of charge adjustments are done at an ambient temperature of 20 ± 10 °C for vehicle-based tests and 22 ± 5 °C for component-based tests. For externally charged batteries, SOC is adjusted at 100%, for batteries designed to be charged by the energy from the vehicle, the battery is charged to maximum SOC possible with vehicle operations.

The operational parameters of multiple tests under UN GTR 20 are highlighted below:

Table 31: Operational parameters for various tests in UN GTR 20

Test	Applicability	Parameters
Vibration	**General, Heavy Duty**	• At an ambient temperature of 22 ± 5 °C, with SOC as per REESS set up stated above, the test is begun. Throughout the test, the protection devices are operational. The device under test is then subjected to a vibration having a sinusoidal waveform with a logarithmic sweep between 7 Hz and 50 Hz and back to 7 Hz traversed in 15 minutes. • After repeating the cycle 12 times for a total of 3 hours in the vertical direction of the mounting orientation of the device, the device is subjected to a standard cycle as discussed at the beginning of this section. Post the standard cycle, the device is observed for 1 hour at ambient temperature for any visible changes / reactions.
Thermal shock and cycling	**General, Heavy Duty**	• This test verifies the resistance of the REESS to sudden changes in temperature. After setting the state of charge as per REESS set up, the device is stored for at least 6 hours at 60 ± 2 °C or higher, if requested by the manufacturer, followed by storage for at least 6 hours at -40 ± 2 °C or lower, if requested by the manufacturer. Between the temperature test extremes, a maximum of 30 minutes interval is allowed, and the procedure is repeated for at least 5 cycles. After the cycles, the test device is stored for 24 hours at an ambient temperature of 22 ± 5 °C. Throughout the test, the protection devices are kept operational. • After storing for 24 hours, the test device is subjected to a standard cycle. The test device is observed for 1 hour at ambient temperature for any visible changes / reactions.
Fire Resistance	**General, Heavy Duty**	• As per the manufacturer's choice, the test can be carried out with either gasoline pool fire or LPG burner. During the test, the device is exposed to flame for 2 minutes and the temperature is allowed to reach 800 °C. After direct exposure to the flame, the test device is observed until its surface temperature reaches ambient temperature or has been decreasing for at least 3 hours.
External short circuit protection	**General, Heavy Duty**	• The test is conducted at an ambient temperature of 20 ± 10 °C or a higher temperature if requested by the manufacturer. The state of charge is adjusted as per the battery set up and the protection devices of the battery and subsystem are left operational. For testing, the positive and negative terminals shall be connected using a connection whose resistance shall not exceed 5 mΩ. • The test is continued until the protection function operation of the REESS terminates the short circuit or for at least 1 hour after the temperature measured on casing of the tested device has stabilized with change less than 4 °C through 2 hours. • After the termination of short circuit, the test device is subjected to a standard cycle of discharging and charging if not inhibited by the device due to any failure. The battery is then observed for 1 hour at ambient temperature.

Test	Applicability	Parameters
Overcharge Protection	**General, Heavy Duty**	• The test is conducted at an ambient temperature of 20 ± 10 °C or at a higher temperature if requested by the manufacturer. The state of charge is adjusted as per the battery set up and the protection devices of the battery and subsystem are left operational. • The charging of the battery is carried out either through vehicle driving operation or through external electricity supply. Through vehicle driving operation, the vehicle is driven on a chassis dynamometer and the battery is charged through on-board energy sources such as energy recuperation or on-board energy conversion systems. Through external supply, break-out harnesses are connected to the battery for supplying external electricity. In both the cases, charging is continued till it terminates automatically due to the installed protection device. • After the termination, the test device is subjected to a standard cycle of discharging and charging if not inhibited by the device due to any failure. The battery is observed for 1 hour at ambient temperature.
Over-discharge protection	**General, Heavy Duty**	• The test is conducted at an ambient temperature of 20 ± 10 °C or at a higher temperature if requested by the manufacturer. The state of charge is adjusted as per the battery set up and the protection devices of the battery and subsystem are left operational. • Discharge is carried out based on the battery set up which varies from vehicle driving operation to auxiliary equipment to discharge resistor to external equipment till the discharge terminates automatically. • In vehicle driving operation, the vehicle is driven on a chassis dynamometer that will deliver a constant discharging power achievable reasonably. With auxiliary equipment, the vehicle shall be switched to a stationery mode that allows for consumption of electrical energy from the batteries to the auxiliary equipment such as air conditioning, heating, lighting, audio-visual equipment, etc. Using a discharge resistor, breakout harnesses are connected to the battery to discharge at normal operating conditions. For all the methods, the discharging is continued till the battery is discharged to 25% of nominal voltage level. • After the termination, the test device is subjected to a standard cycle of discharging and charging if not inhibited by the device due to any failure. The battery is observed for 1 hour at ambient temperature.
Over-temperature protection	**General, Heavy Duty**	• At the beginning of the test, all protection devices relevant to the output of the test such as cooling device are kept operational except for system deactivation. • The tested devices shall be continuously charged and discharged by the external charge/discharge equipment with a current that will increase the temperature of cells as rapidly as possible. This is done within the range of normal operation as defined by the manufacturer. The charging and discharging may also be conducted by vehicle driving operations on chassis dynamometer in consultation with manufacturer to determine operating conditions. • The temperature of the chamber housing the tested device shall be gradually increased from 20 ± 10 °C until the operational threshold specified for the device. The test is ended when the device restricts charging/ discharging or the temperature of the device is stabilized (varies less than 4 °C in 2 hours) or any failure occurs leading to venting, leakage, fire, or explosion.
Overcurrent protection	**General, Heavy Duty**	• The test is conducted at an ambient temperature of 20 ± 10 °C or a higher temperature if requested by the manufacturer. The state of charge is adjusted to around the middle of normal operating range as recommended by the manufacturer. The overcurrent level and maximum voltage shall be determined, if necessary, through consultation with the manufacturer. The battery is subjected to overcurrent while being charged. • The test is stopped when the protection device automatically terminates current flow or when the temperature of the device is stabilized (varies less than 4 °C in 2 hours). After the termination, the test device is subjected to a standard cycle of discharging and

Test	Applicability	Parameters
		charging if not inhibited by the device due to any failure. The battery is observed for 1 hour at ambient temperature.
Mechanical shock	**General, Heavy Duty**	• At an ambient temperature of 20 ± 10 °C and state of charge as per set up of battery mentioned in the beginning of this section with all protection devices operational, the test is initialized. The tested device is then accordingly put through deceleration and acceleration cycles as specified in the regulations. After completing the cycles, the device is put into an observation of 1 hour at ambient temperature to observe any changes.
Mechanical Integrity	**General**	• The purpose of this test is to verify the safety performance of the REESS under contact loads which may occur during vehicle crash situation. At an ambient temperature of 20 ± 10 °C and state of charge as per set up of battery mentioned in the beginning of this section with all protection devices operational, the test is initialized. • The device is crushed between a resistance and crush plate with force of 100 kN but not exceeding 105 kN with an onset time less than 3 minutes and a hold time of at least 100 ms but not exceeding 10 seconds. After the crushing is complete, the device is put into an observation of 1 hour at ambient temperature to observe any changes.

Source: UN GTR 20; Note: General: all vehicles of Category 1-1 and vehicles of Categories 1-2 and 2 with GVM of 4,536 kg or less; Heavy Duty: Vehicles of Category 1-2 and Category 2 with GVM exceeding 3,500 kg

The requirements from each of the test is mentioned in the consequent sections covering requirement of safety performance in use and after crash.

Requirements specified in GTR for batteries in EVs

The GTR regulations provide multiple requirements for REESS (Rechargeable Electrical Energy Storage System) in a vehicle. The requirements for REESS are as follows:

1. Requirement with regard to installation and functionality of REESS in a vehicle
2. Requirements with regard to safety of REESS – in use
3. Requirements with regard to safety of REESS – post crash

The requirements stated above are provided for EVs in general and also specifically for Heavy duty vehicles.

Regarding installation and functionality of REESS in a vehicle

The regulations required adherence to basic requirements that have to be met prior to the installation of REESS in vehicles. These include safety requirements of REESS in use and post-crash conditions. Following are the various installation requirements to be complied to:

- The components of the REESS should be properly insulated from the body frame of the vehicle to prevent contact with possible obstacles on the ground.
- The vehicle shall provide warning to the driver in the event of failure of controls that manage the safe operations of the REESS. Vehicle manufacturers have to furnish system diagrams of the battery identifying what components are used to generate a warning due to operational failure and an explanation on the basic operation of the vehicle controls managing the battery's operations.
- In case of a thermal event, the warning should be provided to the driver. Vehicle manufacturer shall provide the parameters (e.g. temperature, temperature rise rate, SOC level, voltage drop, electrical current, etc.) and their threshold levels to indicate that a thermal event has happened. A system diagram describing operation of sensors and operations of vehicle controls to manage the REESS should also be provided.
- Along with warnings for operational failures and thermal events, the REESS must also have warning system to determine low energy content left in the REESS.

Regarding safety of REESS in-use

The REESS in-use are observed after all the tests mentioned in Table 31. Based on the observations, whether the REESS fits the requirements or not is determined. The requirements are mentioned below for general electric vehicles and heavy-duty vehicles.

Requirement	General Electric Vehicle Tests	Heavy Duty Vehicle Tests
• No evidence of electrolyte leakage, rupture, venting, fire or explosion.	• Vibration, Thermal shock and cycling, Fire resistance, External short circuit, Overcharge protection, Over-discharge, Over-temperature, Overcurrent	• Vibration, Thermal shock and cycling, Fire resistance, External short circuit, Overcharge protection, Over-discharge, Over-temperature, Overcurrent
• No evidence of explosion.	• Fire resistance	• Fire resistance

Source: UN GTR 20; Note: General: all vehicles of Category 1-1 and vehicles of Categories 1-2 and 2 with GVM of 4,536 kg or less; Heavy Duty: Vehicles of Category 1-2 and Category 2 with GVM exceeding 3,500 kg

Regarding safety of REESS post-crash

The UN GTR 20 specifies certain requirements to be adhered for being compliant with the regulations. For ascertaining safety of REESS after crash, there should be no evidence of electrolyte leakage, fire or explosion after the tests mentioned in Table 31 are conducted. The applicable test(s) for general electric vehicles and heavy-duty vehicles for this safety aspect are captured below.

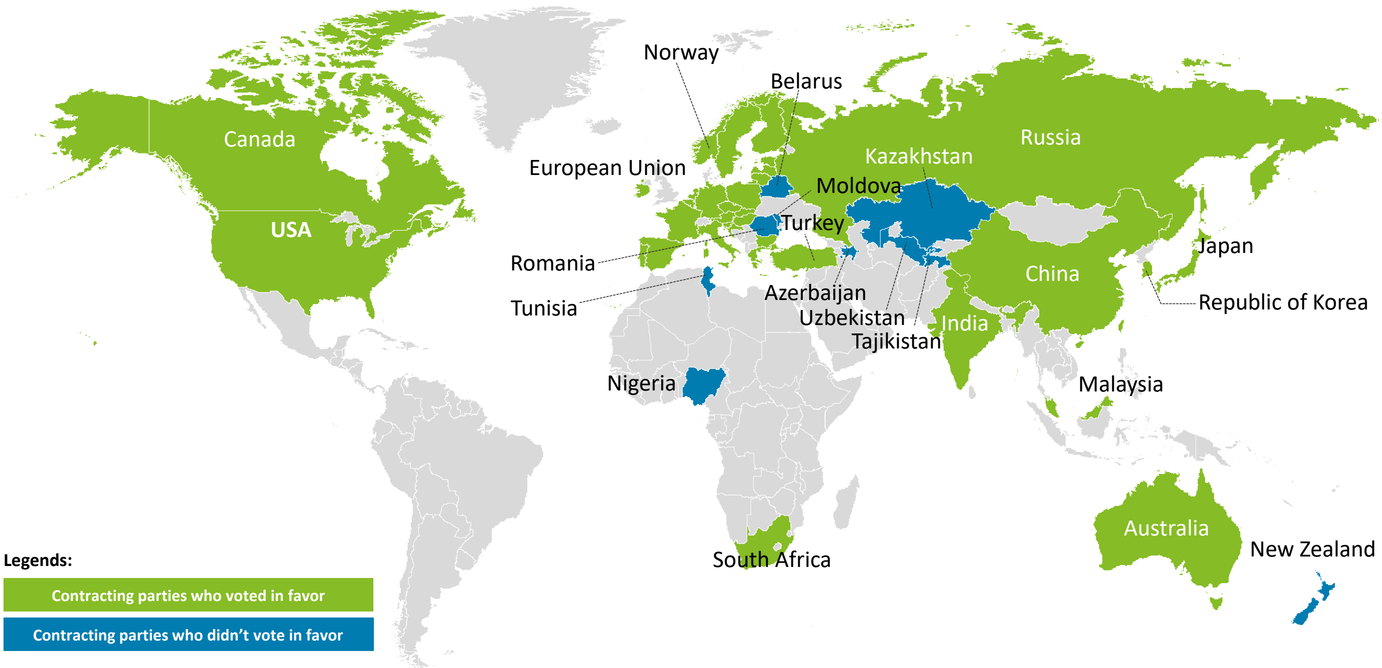
Requirement	General Electric Vehicle Tests	Heavy Duty Vehicle Tests
• No evidence of electrolyte leakage, fire, or explosion.	• Mechanical shock, Mechanical Integrity (crush)	• Mechanical shock

Source: UN GTR 20; Note: General: all vehicles of Category 1-1 and vehicles of Categories 1-2 and 2 with GVM of 4,536 kg or less; Heavy Duty: Vehicles of Category 1-2 and Category 2 with GVM exceeding 3,500 kg

Status of GTR for batteries in EVs across the world

The Global Technical Regulations have 24 Contracting parties (countries). The 24 contracting parties are Australia, Azerbaijan, Belarus, Canada, China, European Union, India, Japan, Kazakhstan, Republic of Korea, Malaysia, Moldova, New Zealand, Nigeria, Norway, Romania, Russian Federation, San Marino, South Africa, Tajikistan, Tunisia, Turkey, United States of America and Uzbekistan.

Figure 21: Contracting parties and their voting of GTR No. 20



Source: Deloitte Analysis

Out of the 24 contracting parties, 11 didn't vote in favor of GTR No. 20. The parties voting in favor are Australia, Canada, China, European Union, India, Japan, Republic of Korea, Malaysia, Norway, Russia, South Africa, Turkey and USA.

Table 32: Status of GTR 20 amongst contracting parties

Sl. No.	Contracting Parties	Status	Details
1.	**Australia**	**In process**	• The country has submitted the 1st status report in July 2019. The country accepted category 1 and 2 vehicles that comply with GTR without adopting into its own laws since the GTR was established. In accordance with Article 7.4 of the GTR, Australia is continuing to study the case for the adoption of GTR No.20 into its own laws.
2.	**Canada**	**In process**	• The country has submitted the 1st status report in March 2021. At present, Canada has no regulatory requirements regarding electric vehicles, but should it decide to move forward with a regulatory proposal it will consider the UN GTR and its subsequent amendments.
3.	**China**	**Established**	• China submitted the 1st status report in November 2018. With some modification, China has established the standards of Electric vehicles safety requirements, Electric vehicles traction battery safety requirements, and electric buses safety requirements, with full coordination with GTR NO.20 and widely soliciting comments of automotive manufacturers both home and abroad. Now the standard content has been completed and is in the process of approval and release.
4.	**European Union**	**Status unavailable**	• As of June 2021, there is no fresh status on the same after the vote on GTR No. 20.
5.	**India**	**Status unavailable**	• As of June 2021, there is no fresh status on the same after the vote on GTR No. 20.
6.	**Japan**	**In Process**	• Japan provided the 1st status report in May 2019. As per the status report, Japan awaited the amendment to UN Regulation 100 by the working party on Passive safety and intends to incorporate GTR No. 20 into its national regulations.
7.	**Republic of Korea**	**Established**	• Submitted the 1st status report in July 2021. As per the status report, the date for the mandatory application of GTR No.20 was from 10th May 2021. The country has implemented the GTR in Ordinance of Enforcement Vehicle Regulation.
8.	**Malaysia**	**Status unavailable**	• As of June 2021, there is no fresh status on the same after the vote on GTR No. 20.
9.	**Norway**	**Status unavailable**	• As of June 2021, there is no fresh status on the same after the vote on GTR No. 20.
10.	**Russia**	**In process**	• Russia submitted its 2nd status report in June 2021. As per the report, the GTR will be included in the Customs Union Technical Regulation on safety of wheeled vehicles.
11.	**South Africa**	**Status unavailable**	• As of July 2021, there is no fresh status on the same after the vote on GTR No. 20.
12.	**Turkey**	**Status unavailable**	• As of July 2021, there is no fresh status on the same after the vote on GTR No. 20.
13.	**USA**	**Status unavailable**	• As of July 2021, there is no fresh status on the same after the vote on GTR No. 20.

It can be seen that GTR No. 20 has found a mixed reaction from the contracting parties. Nearly half of the parties didn't vote for the regulation but the countries voting in favor have taken several steps in adopting the same. Two countries, China and Republic of Korea have successfully established the GTR. Japan and Russia are on the cusp of implementing the regulations.

2.4 Standards applicable for communication between the battery, the various components of the EV and EVSE

The various standards which relate to communication between the battery and various components on the EV and EVSE are shown in the table below:

Table 33: Standards applicable for communication

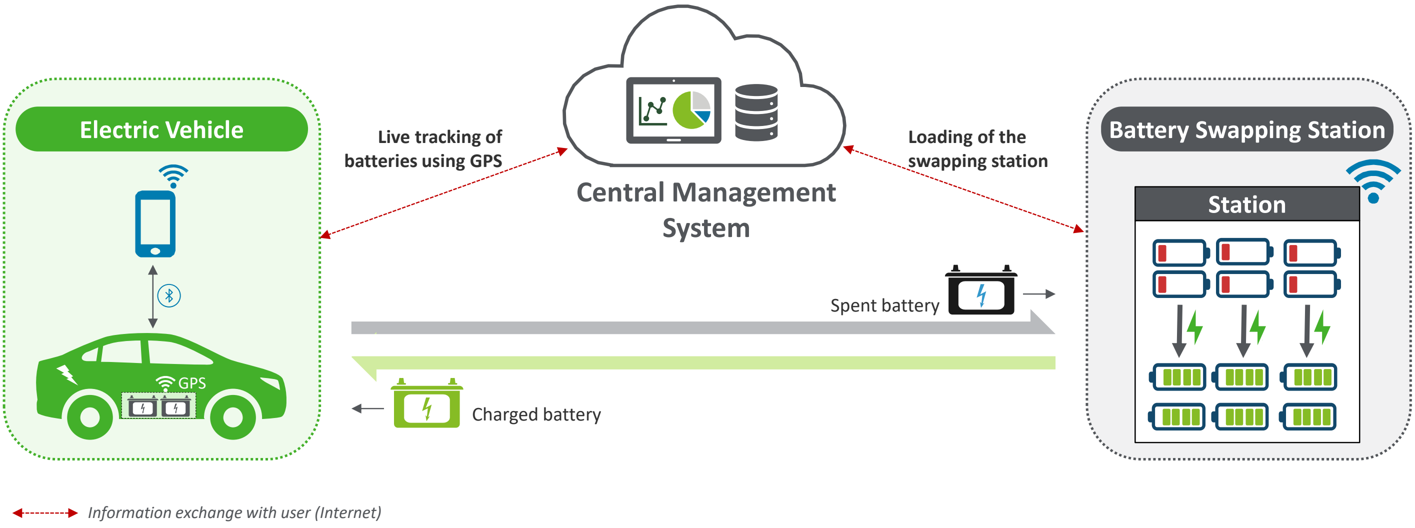
Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC / CENELEC**	**IEC / EN 61851-24:2014**	**Global**	• This specifies the mechanism of digital communication between a D.C. EV charging station and an electric vehicle for control of D.C. charging, with an A.C. or D.C. input voltage up to 1 000 V A.C. and up to 1 500 V D.C. for the conductive charging procedure.
2.	**ISO**	**ISO 15118-1:2019**	**Global**	• The standard specifies terms and definitions, general requirements and use cases for conductive and wireless HLC (High Level Communication) between the EVCC (Electric Vehicle Communication Controller) and the SECC (Supply Equipment Communication Controller). • This is also applicable to energy transfer either from EV supply equipment to charge the EV battery or from EV battery to EV supply equipment in order to supply energy to home, to loads or to the grid
3.	**ISO**	**ISO 15118-2:2014**	**Global**	• This specifies network and application protocol requirements for vehicle-to-grid communication. The communication between battery electric vehicles (BEV) or plug-in hybrid electric vehicles (PHEV) and the Electric Vehicle Supply Equipment is specified in this standard.
4.	**ISO**	**ISO 15118-3:2015**	**Global**	• This specifies the physical and data link layer requirements for Vehicle to grid communication are specified in the standard.
5.	**Chinese Standards**	**GB/T 27930-2015**	**Global**	• The standard is based on SAE J1939 and uses CAN bus accordingly for point to point connection between the charger and the BMS. Applicability of the standard spreads across BEVs and HEVs.
6.	**ARAI**	**AIS 138 Part -2**	**Indian**	• This standard gives the requirements for DC electric vehicle (EV) charging stations for conductive connection to the vehicle, with an AC or DC input voltage up to 1000 V AC and up to 1500 V DC. This standard also applies to digital communication between a DC EV charging station and an electric road vehicle (EV) for control of DC charging. Multiple IEC standards such as IEC 61851, ISO 11898, etc. have been utilized to develop the standard.

Source: IEC, CENELEC, ISO, GB/T, ARAI

Locked smart batteries

Battery swapping provides a unique opportunity to do away with waiting time for battery charging. However, the swappable feature of batteries makes it prone to theft. To reduce this risk, there is a need to have integrated systems which would enable the battery to communicate with other battery swapping infrastructure components for monitoring and tracking.

Figure 22: Smart Battery Communication illustration



Source 1: CBEEV, ESMITO, Deloitte Research

The smart batteries utilize CAN (Controlled area network) protocol, Bluetooth Low energy (BLE), GPS and 2G/4G for communication. CAN protocols are used by the BMS (battery management system) to interact with the other systems of the vehicle. The battery has a GPS installed which helps the CMS (central management system) track the batteries and manage the load that the battery swapping operation puts on the grid. The HHD (hand-held device) of the driver connects with the battery through BLE giving updates on the battery charge and other vital information of the battery.

A case in point would be Gogoro which has come up with smart batteries which aggregate to form The Gogoro Network[45]. The batteries contain an array of sensors and a microcomputer that allows it to wirelessly and securely communicate with a central system. The cloud connected flow of data allows the Gogoro Network to manage grid overloading by intelligently scaling and distributing energy. Each battery contains an integrated chip (fully encrypted 256 bit) that also curbs battery theft by subjecting it to monitoring and tracking.

In India, Sun Mobility[46] has introduced smart battery as well. These batteries house over 30 onboard sensors and a GPS tracking system that ensures that it is secured from theft. The batteries also have Bluetooth Low Energy (BLE) which connects to the driver's app providing parameter wise information such as state of charge, distance to empty, nearest quick interchange station, and payment transactions.

Standards applicable for Battery Management System (BMS) in an electric vehicle

The BMS in an electric vehicle has a significant role in safe operations, energy optimization, charging functionality, and overall control of an electric vehicle. The BMS can control the disconnection of the modules from the overall system in the event of an abnormal condition.

Table 34: Standards applicable to Battery Management System

Sl. No.	Organization	Standard	Standard Scope and relevance of BMS
1.	**ISO**	**ISO 6469-1:2019 Edition 3.0**	• This covers safety specifications for electrically propelled vehicles especially on-board rechargeable energy storage system. This standard specifies requirements for the on-board rechargeable energy storage system for electrically propelled vehicles such as hybrid-electric vehicles, battery electric vehicles, and fuel cell vehicles. The standard

[45] Gogoro (access here)
[46] Sun Mobility (access here)

Sl. No.	Organization	Standard	Standard Scope and relevance of BMS
			covers climatic, electrical, functional, and simulated vehicle accident requirements. However, the standard does not comprise of similar requirement for motorcycles.[47]
2.	**ISO**	**ISO 6469-3: 2018**	• This standard specifies electrical safety requirements of voltage class B electric circuit of electric propulsion systems and electrically propelled road vehicles. It specifies electrical safety requirements for protection of persons against electric shock and thermal incidents.
3.	**ISO**	**ISO/TR 11955:2008**	• These guidelines explain the charge balance measurement procedure of hybrid electric vehicles (HEV) with batteries. The document does not consider any test for fully electric vehicles (EV). The "charge balance" term refers to the capacity of the battery.
4.	**SAE**	**SAE J2289: 200807**	• The standard covers the electrical, physical, environmental, safety, and labeling requirements with product description, and shipment characteristics of the battery system for electric vehicles. There is also explanation for abnormal condition operation of the battery system which is very much in line with the functions of BMS.
5.	**IEC**	**IEC 61508**	• This covers the design and safety requirements to be considered while designing a programmable electric and electronic system for safe operation are covered in this standard.[48]

Source: IEC, ISO, SAE

While none of the standards specifically cover the BMS requirements, all these standards have certain requirements which pertain to BMS of a battery system. This is mainly because BMS is more of a standard electronic device that automatically gets covered in specific sections of multiple standards. In addition, many of the safety, abuse testing and reliability related standards mention about safety systems of batteries which automatically covers the functionalities required in a BMS.

[47] Gabbar, H.A.; Othman, A.M.; Abdussami, M.R. Review of Battery Management Systems (BMS) Development and Industrial Standards, 2021

[48] EVERLASTING, Electric Vehicle Enhanced Range, Lifetime And Safety Through INGenious battery management

Indian v/s global standards for traction batteries – Comparison

In terms of battery standards, India standards lag behind international standards such as IEC, ISO, QC/T, etc. when it comes to coverage of the entire battery value chain and extensive testing of batteries in certain aspects. The coverage of various international standards and Indian strandards is shown in the table below:

Table 35: High level comparison of Indian and global standards in terms of availability

Chemistry	Standards				
	General	Performance and Lifecycle	Safety	Transportation	Recycling
Lead Acid	✓	✓	✓	✓	EN 61429:1996, IEC 61429:1995, J3071, J2984
Lithium-ion	✓	✓	✓	QC/T 989-2014, J2950, IEC 62281:2019, UN Manual (Section 38.3), J2289, QC/T 1023-2015, QC/T 743-2006	J3071, J2984
Nickel Metal Hydride	IEC 62902:2019, QC/T 1023-2015, QC/T 840-2010	✓	✓	✓	EN 61429:1996, IEC 61429:1995, J3071, J2984
Nickel Cadmium	IEC 62902:2019, QC/T 1023-2015	✓	✓	✓	EN 61429:1996, IEC 61429:1995, J3071, J2984

✓means that the standard is adopted/ notified in India; Standards mentioned in the table could be referred to develop Indian standards in appropriate regard

2.5 Key takeaways

While existing Indian standards for batteries have comprehensively covered lead-acid, nickel-cadmium, nickel-metal-hydride as well as Lithium based chemistries, there are some additional tests or additional ambient conditions which need to be considered in the Indian standards.

Following are the key inferences based on the comprehensive evaluation of standards:

Particulars	Takeaways
Lead acid	1. International standards such as QC/T cover requirements related to **mechanical strength, environmental resistance and assembly**. QC/T standards also include requirements for other components viz. vehicle **charging battery enclosure** and **swapping battery enclosure** which may be relevant for uptake of swapping business in India 2. **Rated capacity** could be measured at **different charge / discharge rates** as specified by SAE J1798 through newer version of current Indian standards of IS 13514: 2015 3. EV battery must be able to deliver rated power during high acceleration periods. Methodology for measurement of this could be **adopted from SAE J1798**. **Storage capacity test** specified by SAE J1798 could be utilized in newer versions of IS 13514: 2015 and IS 5154: Part 1: 2013 4. Electric vehicles could be subjected to **long duration of idling** and hence it is important to ensure batteries do not lose energy when kept at rest for long duration. During driving conditions, battery should be able to deliver the **minimum rated power**. SAE J1798 specifies a test procedure for the same which can be adopted. 5. There is **no methodology** to **measure cycle life** of traction batteries in BIS standards. The same could be adopted from SAE J2288 / IEC 61982 6. IS 16894 and AIS-048 combinedly provide a good reference point for **assessing the safety standard** of lead acid batteries. 7. AIS 048 lacks in certain aspects such as **thermal shock test, thermal cycling, fire test, emissions** and **flammability;** these aspects could be derived from **UL 2580** to make lead acid batteries safer for mobility applications.
Lithium ion	1. **ISO 12405-4:20181** specifies that energy capacity of a cell should also be measured at **10C**. This is because electric vehicle batteries tend to be exposed to variety of driving conditions. At present, **Indian standards** specifies measurement of energy capacity at **C and C/3 only**. 2. Battery should be able to deliver a proper **cranking power** is in case the vehicle is idle for a long time. Moreover, losses during charging and discharging should also be kept minimum since traction batteries are always subjected to frequent charge and discharges. At present, Indian standard **does not mention** any test for determining **energy efficiency** and **cranking power**. Reference from the same can be taken from IEC and ISO standards 3. IS 16893-3 and AIS-048 combinedly provide a good reference point for assessing the **safety standard of lithium-ion batteries**. IS 16893: Part 2 covers the reliability and abuse testing procedures for lithium-ion chemistry cells but because of the derived nature of the standard, it also carries the shortcomings of IEC 62660-2. The standard lacks some basic **mechanical tests for drop**, **penetration**, and **immersion**. 4. AIS 048 lacks in certain aspects such as th**ermal shock test, drop test, immersion test, fire test, emissions** and **flammability**. These aspects could be referenced from UL 2580. Apart from the tests mentioned, ISO 18243 can also be referred to include **dewing and salt spray tests** which are very relevant for Indian conditions to make batteries safer. 5. AIS-048 covers **mechanical and electrical tests** but **lacks** any tests for **environmental** (thermal tests, temperature related tests) and **chemical tests** (flammability and emission tests). Such aspects for new standards can be derived from **SAE J2929 and SAE J2464** which have complete array of tests when it comes to abuse and reliability tests.

Particulars	Takeaways
	6. QC/T, SAE, and IEC **transportation standards** can be referred to for Li-ion chemistries. 7. At present, there are no standards related to **recycling in India** covering lithium-ion traction batteries. Suitable standards need to be defined for recycling
NiMH chemistry	1. Measuring **rated capacity at -20 °C** may not be relevant for a large geography within Indian. 2. Rated capacity could be measured at **different charge / discharge** rates as specified by SAE J1798 3. EV battery must be able to deliver **rated power** during high acceleration periods. Methodology for measurement of this could be adopted from **SAE J1798**. **Storage capacity** test specified by **SAE J1798** could be utilized. 4. Electric vehicles could be subjected to long duration of idling and hence it is important to ensure batteries do not lose energy when kept at rest for long duration. 5. At present, there are no standards related to **recycling** in India covering NiMH batteries. Suitable standards need to be defined for recycling

To carry out testing for other advanced chemistries, laboratories may need **capacity building** and **strengthening**. Moreover, the additional tests, as suggested above, need to be within the realms of technical competence of these laboratories. In addition, one of the encouraging signs for the Indian battery ecosystem is that the country is one of the contracting parties of the **UN GTR No.20** and this helps in guiding the policy makers to develop the standards and legislations accordingly.

Battery Policies & Regulations

Chapter 3. Review of policy and regulatory environment for traction batteries

3.1 Battery storage policy and regulatory landscape - India

India has charted out an ambitious roadmap in attaining a cleaner fuel-based economy and is currently transitioning away from conventional fuel. With electric mobility expected to play a vital role in this transition, India needs a well-established policy ecosystem for EV batteries. This section highlights the various policy measures adopted by India, both at Central and State level, to promote the EV battery ecosystem.

The assessment of existing policies has been conducted on five (5) key areas viz. 1) Sourcing of raw materials; 2) Battery manufacturing; 3) R&D and supply chain development; 4) Battery swapping; and 5) Reuse & recycle. Figure 1 highlights the key promotional measures adopted by India in each of highlighted areas.

Figure 23: Promotional measures adopted by India for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
– **MoU** between India and Bolivia to develop vast lithium deposits in Bolivia who in turn would supply lithium, cobalt, and lithium carbonate to India – **MoU** between JEMSE and KABIL for future projects related to the exploration and **production of lithium** – **India-Australia Strategic Partnership**: Supply of critical minerals such as Lithium to India	– **National Program on Advanced Chemistry Cell (ACC) Battery Storage:** Incentive payout of INR 18100 crores for 5 years – **National Mission on Transformative Mobility and Battery Storage:** Aims at localizing production – **Automotive Mission Plan 2016-2026:** Incentivize value addition domestically and rationalize custom duties	– Scheme for **Faster Adoption and Manufacturing of Electric Vehicles (FAME) II in India:** Outlay of 10000 crores in a period of three years – Grants for battery **R&D grants** by DHI/ DST	– Draft **Battery Swapping Policy** at national level – Several **state level policies** promote battery swapping	– **Battery Waste management rules 2020:** Mandatory collection of used batteries by dealers and manufacturers against the new ones sold by them – **No uniform regulations** of battery reuse and cycle as of now

In the subsequent sections, we will deep dive into each of the areas as highlighted above.

Sourcing of raw materials

Amongst all the existing technologies, lithium-ion has been gaining the most traction due to its high-performance characteristics (such as energy density, power density, efficiency etc.) and its potential to become one of the cheapest technologies available within the advanced chemistry cells. The key minerals used in the Li-ion batteries are Lithium, Nickel, Cobalt and Manganese. These minerals are used to make the cathode material whereas, predominantly graphite (Natural and Synthetic) is used to manufacture the anode material.

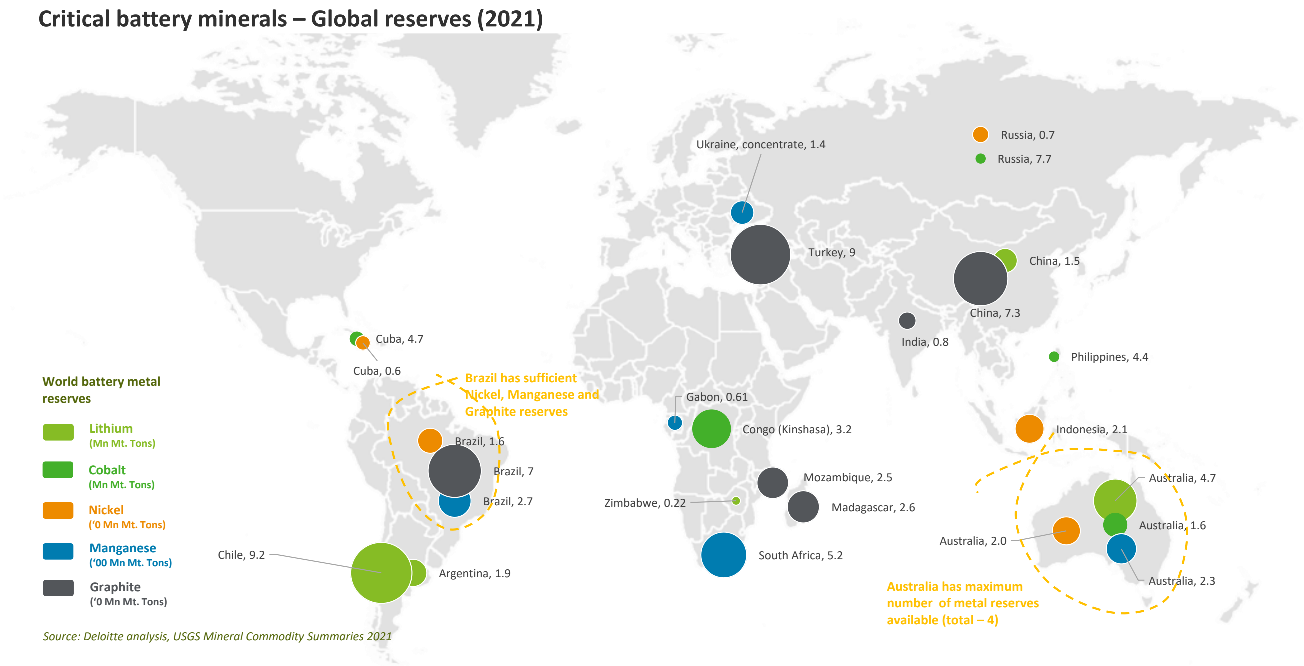
Table 36: Key Minerals in generally used battery technologies

Particulars	Lithium Ion	Lead Acid	Flow Batteries	High Temperature Batteries	Nickel Cadmium	Nickel Metal Hydride
Key Minerals	Lithium, Nickel, Cobalt, Manganese, Graphite	Lead, Antimony, Calcium	Vanadium, Zinc	Sodium, Nickel	Nickel, Cadmium	Nickel, Cobalt, Iron, Zirconium

Focus technology

Global availability of minerals required for **Li-ion battery** is presented in the figure below:

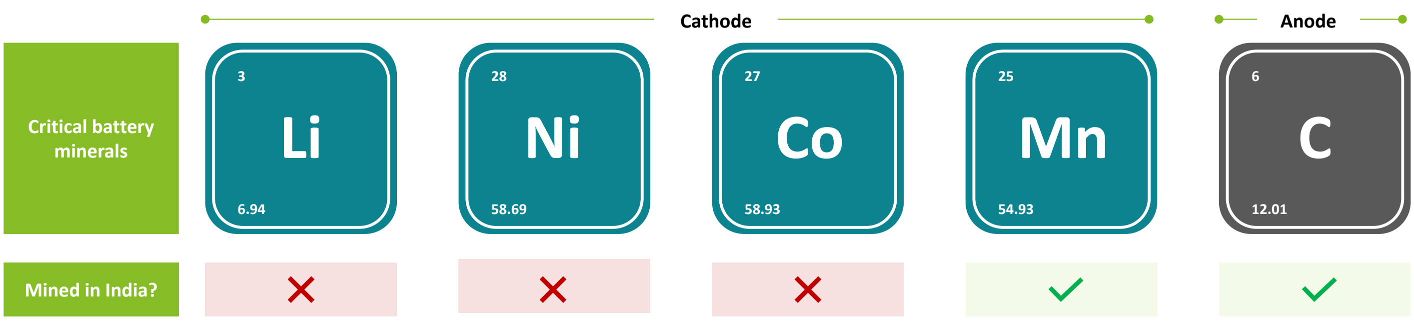
Figure 24: Key mineral reserves worldwide



Source: Deloitte analysis, USGS Mineral Commodity Summaries 2021

Except for Manganese and Graphite, India does not have declared reserves for any of the other battery materials. Shown below is also the geographic distribution of key battery minerals around the world:

Figure 25: Snapshot of battery mineral mining status of India



Due to the absence of key mineral reserves, India needs access to the reserves of resource rich countries. India has already set up commercial arrangements with countries such as Bolivia, Argentina, and Australia. Details of the commercial arrangements are provided below:

South-South Cooperation[49]: A technical cooperation between the developing countries present in the global south.

1. India – Bolivia MoU

India has signed 9 MoUs with Bolivia in 2019. One of the MoUs was on the Cooperation in the field of Geology and Mineral Resources which aimed to promote and expand the bilateral relations in the field of mineral resources and geology. The MoU is responsible for providing an institutional mechanism for co-operation between India and Bolivia for Mineral resources. It will provide for exchange of information on laws and policy, resources, encouraging technology transfer between both the countries, organizing seminars to discuss on development strategies, promoting value addition, etc. The MoU also promotes the industrial use of lithium to manufacture lithium-ion batteries. This will make Bolivia one of the major suppliers of India's e-mobility needs.

This MoU/ partnership between the two countries will foster the development of lithium battery manufacturing plants in India. This agreement paves the way for more Indian companies to set up production capabilities in Bolivia thereby ensuring increase in imports of lithium by India. This agreement was envisioned to be the backbone of Faster Adoption and Manufacture of (Hybrid and) Electric Vehicles (FAME) policy.[50]

India and Bolivia will forge mutually beneficial partnership to foster joint ventures for lithium battery/cell manufacturing in India and facilitate the supply of Lithium Carbonate from Bolivia to India. Both the country will also commercialize Lithium Carbonate and Potassium Chloride produced by Yacimientos de Litio Bolivianos Corporacion (YLB – Corporation). Following are various bilateral knowledge exchange and visits which were carried out in the past:

- A delegation from National Mission on Transformative Mobility and Battery Storage of India also had a follow – up visit to Bolivia in order to facilitate cooperation in battery storage solutions space.
- Khanij Bidesh India Ltd (Joint venture between NALCO, HCL and MECL) had sent a delegation to visit lithium mining areas in Salar de Uyuni in Bolivia.
- A delegation of companies had also visited and held discussions with Bolivian companies.

These bilateral visits would enable India to be a partner to provide the technology knowhow and skills to help Bolivia with the industrialization of its resources. India also announced a $100 million line of credit to Bolivia for developmental projects of interest.

2. India - Argentina MoU

India has established a strategic agreement with Argentina to cooperate in the field of lithium. This agreement fosters joint exploration, production, and commercialization of various mineral products. The goal of the MoU is to develop an ecosystem which fosters the development, building and operations of projects which have higher technological demands in fields such as mining, energy, and natural resource exploitation in Jujuy (province in Argentina). This MoU marks India's response to Chinese dominance and control of key mineral reserves and rare earth metals worldwide. India aims to secure critical minerals, reduce dependency on Chinese markets for the supply of lithium-ion cells and boost domestic manufacturing. Exchange of scientific and technical information, knowledge exchange, promotion of investment and development in the mining sector and training and capacity building are also key tenets of this agreement.

This MoU was signed between Khanij Bidesh India Ltd (Joint venture between NALCO, HCL and MECL) and JEMSE (Argentine state-owned enterprise). The important stakeholders are the Argentine province of Jujuy, JEMSE, Ministry of Productive Development of the Argentine Republic, Ministry of Mines (Government of India) and Khanij Bidesh India Ltd. The MoU allows both the countries to work jointly in exploring and producing lithium and polymetallic and in projects related to value addition of lithium carbonate, production, and transmission of electricity. There is also a possibility of further collaboration in the field of base metals, strategic and critical minerals in the future.

[49] UN Department of Economic and Social affairs (access here)
[50] ET Auto (click here)

India-Australia Strategic Partnership[51]

India signed a MoU on co-operation in the field of mining and processing of critical and strategic minerals with Australia in 2020, to procure critical minerals such as lithium from Australia. The focus is on augmentation of bilateral trade, R&D and investments in critical minerals. The MoU gives a boost to India's drive for self-sufficiency and Australia's need to diversify and strengthen the supply chain. The important stakeholders in this MoU are Ministry of Mines (Government of India) and Ministry of Resources, water and Northern Australia.

Policy environment – Battery manufacturing

National level measures

The Indian battery manufacturing industry is at a nascent stage. To foster the development of battery manufacturing in India, India has adopted a phased manufacturing approach which focuses on localization of pack assembly and long-term local cell production. Several schemes like the ACC battery storage programme, National Mission on Transformative Mobility and Battery Storage and Automotive Mission Plan have focused on incentivizing investments in the battery manufacturing industry.

1. National Mission on Transformative Mobility and Battery Storage[52]

The National Mission on Transformative Mobility and Battery Storage was announced in March 2019 with the mission to drive clean, connected, shared, sustainable, and holistic mobility initiatives. The mission is aimed at reducing India's oil import dependence, improving air quality and enhancing the uptake of renewable energy and storage solutions.

As per this programme, NITI Aayog shall be the steering body. The incentives for manufacturers are categorized into two parts - the first one applicable to all entities interested in opening a Li-ion battery manufacturing plant, and the second only those selected through a competitive process.

The Phased Manufacturing Programme was launched as a part of the National Mission on Transformative Mobility and Battery Storage till 2024 to support setting up of a few large-scale, export-competitive integrated batteries and cell-manufacturing Giga plants in India. The programme is aimed at driving manufacturing, their components and batteries and localize production across the entire value chain. Under this programme, the initial focus shall be on large-scale module and pack assembly by 2019-20. This will be followed by integrated cell manufacturing by 2021-22. The Phased Manufacturing Program proposed to increase the basic custom duties (BCD) on import of electric vehicles and components. The table below presents the targets of the PMP.

Table 37: Phased manufacturing program targets

Sl. No	Item description	BCD as of 30/01/2019	Proposed BCD	Proposed date of PMP
1.	Bus and Truck (Complete Built Up)	25%	50%	April 2020 onwards
2.	PV and e-3W (Complete Built Up)	15%	30%	April 2020 onwards
3.	e-2w (Semi knocked down)	15%	25%	April 2020 onwards
4.	Bus (Semi knocked down)	15%	25%	April 2020 onwards
5.	Truck (Semi knocked down)	15%	25%	April 2020 onwards
6.	Bus (Completely knocked down)	10%	15%	April 2020 onwards
7.	PV (Completely knocked down)	10%	15%	April 2020 onwards
8.	e-2w (Completely knocked down)	10%	10%	April 2020 onwards
9.	e-3w (Completely knocked down)	10%	15%	April 2020 onwards
10.	Truck (Completely knocked down)	10%	15%	April 2020 onwards
11.	Lithium-ion cells for use in manufacturing of lithium-ion accumulator for EVs	5%	10%	April 2021 onwards

[51] Ministry of External Affairs (https://indbiz.gov.in/about-us/)
[52] Press Information Bureau (PIB) (access here)

Sl. No	Item description	BCD as of 30/01/2019	Proposed BCD	Proposed date of PMP
12.	Battery packs for use in the manufacture of EVs	5%	15%	April 2021 onwards
13.	Charger, Motor, Motor controller, Power control unit, Energy monitor, Contactor, Brake system, Electric compressor	0	15%	April 2021 onwards

Source: NITI Aayog (access here)

Note: *In the above table, completely built up (CBU) refers to an EV which is directly imported from its country of origin. Completely knocked down (CKD) refers to the importing sub-assemblies and parts of EVs to assemble in India. Semi knocked down (SKD) refers to importing the EV in parts. In SKD, the parts are more stable as compared to CKD requiring less work on assembling the components*.

2. National Programme on Advance Chemistry Cell (ACC) Battery Storage Manufacturing[53]

NITI Aayog in its "Zero Emission Vehicles (ZEVs): Towards A Policy Framework" report stated that "India needs a minimum of 10 GWh of cells by 2022, which would need to be expanded to about 50 GWh by 2025". Under the National Mission on Transformative Mobility and Battery Storage, Government of India has devised the ACC Battery Storage Programme to incentivize production of Advanced Chemistry Cells (ACC) in India through production-linked incentives.

Under this programme, the government aims to setup 50GWh of Advanced Chemistry Cells (ACCs) manufacturing which will enhance India's domestic capabilities in energy storage. The scheme has been formulated by NITI Aayog and Department of Heavy Industries. The relevant state government, central government and manufacturers will have to enter into a tripartite agreement. The scheme envisages a total incentive payout of INR 18100 crores which will be done over a period of five years. In addition to ACCs, 5 GWh has been earmarked for niche ACC supply.

Under this programme, each ACC battery storage manufacturer selected needs to set up a manufacturing facility of at least 5 GWh capacity and achieve at least 25% domestic value addition within 2 years. The manufacturer must also incur a mandatory investment of INR 225 crore/GWh within 2 years. The beneficiary firms must ensure at least 60% domestic value addition in 5 years. The state government shall extend support to the manufacturer by providing lands for the facility and assist in procuring permits and licenses. Central government will be responsible for disbursement of subsidies / incentives to the manufacturers. The disbursement of incentives will be done over a period of 5 years based on sales, battery cycle life, energy density and value addition done locally.

Box 5: National Programme on Advance Chemistry Cell (ACC) Battery Storage Manufacturing – Award

The production linked incentive scheme received an encouraging response from both local as well as global investors. The scheme attracted a total number of 10 bids which correspond to ~130 GWh capacity (2.6 times of 50 GWh). Ola Electric Mobility Private Limited, Amara Raja Batteries Limited, Reliance New Energy Solar Limited, Mahindra & Mahindra Limited, Larsen & Toubro Limited, Hyundai Global Motors Company, Lucas TVS Limited, Exide Industries Limited, Rajesh Exports Limited and India Power Corporation Limited were the ten companies which had submitted their bids.

Four bidders were selected for the scheme based on QCBS (Quality & Cost Based Selection) namely **Rajesh Exports, Hyundai Global Motors, Ola Electric,** and **Reliance New Energy Solar Limited.** Both Hyundai and Ola Electric were awarded 20 GWh of capacity individually, and Reliance New Energy and Rajesh Exports were awarded 5 GWh of capacity individually.

With the programme kicking-off in 2022, India is expected to have battery cell manufacturing facility of at least 50 GWh by 2027.

Source: Department of Heavy Industries (DHI) (access here)

3. Automotive Mission Plan 2016-2026[54]

The Automotive Mission Plan 2016-26 is the collective vision of the Indian Automotive Industry and Government of India on where the vehicles, tractor and auto-components industry should reach in terms of size, global footprint, technological maturity,

[53] Press Information Bureau (PIB) (access here)
[54] Department of Heavy Industries (DHI) (access here)

competitiveness & contribution to India's development and capabilities. The central objectives of Automotive Mission Plan 2016-26 are:

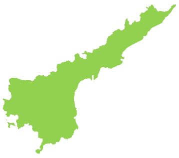
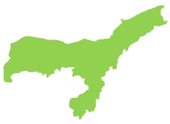
- to propel the Automotive sector in India to be the engine in Make in India programme,
- to ensure that the Automotive sector becomes an important contributor to the Skill India programme to enhance universal mobility.
- To make the automotive industry one of the largest jobs creating industries and increasing net exports of the industry and designing.

AMP 2026 also includes the vision on electric vehicles and associated infrastructure. AMP 2016-2026 also states the need of planned establishments of charging stations for electric vehicles in both rural and urban areas as well as in highways.

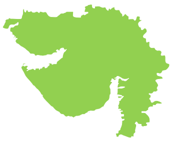
State level measures

In order to support battery manufacturing in India, 19 states of the country have rolled out supportive measures. Table 36 lists down all the supportive measures mentioned by the state governments in their respective EV policies.

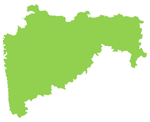
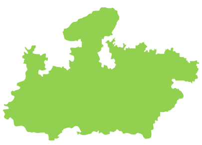
Table 38: State level measures for battery manufacturing in India

Sl. No	State	Measures
1.	 **Andhra Pradesh**	**Andhra Pradesh Electric Mobility Plan (2018)** • 10% subsidy of fixed cost investment on large and mega projects[55] up to 10 crores and 20 crores respectively for the first 2 units in battery and charging equipment and each segment of EV • 100% reimbursement of stamp duty and transfer duty • Fixed power cost reimbursement at INR 1.00 per unit for 5 years from commercial production • 100% reimbursement of net SGST accrued to the state for 10 years • The state government has allocated 500-1000 acre of land to promote development of EV parks including all necessary facilities and infrastructure along with a financial assistance of 50% of fixed cost investment up to INR 20 crores in building and common infrastructure to the developers of Auto Clusters and Automotive Suppliers Manufacturing Centers
2.	 **Assam**	**Assam Electric Vehicle Policy (2021) and North East Industrial Development Scheme (NEIDS, 2017)** • Incentive of 10% of Plant and Machinery cost up to INR 10 crore for large manufacturing units of EV and its components • 30% Capital Investment subsidy under NEIDS, 2017 up to INR 5 crore • Additional interest subsidy of 2% on working capital loan in addition to 3% interest subsidy on working capital loan for the first five years from commencement of commercial production under NEIDS, 2017. The working capital requirement is capped at 25% of their annual turnover.
3.	 **Bihar**	**Industrial Investment Promotional Policy (2016) & Bihar Electric Vehicles Policy (2020)** • 100% reimbursement of registration fee, land conversion fee, electricity duty and stamp duty • 10% interest subvention up to INR 10 crores, and reimbursement of 80% against admitted VAT/CST/entry tax for a period of 5 years • The state government also announced the creation of one EV manufacturing cluster including R&D center, common facilities and vehicle testing track
4.	 **Goa**	**Draft Electric Vehicles Policy of Goa (2021)** • Capital subsidy up to 20% on Fixed capital Investment[56] • 100% reimbursement of net SSGST for five years • 100% exemption on stamp duty for manufacturing of EV and associated components

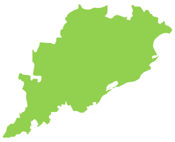
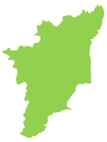
[55] Large projects: Investment: INR 50 crores – INR 200 crores
Mega Projects: Investment: INR 200 crores - 1000 crores
[56] No monetary restriction is set according to Electric Mobility Promotion Policy (2021) of Goa

Sl. No	State	Measures
5.	 **Gujarat**	**The Electric Vehicles Policy of Gujarat (2021) & Gujarat Industrial Policy (2020)** • Cash subsidy of 6-12% of Fixed cost investment eligible up to 10 years in equal annual installments up to annual ceiling for INR 40 crores to attract investments to set up industries • Incentive to support setting up new industrial or upgrading existing infrastructure at 80% of project cost up to INR 25 crores • Incentive on cost of the infrastructure at 25%-50% of Fixed Capital Investment up to INR 30 crore for development of industrial parks
6.	 **Haryana**	**Draft Electric Vehicles Policy of Haryana (2021)** • Allocated 100-200 acres of land for the development of EV parks with common facilities, external infrastructure and plug and play internal infrastructure meant to attract manufacturers across EV value chain • Subsidy of 10% of fixed cost investment on large and mega projects up to 10 crores and 20 crores respectively for the first 2 units in battery and charging equipment and each segment of EV • A subsidy of 25% on fixed cost investment to undertake sustainable green measures up to INR 50 crore • 100% reimbursement of stamp duty • 100% reimbursement of SGST accrued to the state

7.	
	Karnataka
		Electric Vehicles and Energy Storage Policy of Karnataka (2017)
		• Encourages the creation of EV manufacturing parks/zones
		• Exemption on stamp duty and electricity tariff for five years
		• Interest free loans on net SGST from the date of commencement of production [57]
		  ○ Large enterprises: Up to 60% of value of fixed assets up to 8 years
		  ○ Mega enterprises: Up to 70% of value of fixed assets up to 10 years
		  ○ Ultra-Mega enterprises: Up to 80% of value of fixed assets up to 11 years
		  ○ Super Mega enterprises: Up to 95% of value of fixed assets up to 13 years
		• Concessional registration charges at INR 1 per INR 1000
		• 100% reimbursement of land conversion fee
		• Capital subsidy up to 50% on the cost of Effluent Treatment Plan up to INR 200 lakh

8.	 **Kerala**	**Policy of Electric Mobility of Kerala (2017)** • Localized manufacturing will focus on power electronics, complete vehicle, electric drive train, energy systems and storage • EV manufacturing units will benefit from the financial and regulatory benefits from the state's IT and industrial policy
9.	 **Maharshtra**	**Draft Electric Vehicles Policy of Maharashtra (2021)** • Customized package of incentives on case-to-case basis on projects of special importance • Exemption from electricity duty for 7 years for manufacturing EV and related components
10.		**Electric Vehicles Policy of Madhya Pradesh (2019)** • Allocation of 100 acres land for development of EV industrial parks

[57] Large enterprises: Investment on fixed assets: INR 10 crore – INR 250 crore
Mega enterprises: Investment on fixed assets: INR 250 crore – INR 500 crore
Ultra-Mega enterprises: Investment on fixed assets: INR 500 crore – INR 1000 crore
Super Mega enterprises: Investment on fixed assets: Above INR 1000 crores

Sl. No	State	Measures
	Madhya Pradesh	• Capital subsidy of 10% of fixed cost investment on large and mega projects[58] up to 10 crores and 20 crores respectively for the first 2 units in battery and charging equipment and each segment of EV • 10% subsidy on cost of plant and machinery up to 35 lakhs for undertaking clean production measures • The state also announced 100% reimbursement of stamp duty and net SGST accrued to the state
11.	 **Odisha**	**Electric Vehicles Policy of Odisha (2021)** • Reimbursement of SGST for EV and components manufacturing • The state also announced its intention to venture into battery manufacturing by exploring possibilities of having an MoU with lithium cell manufacturers to open a battery assembly plant in Odisha • Other incentives include capital subsidy, tariff and tax incentives and other policy support to attract private investments in zones dedicated to lithium-ion battery manufacturing in the long run
12.	 **Punjab**	**Punjab Electric Vehicle Policy (2019)** • 100% reimbursement of SGST accrued for 15 years up to 200% of Fixed Capital Investment (FCI) • Exemption from change of land use charges and external development charges • Exemption from electricity duty for 15 years and labor flexibility to promote EV and component manufacturing
13.	 **Tamil Nadu**	**Electric Vehicles Policy of Tamil Nadu (2019)** • For investments made in the manufacturing of intermediate products used in EV and charging infrastructure manufacturing and where SGST reimbursement is not applicable, Capital subsidy of 15% on eligible investments[59] till 2025 • Exemption from electricity tax and stamp duty till 2025 • 20% subsidy on land cost (50% for southern districts) till 2022
14.	 **Telangana**	**Telangana Electric Vehicles and Energy Storage Policy (2020)** • Capital investment subsidy of 20% up to INR 30 crores for 20 years • 100% reimbursement of stamp duty, transfer duty and registration fees for first transaction and 50% on next • 100% reimbursement of SGST for 7 years up to 25 crores (up to 5 crore per year) • Electricity duty exemption up to INR 50 lakhs and interest subvention at 5.25% for 5 years up to INR 5 crore • Design, prototyping and testing facilities will be there for all the units. Special automotive electronics cluster will be present to manufacture EV batteries
15.	 **Uttar Pradesh**	**Uttar Pradesh Electric Vehicles Manufacturing Policy (2018)** • Capital interest subsidy up to 5% on loan taken for procurement of plant and machinery up to INR 50 lakhs • Infrastructure interest subsidy at 5% up to INR 1 crore, industrial research subsidy at 5% up to INR 1 crore • Exemption from electricity duty, reimbursement of stamp duty (50-100% for different districts) • 90% SGST reimbursement for 5 years

[58] Large projects: Investment: INR 10 crores to INR 100 crores
Mega projects: Investment: More than INR 100 crores
[59] Eligible Investments should begin from April 1, 2018, have a minimum investment of INR 50 crores and create at least 50 jobs

Sl. No	State	Measures
16.	 **Uttarakhand**	**Electric Vehicle manufacturing, E.V usage promotion and related Services Infrastructure policy of Uttarakhand (2018)** • Interest subsidy up to 7% for 5 years up to INR 50 lakhs • Exemption from electricity duty for 5 years • 50% exemption from stamp duty • Up to 50% reimbursement in SGST for 5 years • Land cost concessions up to 30% • Environment protection incentives of 30% up to INR 50 lakhs

Source: Electric Vehicles Policy of individual states

Policy environment – Supply chain development and R&D

National level measures

1. Technology Platform for Electric Mobility (TPEM)[60]

This is a joint initiative between Department of Science and Technology (DST) and Department of Heavy Industry (DHI), which has created a collaborative platform for suppliers, automakers, and developers to work on lithium-ion battery, Charging – Low voltage platform, Driving cycle & Traffic Pattern, Motors & Drivers, Ultracapacitor, etc. In this scheme, the government aims to provide 60% of R&D costs for eligible projects. User industry partners are expected to contribute the rest of the costs. The mechanism followed by the TPEM constitutes creating Centers of Excellence, formation of Industry Technology Consortia (ITC) which are led by automotive and component companies, with appropriate participation. The mechanism also encourages innovation programmes to support scientific research by laboratories/academia and supporting new product development by private companies.

2. R&D grants by Department of Heavy Industries (DHI)[61]

Department of Heavy Industries (DHI) has approved a R&D grant of 297.5 crores for a research by IISc, Bangalore for development of Solid-State Li-Ion Batteries for Automotive Applications and their Techno-Commercial Viability Studies. DHI has also approved 134.73 crores for a research by ARAI (IIT Ropar) on Development of Efficient Battery Thermal Management System for Two and Three-Wheeler EV application through design of innovative Packaging Material. Such incentives are slated to increase technical prowess of the country on in-house development of battery technologies.

3. Scheme for Faster Adoption and Manufacturing of Hybrid and EV (FAME II) in India[62]

The scheme focuses mostly on providing demand incentives and development of charging infrastructure to create a demand for xEVs in the country. Demand incentives are available to consumers (buyers and users) as an upfront reduction in purchase price of an electric vehicle or hybrid electric vehicle. This will further be reimbursed to respective OEMs by the government. FAME II has also allocated grants worth INR 10 Billion to support the deployment of charging infrastructure. Several grants were also allocated for certain projects under R&D/Technology Development and Public Charging Development, and pilot projects.

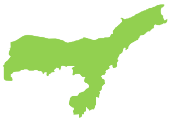
The incentives will be disbursed through an e-enabled framework and mechanism which is set up under DHI. The vehicle manufacturers (OEMs) will further submit their claims monthly to the DHI in order to receive the reimbursements.

State level measures

Many states have provided grants and taken initiatives for establishment of centers of excellence, etc. to support R&D in the electric mobility space. Table 37 lists down the measures taken by several states to support research and development of batteries.

[60] Economic Times (access here)
[61] Ministry of Heavy Industries (access here)
[62] Ministry of Heavy Industries (access here)

Table 39: State level measures for battery R&D in India

Sl. No	State	Measures
1.	 **Assam**	**Assam Electric Vehicle Policy (2021) and North East Industrial Development Scheme (2017)** • Financial support to start ups for research and innovation in EV & battery technologies • Partnership with premier technical institutes to establish centers of excellence for conducting market focused research on battery management, battery technologies, motors, and controllers
2.	 **Karnataka**	**Electric Vehicles and Energy Storage Policy of Karnataka (2017)** • State had formulated the "Karnataka Electric Mobility Research & Innovation Center" which aims to bolster the research on e-mobility • Focus on forming working group for development of necessary technologies in battery technologies, drive technologies, charging infrastructure and network integration, materials and recycling, standards and certifications and quality and training • Provided for setting up on startup incubation to foster the EV ecosystem • Various research programs will be introduced in Engineering Universities in collaboration with EV industry to focus on battery innovation • Provides for a venture capital fund to be set up for EV mobility research
3.	 **Punjab**	**Punjab Electric Vehicle Policy (2019)** • Provides for development of Punjab E Mobility Centre of Excellence which will act as a focal point for R&D in the state. Research in this center will be focused on reducing battery costs and assimilation of global developments in Electric vehicles domain
4.	 **Tamil Nadu**	**Electric Vehicles Policy of Tamil Nadu (2019)** • Provides for establishment of a Center of Excellence to conduct market focused research on battery management, battery technologies, motors, and controllers • Provides for forming working group for development of necessary technologies in battery technologies, drive technologies, charging infrastructure and network integration, materials and recycling, standards and certifications and quality and training
5.	 **Telangana**	**Telangana Electric Vehicles and Energy Storage Policy (2020)** • Provides for establishment of a Center of Excellence to conduct market focused research on battery management, battery technologies, motors, and controllers • Envisages provision of T-fund to support startups for R&D in e mobility space. T-Works Automotive Prototyping Center will also have a dedicated wing for the prototyping of EV components/assembly and batteries[63]

Source: Electric Vehicles Policy of individual states

Policy environment – Battery Swapping

National level measures

Battery swapping is a potential alternative to charging infrastructure especially for commercial fleet operators experiencing high vehicle utilization in the e-2W and e-3W segments. Such sentiments were reverberated in the budget 2022-23 speech by Hon'ble Finance Minister where it was announced that Union government would come up with a Battery swapping policy and interoperability standards to improve efficiency in the EV ecosystem. Some states have already incorporated battery-swapping as a part of their EV policies.

Recent Developments by the Government of India on battery swapping are listed below:

- NITI Aayog has developed a draft Battery Swapping Policy through inter-ministerial discussions in April 2022. The policy has been made open for comments from stakeholders.

[63] T-Works (access here)

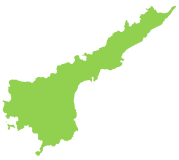
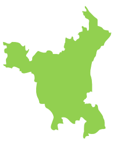
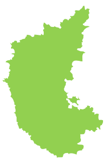
- The Ministry of Power (MoP) has recognized the concept of battery swapping through an amendment in the revised Guidelines and Standards for Charging Infrastructure for Electric Vehicles.[64]
- Delhi Transco Limited had floated a tender for setting up EV battery swapping and charging station in demarcated areas across national capital territory of Delhi. The scope of work included installation, operation and maintenance of the battery swapping stations and charging stations.[65]
- The Ministry of Road Transport and Highways (MoRTH) issued a notification which allowed the sale of e-2W and e-3W without pre-fitted batteries in order to reduce the upfront cost of EVs. The batteries can be sold by energy service providers and manufacturers. The energy service provider can even rent these batteries to EV users similar to refueling. This also encourages battery swapping service providers.

***Note:** Details on the Draft Battery Swapping Policy 2022 is provided in the Battery Swapping chapter*

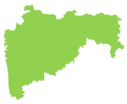
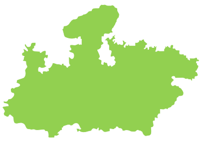
State level measures

Several state governments have supported battery swapping by incorporating them into their respective Electric Vehicle policies. The measures taken by 9 states to support battery swapping has been listen down in Table 40.

Table 40: State level measures for battery swapping in India

Sl. No	State	Measures
1.	 **Andhra Pradesh**	**Andhra Pradesh Electric Mobility Plan (2018)** • Capital subsidy of 25% on first 50 battery swapping stations on fixed cost (excluding battery inventory cost) up to INR 10 lakhs • Promotes sale of power from Vehicle to grid for battery swapping stations • External Infrastructure subsidy of 50% of the cost of infrastructure up to INR 2 crores for external infrastructure include battery swapping stations • 100% reimbursement to be provided on SGST accrued to the state for firms involved in battery swapping until 2024 • Land allocation would be facilitated for setting up battery swapping stations
2.	 **Delhi**	**Delhi Electric Vehicles Policy (2020)** • Land will be provided for battery swapping at a bare minimum rental lease • Swapping stations will be set up by inviting energy operators • Facilities such as power banking and open access will be provided for Battery Swapping stations which have been integrated with Renewable Energy
3.	 **Haryana**	**Draft Electric Vehicles Policy of Haryana (2020)** • Capital subsidy of 25% on first 50 battery swapping stations on fixed cost (excluding battery inventory cost) up to INR 10 lakhs • 100% reimbursement will be provided on SGST for firms involved in battery swapping • Incentives will be provided for setting up battery swapping station in existing buildings • Separate land will also be provided to set up battery swapping stations
4.	 **Karnataka**	**Electric Vehicles and Energy Storage Policy of Karnataka (2017)** • Capital subsidy of 25% on equipment/machinery for battery swapping stations up to INR 3 lakhs per station for first 100 battery swapping stations for e-2Ws and e-3Ws, INR 5 lakhs per station for first 50 battery swapping stations for e-cars and INR 10 lakhs per station for first 50 battery swapping stations for e-buses.

[64] Ministry of Power (access here)
[65] Mercom India (access here)

Sl. No	State	Measures
5.	 **Kerala**	**Policy of Electric Mobility of Kerala (2019)** • Capital subsidy of 25% on first 50 battery swapping stations on fixed cost up to 10 lakhs
6.	 **Maharshtra**	**Draft Electric Vehicles Policy of Maharashtra (2021)** • Establishment of robotic arms for battery swapping at public bus stations in 2018. • 50% of the demand incentive (demand incentive is capped at INR 1 lakh per vehicle) shall be given to the battery swapping operator for defraying any deposits required from the end user for vehicles sold without battery
7.	 **Madhya Pradesh**	**Electric Vehicles Policy of Madhya Pradesh (2019)** • Capital subsidy of 25% on charging equipment/machinery up to pre decided maximum subsidy amount • Incentives for setting up battery swapping stations in private buildings • Facilities such as open access and net metering for battery swapping stations integrated with renewable energy • Public charging stations need to have standalone battery swapping facilities
8.	 **Uttar Pradesh**	**Uttar Pradesh Electric Vehicles Manufacturing Policy (2018)** • Capital subsidy of 25% on battery swapping stations on fixed cost (excluding land cost) up to INR 6 lakhs.

Source: Electric Vehicles Policy of individual states

Policy environment – Battery disposal, reuse and recycle

National level measures

Unsafe battery disposal can cause leakage of hazardous elements and harm the environment. To avoid the same, a collection mechanism is needed to ensure the safe transport of batteries to recyclers. Furthermore, discarded batteries, if recycled appropriately, can be a valuable resource. As of now, India does not have a recycle or reuse standard or rule. However, the draft battery waste management rules prepared in 2020, covers all such requirements.

1. Draft Battery Waste Management Rule, 2020[66]

The battery waste management rules, 2020 makes it mandatory for dealers and manufacturers to collect used batteries against the new ones sold by them. The draft rules will not be restricted to lead-acid batteries but will include all kinds of batteries. Further, dealers and manufacturers will need to ensure the transport of used batteries to registered recyclers as well and ensure that no harm is caused to the environment during this process. Battery dealers are also required to issue purchase invoice while collecting used batteries. The draft rules also cover industrial batteries which can be used as power source for propulsion in an EVs as well.

Table 41: Targets for Extended Producer Responsibility -Authorization

Sl. No	Timeline	Battery-Waste Collection Target
1.	During the first two years of implementation of rules	30% of the quantity of waste generation as indicated in the EPR
2.	During third and fourth years of implementation rules	40% of the quantity of waste generation as indicated in the EPR
3.	During fifth and sixth years of implementation of rules	50% of the quantity of waste generation as indicated in the EPR
4.	Seventh year onwards of implementation of rules	70% of the quantity of waste generation as indicated in the EPR

[66] Ministry of Environment, Forest and Climate Change (access here)

Other miscellaneous rules regarding battery disposal are highlighted below:

1. **Batteries (management and handling) rules (2001):** This had the primary objective of channeling the used/spent lead acid batteries for recycling. These rules mandate the various State Pollution Control Boards to collect data on import, sale, generation, collection & recycling of spent batteries from assemblers, manufacturer, importer, reconditioners, auctioneers and batteries recycler to track used batteries. This rule only mentioned regulation for lead acid batteries. Battery manufacturers were not required to register their business. Battery dealers were not mandated to issue public invoices as well. Moreover, EV batteries were not covered in the scope of this rules.

2. **The Hazardous Wastes (Management, Handling and Transboundary Movement) Rules (2008):** Notified in 2008, these rules ensure proper management and handling of hazardous waste by regulating reception, collection, treatment, storage, and disposal of hazardous wastes. It covers industries involved in oil & gas, petroleum, mines and minerals, zinc copper and lead based production, textiles, steel, asbestos, electronics, and tannery. It does not include EV batteries in its scope.

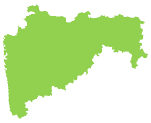
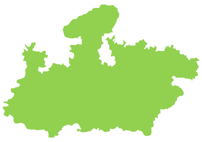
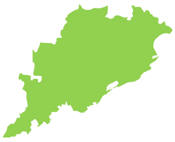
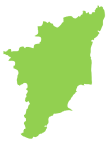
3. **E-waste Management Rules (2016):** Notified in 2016 and amended in 2018, it's applicability was extended to include manufacturers, dealers, refurbishers and producer responsibility organizations (PRO) in addition to producers, consumers/bulk consumers, collection center, dismantler and recycler to address e-waste leakage in informal sector. In order to ensure pan India implementation, CPCB was given the responsibility for single EPR authorization for producers. As per OECD, EPR is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products. The E-waste management rules of 2016 also included phase wise collection targets: 30% of quantity of waste generated during first 2 years, 40% in third and fourth year, 50% during fifth and sixth and 70% during the seventh year. It did not include EV batteries in the scope and only covered batteries included in the Battery (Management and Handling) Rules, 2001.

State level measures

Several states have developed measured which incentivize EV owners for proper disposal of batteries. The measures taken by several states to promote battery disposal, reuse and recycling have been listen down in table 40.

Table 42: State level policies for battery disposal, recycling and reuse in India

Sl. No	State	Measures
1.	 **Assam**	**Assam Draft Electric Vehicle Policy (2021) and North East Industrial Development Scheme (2017)** • State Government has acknowledged that end of life EV batteries needs to be either reused or recycled. • Setting up recycling businesses in collaboration with EV and battery manufacturers for 'Urban Mining' of rare materials within the battery • EV owners to get a remunerative price on depositing vehicle batteries at charging point or swapping station landfills • Provides for appointment of a nodal agency to act as an aggregator to purchase used batteries (at least 70% of rated capacity) from the charging points and battery swapping stations. These will then be re-used as 'power banks' to store renewable energy
2.	 **Delhi**	**Delhi Electric Vehicles Policy (2020)** • The Delhi Government has acknowledged the need to reuse or recycle end of life EV batteries. The policy shall further encourage the reuse of spent EV batteries. • Setting up recycling businesses in collaboration with EV and battery manufacturers for 'Urban Mining' of rare materials within the battery
3.	 **Goa**	**Draft Electric Vehicles Policy of Goa (2021)** • Setting recycling businesses in collaboration with EV and battery manufacturers for 'Urban Mining' of rare materials within the battery • Convergence Energy Services Limited (CESL) to develop a use case for using used batteries with 70% capacity for energy storage

Sl. No	State	Measures
4.	 **Haryana**	**Draft Electric Vehicles Policy of Haryana (2021)** • The state would drive the creation of a secondary market for EV battery disposal in Public Private Partnership (PPP) model
5.	 **Maharshtra**	**Draft Electric Vehicles Policy of Maharashtra (2021)** • Provides for setting guidelines for safe handling and disposal of EV batteries and components
6.	 **Madhya Pradesh**	**Electric Vehicles Policy of Madhya Pradesh (2019)** • EV owners would get a remunerative price on depositing vehicle batteries at charging point or swapping station operated by Energy Operators or Battery swapping operators • Policy provides for appointment of a nodal agency to act as an aggregator to purchase used batteries (at least 70% of rated capacity) from the Energy operators and Battery swapping operators. These will then be re-used as 'power banks' to store renewable energy
7.	 **Meghalaya**	**Electric Vehicles Policy of Meghalaya (2021)** • EV batteries can be deposited at charging point or swapping station • OEMs will be held responsible for recycling used batteries and components
8.	 **Odisha**	**Electric Vehicles Policy of Odisha (2021)** • EV battery manufacturers shall be responsible for collection of waste batteries • Benchmark label for materials to be recycled from batteries will also be set up to encourage better techniques • A well-defined policy will also be framed for battery recycling
9.	 **Punjab**	**Punjab Electric Vehicle Policy (2019)** • Relevant OEMs and private players will be encouraged for Battery buy back • Government would encourage an e-marketplace for resale of used batteries • OEMs and private players need to set up recycling facilities for batteries and will receive incentives • The Center of Excellence shall help in adopting suitable methods of disposal and recycling
10.	 **Tamil Nadu**	**Electric Vehicles Policy of Tamil Nadu (2019)** • Re-use of EV batteries will be promoted. • Provides for setting recycling businesses in collaboration with EV and battery manufacturers for 'Urban Mining' of rare materials within the battery • EV owners can deposit vehicle batteries at charging point/stations • OEMS shall be responsible for recycling batteries
11.	 **Telangana**	**Telangana Electric Vehicles and Energy Storage Policy (2020)** • The Government will promote reuse of EV batteries in Energy Storage Systems and Urban Mining of rare materials • Cell / battery recycling will be incentivized at par with EV & ancillary manufacturing

Source: Electric Vehicles Policy of individual states

While India has undertaken several policy interventions to promote battery storage, it is essential to undertake a review of similar best practices by various countries to understand additional interventions which could be considered by India.

The following section is aimed at undertaking a review of policy and regulatory interventions adopted by various countries to promote battery storage.

3.2 Battery storage policy and regulatory landscape – International

Following countries have been selected to understand the policy and regulatory interventions adopted by them.

Figure 26: Target countries for battery ecosystem landscape assessment

China

Subsidies and regulations for battery suppliers in China favor large production facilities encouraging cost competitiveness and consolidation. To reduce battery costs and drive consolidation, China also plans to set minimum production capacities for manufacturers. Various guidelines have been implemented which encourage standardization of battery design, production, second life utilization through repairing and repackaging, etc. Table 43 highlights the key measures taken by China to boost the EV battery ecosystem.

Figure 27: Promotional measures adopted by China for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
	– **NEV subsidy program:** Outlay of 37.585 billion yuan under this scheme. Extension of the program with gradual reductions – **New Energy Vehicle Industry Plan:** Sales target of 20% was set for EVs For 2025 – **NEV credit mandate:** Credit requirements were set from 2021-2023 (14-18%) – **Other benefits:** Exemption from traffic restrictions, free parking spaces, bus fleet electrification	– **National Key Research & Development Program:** Outlay of RMB 700 million for about 20 EV and related components research programs – **Foreign Investment Policy:** Encouraging foreign investments in various industries – **Other measures:** Building charging infrastructures, exemption from import duties and consumption tax and reduction in vehicle registration	– **National Standard for battery swap safety requirements.** – **Other measures:** Exemption from subsidy requirements and Focus on infrastructure development of battery swapping stations in new guidance and reports of work of the government	– **NEV Battery recycling regulation:** Rates of recovery for major battery metals were changed. – **Extended Producers Responsibility Plan:** Plan to set the waste recycling rate of 50% by 2025

No information available

Details of each of the measures are highlighted in the table below:

Table 43: Promotional measures in China to boost EV battery ecosystem

Particulars	Policies/Schemes	Details
Battery Manufacturing	New Energy Vehicle (NEV) Industry Plan	• This policy is applicable to car manufacturers effective from 2021-2035. A sales target of 20% was set for NEVs in 2025. In certain areas where pollution levels are high, the policy mandates that 80% of the new vehicles

Particulars	Policies/Schemes	Details
		purchased should be NEVs starting from 2021. By 2035, this policy targeted BEV to become the mainstream of NEV sales and 100% electrification of the stock of public fleets
	NEV Credit mandate Phase 2	• This policy regulates the calculation and trading of corporate average fuel consumption credits and NEV credits. Phase 2 of this policy increased the targets of NEV credit percentages for car manufacturers. In 2020, the programs and targets were extended to 2023. The NEV credits requirements for 2021, 2022, 2023 were 14%, 16% and 18% respectively. Each EV can receive between 1-2.4 credits based on its characteristics. The OEM can achieve it by either selling EVs or trading credits with other manufacturers.
	NEV license plate	• Many cities in China cap the number of new license plates issued each year. To promote the shift towards EV and related components, a significant proportion of the license plates are reserved for NEVs annually. Certain cities have waived off the fee for license plate which has further attracted consumers.
	NEV Subsidy program	• National subsidies for EVs were set to expire in 2020. This program has extended them for 3 additional years. Subsidies were also limited to 2 million NEVs per year. A price limit of CNY 300,000 was set for vehicles.
	Exemptions of EVs from traffic restrictions and free parking spaces	• NEVs are exempted from traffic restrictions that are implemented to control urban congestion. Dedicated parking spots are also allocated in some cities.
	Public bus fleet electrification	• The electrification of public transport has been actively promoted by the Chinese government. Clear targets have been set by many cities. • The Ministry of Transport had set a target that all public transport vehicles in major cities will be replaced by NEVs by end of 2020.
R&D	National Key Research & Development program	• This is the latest R&D program which earmarks RMB 700 million for about 20 EV and related components' research programs. Apart from this programme, New Energy Vehicle Industry plan also focuses on innovation in battery technology such as electrode materials, electrolyte, safety, battery life, light weighting, and cost.
Supply Chain Development	Foreign Investment Policy	• This policy encourages foreign investment in the areas of positive materials of battery, battery separator, battery management system, electronic integration of electric cars, motor management systems, etc.
	Regulating Passenger Vehicle Consumption Tax Policy	• This specifies that purchases of battery electric vehicles are exempted from consumption tax
	Import duty	• This policy provides exemption to NEVs from import duties when imported for self-use
	Vehicle Registration fee	• Vehicle registration fee for NEVs was reduced by 50% by the Ministry of Finance and State Administration of Taxation and MIIT
	Building charging infrastructure	• China intended to build 12000 charging stations by 2020 to accommodate 5 million EVs. To enable the same, local governments can receive around RMB 90 million if they meet certain amount of EV purchases.

Particulars	Policies/Schemes	Details
		• Certain provinces and cities have announced subsidies which could reach up to 30% of the total investment.
Battery Swapping Infrastructure	National standard for battery swap safety requirements for EVs (will be in effect from Nov 1, 2021)	• The State Administration for Market Regulation approved the national standards for battery swap safety requirements for EVs. This will help in improving the level of safety of EVs which use the battery swap technology.
	Exemption from subsidy requirements	• China set a requirement for NEV industry to be priced under RMB 300000 to enjoy subsidies. But models using battery swap were exempted from such a requirement.
	Focus on infrastructure development of battery swapping stations in new guidance and reports of work of the government	• Efforts are being made to promote the construction of battery swapping infrastructures. This will be piloted in Beijing and Hainan. The government has encouraged several enterprises to develop new battery charging and swapping technology. • The New Energy Vehicle Industry plan aims at building efficient battery charging networks by 2035.
Recycling and reuse	NEV Battery recycling regulations	• This regulation specifies minimum rate of recovery for major battery metals. It specifies that the recovery rate for cobalt, nickel and manganese should not be below 98 % and 85 % for lithium. Moreover, rare earth materials should not have a recovery rate below 97 %.
	Extended Producer Responsibility Plan	• This plan aims at extending the responsibilities of producers to include waste disposal and recycling. The aim is to ensure that by 2025, the waste recycling rate is 50% (on an average in China). The plan will first be introduced for lead acid batteries, automobiles, electronics and packing products. • A pilot program was announced to implement this plan. The objectives of the pilot program were as follows: o Significant increase in rate of recycling of end-of-life vehicles and developing an easily adoptable and reproducible model of End-of-life Vehicle (ELV) recycling o Increasing the ELV body's recycled portion in phases and achieve a recycling level of 75% o Developing a green supply chain system to increase vehicular recycling rate to 95% and ensuring 5% of each key part is made from recycled material o Information disclosure such as reliable traceability of traction batteries for recycling, publishing manuals or creation of systems to share information on fulfillment of producer responsibility should be enhanced

Source: International Council on clean energy transportation (access here) ,International Council on clean energy transportation (access here) US DOE (Osti) (access here) , IEA (access here), sustainanalytics (access here), cnet (access here)

Australia

Australia currently does not commercially produce battery grade materials or chemicals. However, the country has huge deposits of raw materials available within its geography. To realize the potential of manufacturing, the Australian government has announced the prioritization of domestic consumption and production of critical materials needed for battery manufacturing. The government has also aimed at scaling up of battery production and expanding global supply chains through various policy interventions. Table 44 highlights the key measures taken by Australia to boost the EV battery ecosystem.

Figure 28: Promotional measures adopted by Australia for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
– **Junior Minerals Exploration:** $100 million incentive to eligible companies who would generate tax credits by giving up parts of their losses in tax from expenditure in greenfield mineral exploration. – **Industry Growth centers initiative:** Set up growth centers in sectors including mining equipment sector.	– **Modern manufacturing strategy:** $1.5 billion to leverage the mineral and resources sector to drive battery manufacturing – **Attracting foreign investments:** Yearly tax offsets up to A$200000 per year and exemption on capital gains taxes for investments held for at least a year for 10 years. – **Other benefits:** Two years registration fee waived off and stamp duty waived off	– **Automotive transformation Scheme:** financial assistance of up to 50% of R&D investments and 15% of plant and equipment costs up to 1 crore – **Industry Growth centers initiative:** Set up growth centers in sectors having direct relevance to lithium-ion battery to gain competitive advantage.		– **Battery Stewardship Scheme as a part of National waste policy action plan, 2019:** Recyclers will be offered a rebate per kg to collect, sort and process the end-of-life battery.

No information available

Details of each of the measures are highlighted in the table below:

Table 44: Promotional measures to boost EV battery ecosystem in Australia

Particulars	Policies/Schemes	Details
Sourcing raw materials	Junior Minerals Exploration	• This program was initiated in 2017-2018 and aims at assisting junior exploration companies which seek capital for greenfield exploration programs.
	Industry Growth centers initiative	• This calls for an industry-led approach to drive innovation, productivity and competitiveness. The Australian government aims to have growth centers in key sectors to gain competitive advantage. These key sectors identified includes mining equipment sector.
	Funding from North Australia Infrastructure Facility	• The NAIF offers up to $A 5 billion over five years to promote private sector investments in infrastructures that benefit North Australia. Recently NAIF investment mandate was broadened and now covers energy minerals sectors.

Particulars	Policies/Schemes	Details
Battery Manufacturing	Integrated System Plan	• As a part of the federal government's Technology Investment Roadmap, this program aims at turning critical minerals into high value products like batteries and solar cells. It also prioritizes domestic consumption and production of crucial raw materials to promote battery manufacturing.
	Modern Manufacturing Strategy	• This provides a $1.5 billion plan which includes a technology investment roadmap to leverage the mineral and resources sector to drive battery manufacturing. It provides a 10-year roadmap to build sophisticated manufacturing facilities.
	Two years registration fee and Stamp duty waive off	• States like Canberra have waived off registration fees for two years for zero emission vehicles. Stamp duty has also been waived off for cleaner cars to drive the domestic demand. • Households and nonprofit organizations can avail interest free loans up to $15000 to purchase zero emission vehicles.
R&D	Automotive Transformation Scheme	• This scheme promotes innovation, economic sustainability, and competitive investment by providing financial assistance of up to 50% of R&D investments and 15% of plant and equipment costs. Assistance is capped at $1 billion from 2016-2020. • Motor Vehicle Producers receive 55% of the yearly allocated funding while others receive the remaining 45% of the funding. Further, $337 million is available as uncapped assistance for motor vehicle producers. The eligible producers are: o Motor vehicle producers o Automotive component producers o Automotive machine tool and automotive tooling producers o Automotive service providers
	Other Policies & initiatives	• Geoscience Australia has been leading initiatives to gather new data about potential minerals below the surface of the earth which might help in raw material sourcing for batteries.
Supply Chain Development	Industry Growth centers initiative	• This calls for an industry-led approach to drive innovation, productivity and competitiveness. The Australian government plans to set up growth centers in key sectors to gain competitive advantage. The key sectors identified also includes those which have direct relevance to lithium-ion batteries.
	Attracting foreign Investments	• Australia aims to build a battery supply chain including cell manufacturing and chemical technology and aims to attract foreign investment by granting incentives. Government is offering yearly tax offsets up to A$200000 per year and exemption on capital gains taxes for investments held for at least a year for 10 years.
	Roads of Strategic Importance	• This helps in funding key national corridors for efficient freight transport which would connect mining projects to transport hubs.
Recycling and reuse	Battery Stewardship Scheme as a part of National waste policy action pan, 2019	• Approved in 2020, this scheme will charge 4 cents/EBU (24 grams) on import of batteries. • The cost of collection of batteries is high due to the low volumes, lack of incentives and small size of products. So, the recyclers were offered a rebate in order to overcome the cost of collection and sorting batteries. The proposed rebates are highlighted below: o For collection in metropolitan areas: $2.50/Kg o For collection in regional/remote areas: $3.5/Kg o Sorting: $1.00/kg

Particulars	Policies/Schemes	Details
		○ Processing: $1.00/kg • The rebate cannot be used to collect or sort the stockpiles. The members should first demonstrate the collection & sorting in a specified time period. • Recycling and Waste Reduction Bill, 2020 was introduced to enable major battery manufacturers to participate in the battery stewardship program to improve the rate of recycling.

Source: Austrade(access here) , CSIRO (access here), CSIRO (access here)

Brazil

Lack of incentives for newer technologies was one of the barriers Brazil faced while attempting to transition into cleaner vehicles. In order to address the same, Brazil has rolled out several policies starting from 2010.

Several cities and jurisdictions within Brazil (like Sao Paulo) have launched their own policies to push for electric mobility. Such policies drive the market for battery manufacturing and have encouraged research and development in several sectors including battery technology. Table 45 highlights the key measures taken by Brazil to boost the EV battery ecosystem.

Figure 29: Measures adopted by Brazil for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
– **SUDENE:** 75% reduction in corporate income tax and additional nonrefundable amounts calculated based on exploration profit	– **Sao Paulo Climate Change policy:** requires public transport to cut down emissions by 50% in 10 years and 100% in 20 years – **Route 2030 program:** tax credit of 1.5 billion real for vehicle manufacturers if they invest 5 billion real annually. – **Dicreto IPI:** Reduction in taxation	– **ANEEL R&D Call 22:** Outlay of $620 million to stimulate research and development. – **Camex Import tax:** Reduces the import duty on BEVs and FCEVs. Tax reduction for HEVs. – **Other measures:** BNDES program and ANEEL to promote supply chain development		– **Brazilian Waste policy:** Brazil does not have a separate policy for battery waste management

No information available

Table 45: Measures to boost battery ecosystem in Brazil

Particulars	Policies/Schemes	Details
Sourcing raw materials	SUDENE	• This program included incentives such as reduction in corporate income tax for new enterprises by 75%. This also includes a nonrefundable amount which is calculated based on operational profit for a term of 10 years
Battery Manufacturing	Sao Paulo Climate Change policy	• The City law established in 2018 requires that emissions from public transport to be cut down by 50% in 10 years and 100% in 20 years. The emissions for particulate matter must also drop by around 90% in 10 years and 95% in 20 years. Similarly, the emission of nitrogen oxides should drop by 80% in 10 years and 95% in 20 years. This law was

Particulars	Policies/Schemes	Details
		aimed to stimulate the adoption of e-buses by municipalities, which led to large scale manufacturing of batteries.
	Route 2030 program	• This is a long-term program effective for a 15-year period starting from 2018. It offers a tax break on industrial products used in hybrid or electric engines by three percentage points and emphasized on supporting local sourcing of parts. Another key element of the program involves a tax credit of 1.5 billion $ for vehicle manufacturers if they invest 5 billion $ annually.
	Dicreto IPI	• Tax rate was cut from 25% to 7% for BEVs and from 25% to 20% for HEVs
R&D	ANEEL R&D Call 22	• Introduced in 2020, this program was launched to stimulate research and development for a period of four years. This program covers technologies, equipment, services, business models, systems or infrastructure which support the management and development of EVs. To accomplish this, $620 million was allocated for this project.
Supply Chain Development	BNDES program	• Under this program the Brazilian Development Bank allocated R$ 13,800,000 to R&D and energy efficiency projects. Other salient features include the following: o Brazilian development bank set a rate of minimum requirement for local content. This is a long-term target to be achieved gradually o The Brazilian Development bank will finance the production of EVs, HEVs, recharging equipment and components, traction batteries and fuel cells. Support will be extended for setting up assembly lines. o It will also finance the purchase of EVs and vehicles and equipment for construction of charging infrastructure. It also mandates EVs to be included in business models of companies
	Camex Import tax	• This resolution extinguishes the import duty on BEVs and FCEVs to 35%. The benefit for HEV from this incentive ranges from 2-7% tax reduction based on their engine capacity and efficiency.
	ANEEL	• This policy promotes free competition between recharging service providers.
Recycling and reuse	Brazilian waste policy	• Brazil does not have a separate policy for battery waste management. The policies of battery waste management are outdated and only covers lead acid batteries. Hence many manufacturers need to either recycle batteries themselves or export it to companies who can recover the materials. There is a take-back system in place for electronic wastes where consumers give the products back to retailers or distributors who further give it to producers and importers who either recycle it or send it across back to host companies.

Source: Brazilian Electric Mobility Annual Report, 2020 (access here)

South Korea

The battery makers from South Korea were the industry leaders until CATL from China entered the market. To meet the rising competition, substantial investment has happened not only into large scale battery manufacturers but also in smaller and medium sized firms involved in battery/components manufacturing. Table 46 highlights the key measures taken by South Korea to boost the EV battery ecosystem.

Figure 30: Measures adopted by South Korea for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
– **New critical metals strategy:** Funding and tax incentives will be provided for 100 companies to double the stockpile of strategic raw materials like lithium, nickel, cobalt, and rare earths	– **K Battery Strategy:** Investment of 40.6 trillion won by major battery manufacturers – **Subsidies and tax cuts:** Purchase subsidy, exemption from toll fees, discount in parking fees, tax cuts, etc.	– **R&D project for EVs:** Outlay 100 billion won to support technological advancements. 8 billion Korean won was also allocated for Micro EV technology. – **K Battery Strategy:** 20.1 trillion won is earmarked for R&D until 2030. Tax credits will also be provided up to 50% for R&D – **Latest Government roadmap:** transforming 470 component manufacturers into dedicated future vehicles component manufacturers		– **Lithium-Ion battery technology development project:** Outlay of 13 billion won to ensure reuse and recycling of lithium-ion batteries – **Extended Producer Responsibility:** EPR policy was adopted for mercury, NiCd, silver oxide, primary lithium batteries, MnAl and NiMH.

No information available

Table 46: Promotional measures to boost EV battery ecosystem in South Korea

Particulars	Policies/Schemes	Details
Sourcing raw materials	New Critical metals strategy	• The South Korean government plans to double the stockpile of strategic raw materials like lithium, nickel, cobalt, and rare earths in the country under this strategy. The 35 identified materials currently have an average of 56.8 days' worth of supply. South Korea wants to secure an average of 100 days' worth of supplies for these materials.
Battery Manufacturing[67]	K-battery strategy	• It is a government-led initiative where major battery makers (LG Energy Solution Ltd, Samsung SDI Co and SK Innovation Co) in South Korea will invest 40.6 trillion won ($35.4 billion) over the next decade in the EV battery industry to position the country as a global leader. A combined 20.5 trillion won will be spent in facilities and 20.1 trillion won on R&D until 2030. Government in turn will support them by providing tax credit up to 20% for facilities and up to 50% for R&D. According to this initiative, lithium sulfur, solid state & lithium metal batteries will be commercialized by 2025, 2027 and 2028 respectively.
	Subsidies and tax cuts	• In order to commercialize EVs, purchase subsidy was announced for each EV (25,600 EVs in 2018 and 42,000 in 2019). Incentives, exemption from toll fees, discount in parking fees at public parking lots, permission to use exclusive roads were key enablers for growth in EV sales and battery manufacturing. Mandatory EV purchase by public institutions were also encouraged. • Tax cuts were provided for EVs with cumulative maximum of USD 2300 for HEV, USD 4500 for EV and USD 2300 for PHEV

[67] Bloomberg (Access here), Quartz: (Access here), Electrive: (Access here),

Particulars	Policies/Schemes	Details
R&D [68]	R&D Project for EVs	• This scheme included budget allocation of 100 billion Korean won from 2011-2021. Center for Environment Friendly Vehicle (CEFV) was set up as a part of this program to support technological advancements in EV. CEFV finances companies and institutions for specific R&D activities. • Government provided funding for R&D in regions hit by industrial crisis. It subsidized selected medium and small firms in selected regions for R&D of EV components for ~33 months.
	K-Battery Strategy	• This is a government led initiative where 20.1 trillion won has been earmarked for R&D until 2030. Tax credits will also be provided up to 50% for R&D according to this strategy.
	R&D Project for development of technology of Micro EV	• In 2019, government allocated 8 billion Korean won (USD 7 million) for 3 years to medium sized enterprises for the development of Micro EV technology. Micro EVs are designed to provide a long-term solution to current traffic issues. These EVs are smaller electric cars (1 or 2 seats) and run on a more compact battery system.
Supply Chain Development[69]	Latest government roadmap	• The government aims at transforming 470 component manufacturers into dedicated future vehicles component manufacturers. It also aims at establishing autonomous infrastructure to further enhance the industry ecosystem. • • The government also aims at having 5,00,000 EV charging stations by 20205 up from 60,000 in 2020. From 2022, all new buildings will have the obligation to include certain number of charging stations. Fast charging centers will also be installed at select locations.
Recycling and reuse[70]	Lithium Ion battery technology development project	• This four-year 13 billion won (USD 11.7 million) program has been launched in 2021 to ensure that used batteries are either recycled or reused in second life applications. Used EV batteries will be used to produce portable battery packs, ESS, battery management systems with increased stability, etc.
	Extended Producer Responsibility	• In 2003 the EPR policy was adopted for collection and recycling of four battery types: Mercury, NiCd, silver oxide and primary lithium batteries. In 2008, MnAl and NiMH were included as well. EPR mandatory targets for recycling were set and actual recycling rates were calculated by South Korea MOE to check the achievement rate annually.

Japan

Japan intends to be carbon neutral by 2050. To promote this, the Ministry of Economy, Trade and Industry (METI) released the Green Growth Strategy which lays down the action plans for 14 key sectors. To achieve electrification in transport segment, the focus is on next generation batteries. A mix of grants, regulatory reforms and tax incentives have been announced for capital investment, research, development, and demonstration projects. Moreover, the country has targeted to electrify all new passenger vehicles sold by 2030. Hence METI has proposed large scale investments into the EV supply chain. Table 47 highlights the key measures taken by Japan to boost the EV battery ecosystem.

[68]Journal of Technology Management & Innovation (Access here)
[69] Pulse: (Access here)
[70] HEP Frontiers: (Access here)

Figure 31: Measures adopted by Japan for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
	– **Well to Wheel Zero Emission Policy:** Long-term target by 2050 to ensure reduction in emissions to zero regarding a vehicle's overall operation – **Green growth strategy:** Tax incentives of 1.7 trillion yen, for 10 years and 1 trillion yen in 3 years to attract global investment. – **Other measures**: Purchase cost subsidy up to USD 7200 and **Next Generation Cars penetration in 2030.**	– **Green Innovation fund:** 2 trillion yen over the next 10 years to stimulate R&D worth of 15 trillion yen – **Subsidy Program by Tokyo Environmental Public Service Corporation:** A subsidy program to boost the installation of charging stations throughout condominiums in Tokyo. The installations of battery systems could also be eligible for funding if installed along with charging stations		– **Promotion of effective utilization of Resources Act**: This act encourages business operators to independently and autonomously collect and recycle for products where recycling is possible.

No information available

Table 47: Measures adopted by Japan for EV batteries[71]

Particulars	Policies/Schemes	Details
Battery Manufacturing	Well-to-Wheel Zero Emission Policy	• This policy sets a long-term target to make the shift to xEV completely by 2050. Every automobile produced by Japanese automakers should be electrified by 2050. The aim is to bring about the highest level of environmental safety and contribute to ensure reduction in vehicular emissions to zero. Japan envisages that replacing all the vehicles by xEVs will reduce greenhouse emissions by 80% per vehicle and 90% reduction per passenger vehicle.
	Green Growth Strategy	• Japan has declared to be carbon neutral by 2050. The incentives provided by the government to achieve the target are as follows: ○ Green Innovation Fund: Japanese government will invest 2 trillion yen over the next 10 years to stimulate private investment and R&D worth of 15 trillion yen ○ Tax incentives to stimulate private investment for upcoming 10 years' worth 1.7 trillion yen ○ Interest subsidy of 1 trillion yen in 3 years to attract global ESG investment ○ Regulatory reforms in areas such as mobility/battery, hydrogen and offshore wind power ○ International collaboration on innovation policy, standardization and policy drafting, solutions for de-carbonization, joint projects
	Next Generation Cars penetration in 2030	• This program stipulates the 2030 targets regarding the deployment of next generation vehicles/automobiles as follows: ○ Hybrid Vehicles: 30%-40% of sales of new vehicles ○ Battery electric vehicles/plus in hybrid vehicles: 20%-30% of sales of new vehicles ○ Clean diesel: -5%-10% of sales of new vehicles

[71] Source: Office of Science and Innovation, Tokyo

Particulars	Policies/Schemes	Details
		○ Fuel-cell electric vehicles: 3% of sales of new vehicles ○ This program has set a policy target for the penetration of ZEVs in sales of new passenger vehicles. 50% of all new passenger vehicle sales should be ZEVs. These are not regulatory requirements to be met by car manufacturers but will dictate the policies promoting penetration of ZEVs. Furthermore, the country plans to introduce 300 zero emission buses by 2030. All the new service vehicles, passenger cars, buses, taxis and cargo vehicles which are registered as new vehicles by 2030 should be zero emission vehicles.
	Subsidy and Tax incentive for buying next generation vehicle	• The government is offering to subsidize the purchase cost of Clean Energy Vehicles. The maximum amount of xEV subsidy available per vehicle is USD 7200. HEVs will not be considered as a part of this scheme.
R&D	Green Innovation Fund	• This fund was set up as a part of green growth strategy to develop key areas essential in achieving carbon neutrality by 2050. The government will also cover the needs of private companies, from R&D to capital investment. Japanese government will invest over 2 trillion yen over the next 10 years to stimulate private R&D and investment worth 15 trillion yen
Supply Chain Development	Subsidy Program by Tokyo Environmental Public Service Corporation	• A subsidy program was set up in 2018 to boost the installation of charging stations throughout condominiums in Tokyo. The installations of battery systems could also be eligible for funding if installed along with charging stations.
Battery Swapping Infrastructure		• The swappable battery consortium for electric motorcycles in Japan have reached an agreement to ensure the standardization of swappable batteries in Japan. Post technical valuation based on common specifications, the standards will be released.
Recycling and reuse	Promotion of effective utilization of Resources Act	• This act encourages independent and autonomous collection and recycling of specific products. This act covers sealed lead acid batteries, sealed nickel cadmium batteries, sealed nickel metal hydride batteries and lithium batteries as well. This act stipulates manufacturers of batteries to conduct self-collection by installing self-collection points, collection boxes or other such facilities. • Manufacturers of products which use these batteries need to hand over the used batteries to the battery manufacturers. There are three collection schemes for the collection of rechargeable batteries: ○ Japan Portable Rechargeable Battery Recycling Center (JBRC): JBRC is a producer responsibility organization which collects majority of the compact rechargeable batteries and also a small amount of sealed lead acid batteries. ○ Mobile Recycle Network: Lithium batteries are collected and recycled through this scheme. In this case, the recycling is done by each service provider ○ Individual battery manufacturers: They collect most of the sealed lead acid batteries.

Source: Office of Science and Innovation, Tokyo(access here), US DOE Office of Science and Technical Information (access here), PV Tech (access here), IEA (access here), IEA (access here), Ministry of Economy Trade and Industry (access here), Electrive (access here), International Trade Administration (access here), OECD (access here)

USA

US has recently announced new policy measures to scale up domestic battery manufacturing and a local supply chain for advanced battery materials. Table 48 highlights the key measures taken by USA to boost the EV battery ecosystem.

Figure 32: Promotional measures adopted by USA for EV batteries

Sourcing Raw materials	Battery Manufacturing	Research & Development/ Supply Chain Development	Battery Swapping	Reuse & Recycle
	– **Advanced Technology Vehicles Manufacturing Loan Program:** Outlay of USD 17.7 billion in loan authority to support the manufacture of eligible light duty vehicles – **Green growth strategy:** Stronger EV deployment was driven by state level policies such as ZEV by California and bans on ICE.	– **EV battery program in the Vehicle Technology Office:** Outlay of USD 62.75 million on research, development, demonstration, and deployment of vehicles with low greenhouse gases – **Bayh-Dole Act through a Determination of Exceptional Circumstances:** Outlay of more than USD 200 million will be provided to support the research, development and demonstration of battery – **National Blueprint for Lithium Batteries**: The FCAB is engaged to assist the domestic supply chain of advanced batteries		– **EPA recommendations:** Creating awareness regarding and inform people on how to manage battery waste – **Department of Transportation's Hazardous Materials regulation:** These regulations govern the transportation of hazardous materials interstate, intrastate or overseas – Other measures include **Public Law 104-142: The Mercury containing and Rechargeable Battery Management Act and Universal Waste Regulations**

No information available

Table 48: Promotional Measures to boost EV battery ecosystem in US

Particulars	Policies/Schemes	Details
Battery Manufacturing	Advanced Technology Vehicles Manufacturing Loan Program	• The loans program office plans to offer loans up to USD 17.7 billion for manufacture of eligible light duty vehicles and their qualifying components. This program has provided loans cumulating to over USD 8 billion till date.
	State level policies	• California announced a Zero Emissions Vehicle mandate requiring all new cars and passenger light trucks to be zero emission vehicles by 2035. Quite a number of states followed suit. New York, Massachusetts, and New Jersey are considering similar bans on internal combustion engines as well. Other state level policies offer tax credits and/or purchase incentives for EVs. Some states also provide financial and technical assistance for charging infrastructure development.
R&D	EV battery program in the Vehicle Technology Office	• Vehicles Technology Office offered up to USD 62.75 million as a part of its program on research, development, demonstration, and deployment of vehicles with low greenhouse gas emissions. This aims at reducing emissions and improving efficiencies for both on-road and off-road vehicles.
	Bayh-Dole Act through a Determination of Exceptional Circumstances	• Under this act, all the innovations developed with funding from taxpayers, through the DOE Science ad Energy Program, will require awardees to manufacture those products. This in turn creates domestic jobs. This Act also provides for more than USD 200 million support for research, development and demonstration of battery technologies.

Particulars	Policies/Schemes	Details
Supply Chain Development	National Blueprint for Lithium Batteries	• The national blueprint for lithium batteries provides for a 10-year plan to ensure development of a lithium battery supply chain to create equitable clean energy jobs.
Recycling and reuse	EPA recommendations	• This aimed at creating awareness and informing people on how to manage battery waste. The recommendations covered ways to manage removable and non-removable batteries and ensure that the used batteries are appropriately recycled.
	Public Law 104-142: The Mercury containing and Rechargeable Battery Management Act	• This act was passed to phase out the usage of batteries containing mercury. This act also provided for recycling regulations of Nickel Cadmium, sealed lead acid batteries and certain other technologies and mentioned requirement of uniform labeling and battery collection programs.
	Department of Transportation's Hazardous Materials regulation	• These regulations govern the interstate, intrastate or overseas transportation of hazardous materials. The primary goal is to ensure the safety of general public and those involved in the transportation of hazardous materials. It lays out regulation for four general areas: Identification and classification of hazardous materials, communicating/labelling/marking hazardous materials, packaging requirements and operational rules.
	Universal Waste Regulations	• The Universal waste regulations encourages disposal of harmful waste and safe recycling. It includes battery wastes (NiCd and lead acid batteries) which should be recycled. These regulations specify the waste management requirement for those handling small quantity and large quantity of universal waste batteries.

Source: US DOE Office of Science and Technical Information (access here), US DOE Office of Energy Efficiency & Renewable Energy (access here), IEA (access here), IEA (access here), US DOE Loans Program Office (access here). US DOE (access here), US DOE Vehicles Technology Office (access here), US DOE (access here), US DOE (access here), US EPA (access here), US EPA (access here), US EPA (access here), Battery Recyclers of America (access here)

Summary of Indian and International policies and regulations for battery ecosystem

Based on the landscape study of Indian and international policies and regulations for battery ecosystem, the below table summarizes the various measures adopted by select countries and India:

Table 49 Summary of Indian and International policies and regulations for battery ecosystem

Particulars	China	Australia	Brazil	South Korea	Japan	USA	India
Sourcing Raw materials	- NA	- 100 million incentive to for greenfield mineral exploration. - Set up growth centers for mining equipment sector. - $A 5 billion to promote investments in energy minerals sector	- 75% reduction in corporate income tax and additional nonrefundable amounts calculated based on exploration profit	- Funding and tax incentives to 100 companies to double the stockpile of battery raw materials	- NA	- NA	- MoU with Bolivia to access vast lithium deposits - MoU between JEMSE and KABIL for supply of lithium - Deal with Australia to procure critical minerals such as lithium.
Battery Manufacturing	- Outlay of 37.585-billion-yuan subsidy for energy saving projects - Sales target of 20% was set for EVs for 2025 - Credit requirements were set from 2021-2023 (14-18%) - Exemption from traffic restrictions,	- $1.5 billion to drive battery manufacturing - Stamp duty & two years registration fee waived off	- Tax credit of 1.5 billion real for vehicle manufacturers - Public transport emissions reduction by 50% in 10 years and 100% in 20 years - Reduction in taxation: 25% to 7% for BEVs and	- Investment of 40.6 trillion won by major battery manufacturers - Purchase subsidy (USD 42000), exemption from toll fees, discount in parking fees, tax cuts, etc.	- Long-term target by 2050 to reduce emissions to zero for vehicles - incentives of 1.7 trillion yen, for 10 years and 1 trillion yen in 3 years to attract global investment. - Purchase subsidy up to USD 7200 and Next	- Outlay of USD 17.7 billion in loan authority to support the manufacture of eligible light duty vehicles - Stronger EV deployment was driven by state level policies such as ZEV by	- Incentive payout of INR 18,100 crores for 5 years - Incentivize value addition domestically and rationalize custom duties

Particulars	China	Australia	Brazil	South Korea	Japan	USA	India
	free parking spaces, bus fleet electrification		from 25% to 20% for HEVs		Generation Cars penetration in 2030.	California and bans on ICE.	
R&D	- Outlay of RMB 700 million for EV and related components research programs	- Financial assistance of up to 50% of R&D investments and 15% of plant and equipment costs up to 1 crore	- Outlay of $620 million to stimulate research and development.	- Outlay 100 billion won to support technological advancements. 8 billion Korean won for Micro EV technology. - 20.1 trillion won budget for R&D. Tax credits up to 50% for R&D	- 2 trillion yen over the next 10 years to stimulate R&D worth of 15 trillion yen	- Outlay of USD 62.75 million on research, development of ZEVs - Outlay of more than USD 200 million for R&D of battery technology	- R&D grants by DHI/ DST
Supply Chain development	- Encouraging foreign investments, building charging infrastructures - Exemption from import duties and consumption tax	- Set up growth centers in sectors related to lithium-ion battery to gain competitive advantage. - Yearly tax offsets up to A$200000 & exemption on capital gains taxes.	- Reduction in the import duty on BEVs and FCEVs to 35%	- Transforming 470 component manufacturers into dedicated future vehicles component manufacturers	- Subsidy program to boost the installation of battery systems along with charging stations.	- The FCAB is engaged to assist the domestic supply chain of advanced batteries	- Outlay of 10000 crores in a period of three years to promote local supply chain
Battery Swapping Infrastructure	- National standard for battery swap safety requirements for EVs	- NA	- NA	- NA	- NA	- NA	- Draft National Battery Swapping Policy

Particulars	China	Australia	Brazil	South Korea	Japan	USA	India
	- Exemption from subsidy requirements - Infrastructure development of battery swapping						
Battery disposal, reuse & recycle	- Setting the waste recycling rate: 50% by 2025 - Rates of recovery for major battery metals were changed	- Recyclers will be offered a rebate per kg under the battery stewardship scheme	- Brazil does not have a separate policy for battery waste management	- Outlay of 13 billion won for reuse and recycling of lithium-ion batteries - EPR policy was adopted for mercury, NiCd, silver oxide, primary lithium batteries, MnAl and NiMH	- Business operators to collect and recycle	- Creating awareness - Govern the transportation of hazardous materials	- Mandatory collection of used batteries by dealers and manufacturers against the new ones sold by them. - No uniform regulations of battery reuse and cycle as of now

3.3 Key recommendations for India

As illustrated in previous sections, several countries have adopted unique and innovative measures to promote battery adoption. These measures have acted as catalysts for development of battery storage systems. On comparison with the extent of measures adopted by India, the key initiatives that can be additionally considered are presented below:

Table 50: Recommendation of measures for India

Particulars	Measures	*Reference country*
Sourcing Raw materials	• Funding and tax incentives could be provided to companies to build stockpile of strategic raw materials like lithium, nickel, cobalt, and rare earths	*South Korea*
Battery Manufacturing	• Auto companies can be mandated to meet EV credits & corporate average fuel consumption levels.	*China*
	• EV manufacturers could be given tax credits based on the investments made by the manufacturers	*Brazil*
	• A government-led initiative could be developed where major battery makers can invest in the EV battery industry (facilities and R&D) to gain competitive edge. Government in turn could support them by providing tax credit.	*South Korea*
R&D and Supply Chain development	• Financial assistance could be offered for research and development of EV and related components or specifically for battery technology.	*China, Australia, Brazil, South Korea, Japan, USA*
	• Yearly tax offsets could be given to battery manufacturers.	*Australia*
	• Exemption could be given on capital gains taxes	*Australia*
	• Growth centers could be set up in sectors related to lithium-ion battery to gain competitive advantage. This should be an Industry-led approach to drive innovation, productivity and competitiveness.	*Australia*
	• A national blueprint could be designed for development of lithium-ion batteries to assist the domestic supply chain of advanced batteries	*USA*
Battery Swapping Infrastructure	• National standard for safety in battery swapping could be developed. This will help in improving the level of safety of EVs which use the battery swap technology	*China*
	• Construction of battery swapping infrastructures should be promoted through financial and non-financial incentives.	*China*
Battery disposal, reuse & recycle	• Government could set up short term (2025) and long term (2050) battery waste recycling rates as well as rates of recovery of major battery materials	*China*
	• Recyclers can be offered a rebate per kg to collect, sort and process the end-of-life batteries. Participation of importers and retailers can be mandated through the scheme as well. Major battery manufacturers can be encouraged to participate in the same.	*Australia*
	• Financial assistance and subsidies could be offered to promote battery recycling and reuse.	*South Korea*

Battery Manufacturing

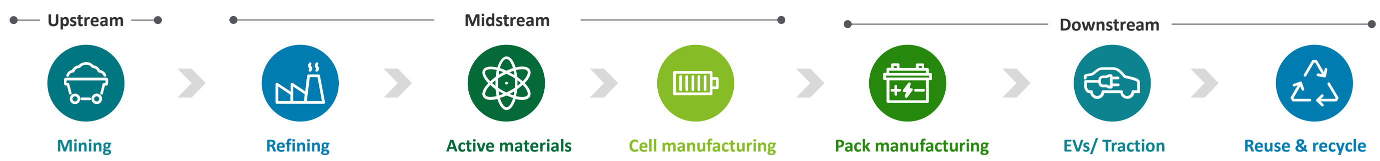
Chapter 4. Overview on battery manufacturing for EVs

4.1 Battery value chain

There are multiple battery chemistries which are currently used in EVs (BEVs, HEVs, and PHEVs) such as nickel-metal hydride, lead-acid and lithium-ion (details on these technologies are covered in Chapter 1). However, it is Li-ion technology which is the undisputed leader owing to its superior energy density, power density and cycle life characteristics. In this chapter, we will focus on the manufacturing value chain of lithium-ion batteries.

The overall value chain of a lithium-ion battery can be categorized into four areas: **raw material supply, battery manufacturing, battery usage** and **battery end-of-life.** An illustration of the battery value chain is provided in the below figure:

Figure 33: Li-ion battery value chain

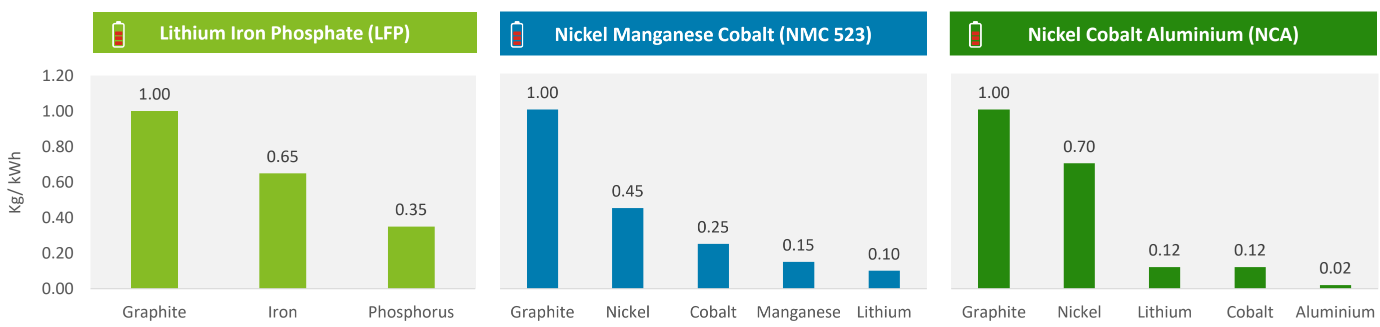


In the following sections, raw material supply and battery manufacturing will be discussed in detail. Battery EoL areas such a reuse and recycle are provided in Chapter 7 & 8.

Raw material supply

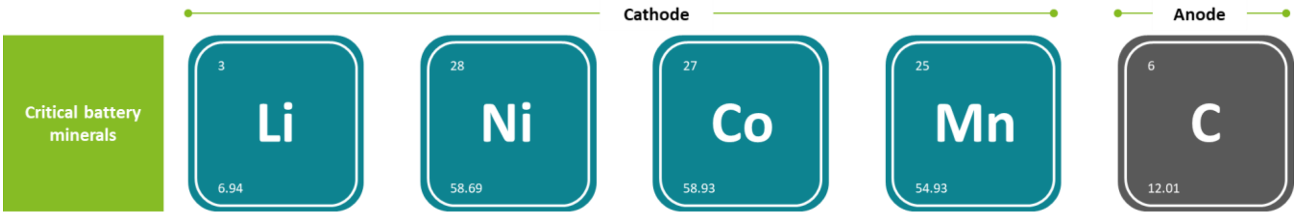
In chapter 1, we discussed that there are various chemistries within lithium-ion which have been adopted globally for EV applications such as Lithium Iron Phosphate (LFP), Lithium Nickel Manganese Cobalt Oxide (NMC), and Lithium Nickel Cobalt Aluminium Oxide (NCA). These chemistries use several critical minerals for manufacturing; mass of these minerals in 1 kWh of various Li-ion chemistries is provided in Figure 34.

Figure 34: Mineral mass (kg) per kWh in various Li-ion chemistries



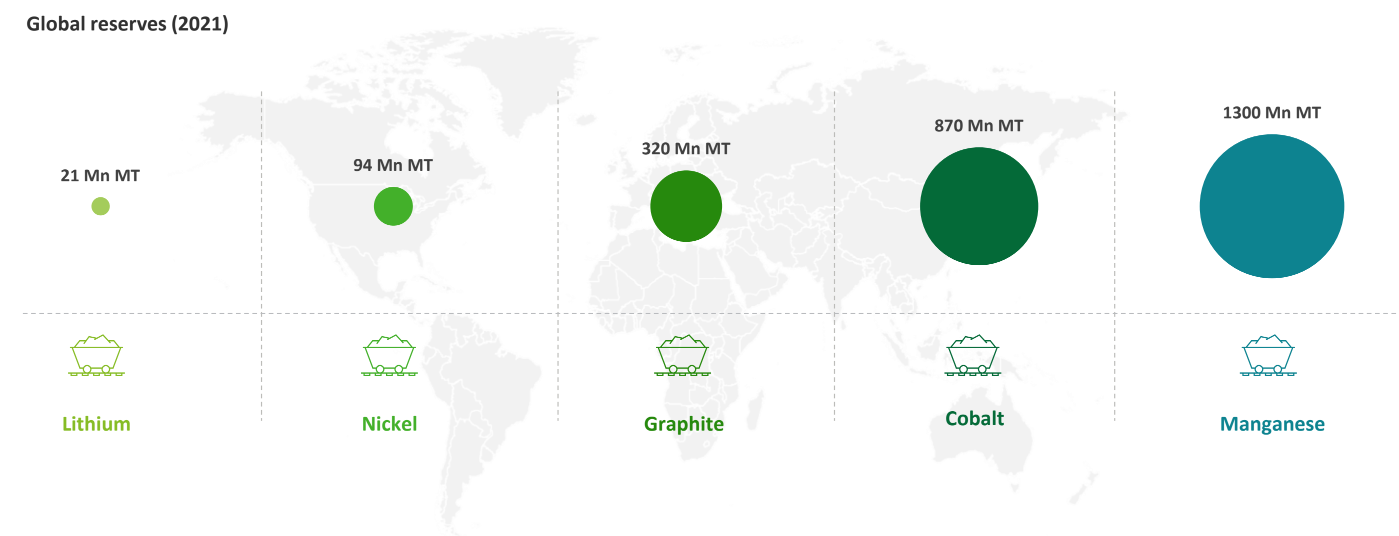
The critical minerals present in these chemistries are **lithium, nickel, cobalt, manganese, and graphite**. In the subsequent sections, we will study the global raw material supply scenario in greater detail.

Figure 35: Critical minerals for lithium-ion battery technology



Of all the identified critical minerals, lithium and nickel have the lowest reserves. Lithium reserves are of only ~21 Mn MT compared to ~1300 Mn MT for manganese (as per USGS 2021). Graphite although has considerable reserve globally, but not all of it can be used for battery application. Only high purity flake (crystalline) graphite with more than 90% fixed carbon is suitable for battery application. Cobalt is present in abundance; however, 70% of its supply comes from Congo, posing a huge supply chain risk due to the political instability in the country.

Figure 36: Global reserves for battery minerals (2021)



Source: USGS 2021; Mn MT: Million Metric Ton

In the following sections, we will assess each of the identified battery mineral in detail along with their related developments in India.

Lithium

Lithium is a highly reactive metal and, therefore, it is not available in nature in its pure element form. It is mostly found as a constituent of salts or other compounds. It is also a highly rate metal – accounts for about 0.006% of the earth's crust.[72]

Lithium is found in underground deposits of brine, clay, sea water, geothermal wells and in granitic pegmatites such as spodumene (Li_2O, Al_2O_3. $4SiO_2$). For battery application, only lithium with purity above 99.5% is preferred.

[72] Battery Metals Report 2021

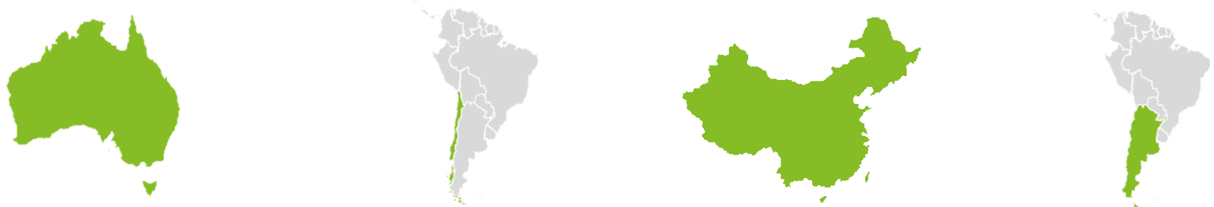
There are two types of different sources for lithium:

1. **"Brine", i.e. (salt) sheet or brine deposits:** In these deposits, lithium carbonate is initially obtained by evaporating lithium containing salt solution (present in a Salt Lake) and sodium carbonate is further added in it. Once lithium carbonate is extracted, it is then processed with hydrochloric acid which ultimately gives metallic lithium.
2. **"Hard Rock Spodumene", i.e., hard rock pegmatite deposits:** In these deposits, lithium compound is extracted from a lithium-bearing aluminium silicate mineral – Spodumene. It is mined using conventional mining technologies which is then converted into lithium carbonate (purity more than 99.5%).

Note: An intensive thermal and hydrometallurgical process is required which is quite costly. These deposits are currently exploited in Australia.

As per U.S. Geological Survey estimates, in 2020, global lithium production stood at 82,000 metric tons (excluding USA production. Globally, there are only four countries which are major producers of lithium. Australia, Argentina, Chile and China accounted for ~96% of world lithium production in 2020. There are five mineral operations in **Australia**, two brine operations in both **Argentina** and **Chile**, and two brine and one mineral operation in **China**.

Figure 37 Top lithium mining countries (2021)

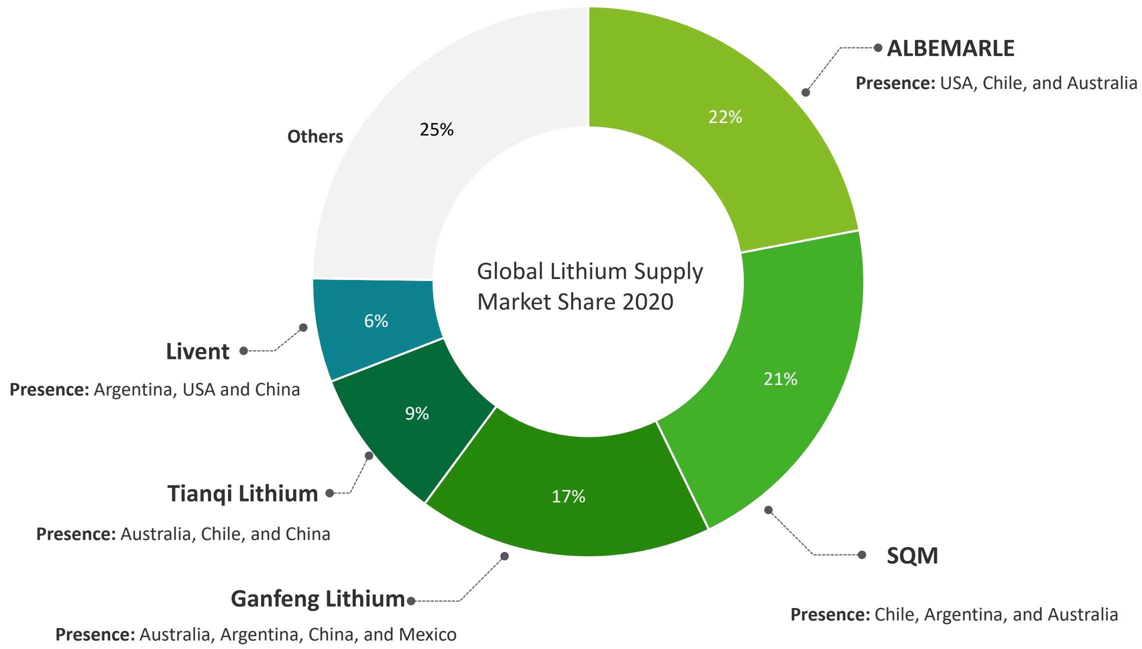


Australia	Chile	China	Argentina
40,000 metric tons *(49% of global production)*	18,000 metric tons *(22% of global production)*	14,000 metric tons *(17% of global production)*	6,200 metric tons *(8% of global production)*

Source: USGS 2021

United States and China based companies are the leaders in lithium mining. In 2020, five companies contributed to more than 70% in global lithium supply, four of which were US or Chinese. These companies are Albemarle (USA), Sociedad Química y Minera de Chile (Chile), Jiangxi Ganfeng Lithium Co. Ltd (China), Tianqi Lithium (China), and Livent (USA).

Figure 38: Leading players in lithium mining - Global



Source: Global X ETFs

India does not have considerable lithium reserves. It currently imports 100 percent of its lithium in various industrial forms, including lithium oxide (about 1 kilo tons), lithium hydroxide (about 1 kilo tons), and lithium carbonate (nearly 1 kilo tons). Lithium cells and battery packs are also imported for smaller electronics products and mobile phones. Lithium is primarily imported as lithium-ion batteries (about 16 kilo tons) for EVs and ESS. [73]

In 2020, India discovered its first lithium pegmatites reserve consisting of 1,600 tonnes in the Marlagalla-Allapatna region of Karnataka's Mandya district.[74] In addition to this, there have been other developments in the country around lithium mining and refining. Some of such developments are mentioned below:

Table 51: Developments in the lithium ecosystem

Sl. No.	Activities	Developments
1	**Exploring domestic and international resources for lithium**	• 2020: India's first lithium reserve of 1,600 tonnes is discovered in Karnataka
2	**Lithium processing and refining**	• 2020: Khanij Bidesh India Limited (KABIL) begins exploration of 17 Mt of lithium in South America (KABIL was formed in 2019) • 2020: Manikaran Power Limited in partnership with Neometals Limited (Australia) conducted a feasibility study for setting up a lithium refinery in India, with a nominal capacity of 20 kt of lithium carbonate equivalent (lithium hydroxide)

[73] UN Comtrade, https://comtrade.un.org/
[74] https://pib.gov.in/PressReleasePage.aspx?PRID=1694796

Nickel

Similar to Lithium, Nickel also occurs in the earth's crust with a content of about 0.008%.72 The Battery Metal Report 2021 suggests that there are only about 50 occurrences of native nickel worldwide. Majority of global nickel production comes from sulfide ores. Nickel mining is now shifting towards lateritic nickel ores however it is a much expensive extraction compared to sulfide ores.

In 2020, around 2.5 million tons of nickel were mined worldwide. The largest producer was Indonesia (7,60,000 metric tons) followed by Philippines (3,20,000 metric tons), Russia (2,80,000 metric tons) and New Caledonia (200,000 metric tons), which belongs to France. These countries account for about 62% of total nickel production worldwide.

Figure 39: Top nickel mining countries (2021)

Indonesia	Philippines	Russia	New Caledonia
7,60,000 metric tons *(30% of global production)*	3,20,000 metric tons *(13% of global production)*	2,80,000 metric tons *(11% of global production)*	2,00,000 metric tons *(8% of global production)*

Source: USGS 2021

India currently imports the majority of its nickel ores and concentrates from countries such as Indonesia, Japan, and the UAE. Nickel oxides and hydroxides are imported from Sweden, China, the Philippines, Germany, Belgium, and Australia.

Cobalt

Like Lithium, Cobalt is a rare element with a frequency of 0.004 percent in the earth's crust.72 However, its extraction is relatively simple and inexpensive. Cobalt is found in many minerals, but usually occurs only in small amounts. The element is always associated with Nickel.

In 2020, around 1,40,000 metric tons of cobalt were mined worldwide. The largest producer was Ghana with around 95,000 metric tons followed by Russia (6,300 metric tons), Australia (5,700 metric tons) and Philippines (4,700 metric tons). These countries account for about 80% of total cobalt production worldwide.

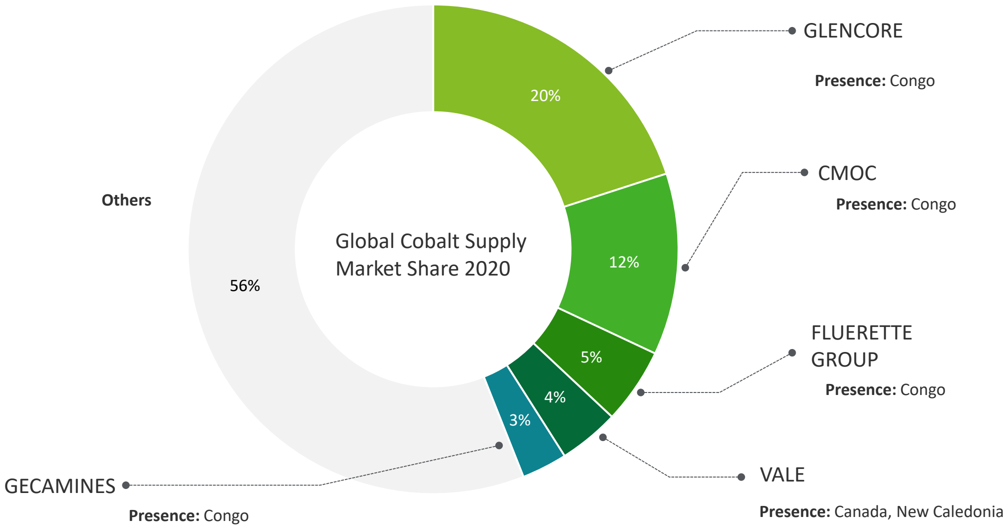
Figure 40: Top cobalt mining countries (2021)

Congo (Kinshasa)	Russia	Australia	Philippines
95,000 metric tons *(68% of global production)*	6,300 metric tons *(5% of global production)*	5,700 metric tons *(4% of global production)*	4,700 metric tons *(3% of global production)*

Source: USGS 2021

Majority of cobalt production is from countries such as Congo, Russia, Philippines – which are rather less stable/ predictable than other countries. Due to this there is always an inherent supply chain risk associated with the supply of cobalt.

Figure 41: Leading players in cobalt mining - Global



Source: Century Cobalt

In 2019, global economic resources of cobalt were 7,200 kilo tons. India had 44.91 million metric tons of cobalt reserves, according to the National Mineral Inventory.[75] Although, India does not currently produce cobalt, it does have modest cobalt refining capacity estimated at 2 kilo tons (of cobalt sulphate) annually, with Nicomet and Rubamin as the leading manufacturers.

India imports cobalt in various forms, including as waste and scrap, which accounted for about 1.5 kilo tons in 2019 and 1 kilo ton in 2020. India primarily imports cobalt ores, oxides, and hydroxide from Belgium, China, and Finland. It imports cobalt sulphate from Finland and China.

Manganese

Manganese is the 12th most abundant mineral of the crust's elements – approx. 0.1% of the Earth's crust. Although, manganese is used various applications such as production of ferromanganese alloys, steel etc., it is a core raw material for batteries. Only high purity manganese is said to be preferred for battery application.

In 2020, around 18,500 metric tons of manganese were mined worldwide. The largest producer was South Africa with around 5,200 metric tons followed by Argentina (3,300 metric tons), Gabon (2,800 metric tons) and Ghana (1,400 metric tons). These countries account for about 67% of total manganese production worldwide.

Figure 42: Top manganese mining countries (2021)

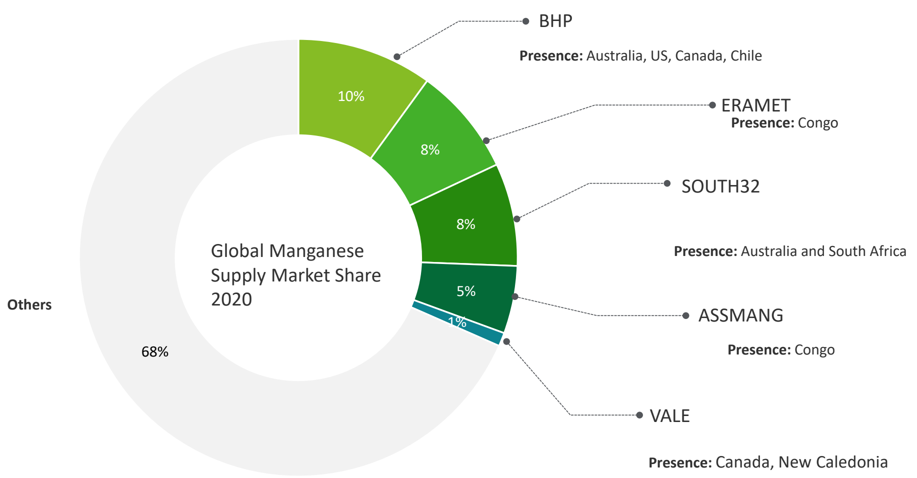
[75] Indian Mineral Yearbook, 2020 – Cobalt, https://ibm.gov.in/writereaddata/files/09022020154028Cobalt_2019.pdf

South Africa	Argentina	Gabon	Ghana
5,200 Thousand metric tons *(28% of global production)*	3,300 Thousand metric tons *(18% of global production)*	2,800 Thousand metric tons *(15% of global production)*	1,400 Thousand metric tons *(8% of global production)*

Source: USGS 2021

Manganese mining industry is highly fragmented. In 2020, top five players mined around 32% of global manganese production.

Figure 43: Leading players in manganese mining - Global



Source: Company websites

India currently has 495.87 million tons of manganese reserve as per NMI database (globally ranked 7th).[76] Out of the overall reserves, only 0.17 million tons is of battery grade. India majorly imports manganese ores from countries such as Indonesia, China, Netherlands etc.

Graphite

Graphite is a form of elemental carbon with a high electrical and thermal conductivity and excellent thermal stability, making it suitable for a wide range of industrial applications. However, only high purity graphite is suitable for production of battery anode.

There are three types of natural graphite mined from earth's crust: Vein (lump) Graphite, Flake (Crystalline) Graphite, and Amorphous (Microcrystalline) Graphite. Of all these three types, Flake (Crystalline) Graphite is the most suitable for battery application.

In 2020, around 1.1 million metric tons of graphite were mined worldwide. The largest producer was China with around 650,000 metric tons followed by Mozambique (120,000 metric tons), Madagascar (47,000 metric tons) and India (34,000 metric tons). These countries account for about 77% of total graphite production worldwide.

[76] Indian Minerals Yearbook- 2019

Figure 44: Top graphite mining countries (2021)

China	Mozambique	Madagascar	India
650,000 metric tons *(59% of global production)*	120,000 metric tons *(11% of global production)*	47,000 metric tons *(4% of global production)*	34,000 metric tons *(3% of global production)*

Source: USGS 2021

Some of the leading companies in natural graphite mining are: Gratomic (Canada), Matrass C-Graphene (China), First Graphene (Australia), Zentek (Canada), Lomiko Resources INC (Canada), Syrah Resources (Australia) etc.

India is ranked 7th globally in terms of Graphite reserves. Bulk of the graphite resources in India are of poor grade as only 2.91 Mt of total resources contain +40 per cent fixed carbon. India is currently a net importer of natural graphite, with about 60 percent of imports sourced from China.[77]

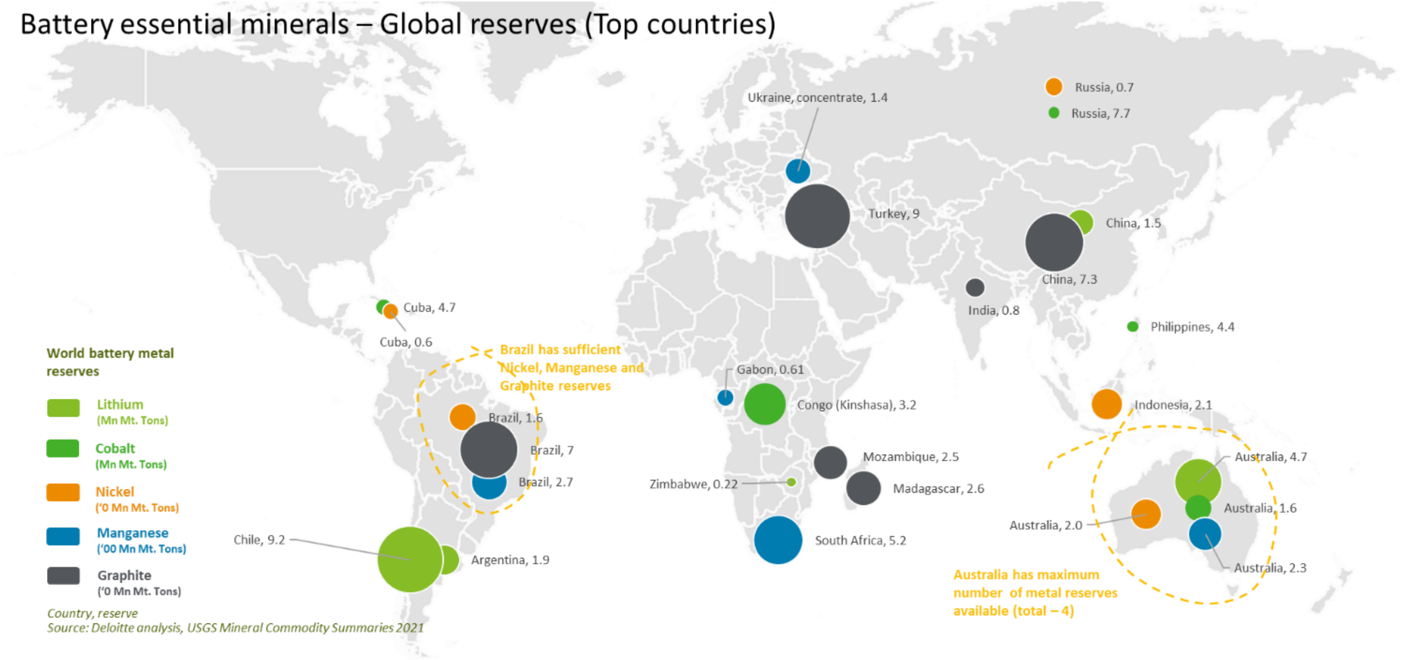
Indian companies, such as Himadri Speciality Chemical Limited and Epsilon Carbon Private Limited have moved into graphite processing to produce SPG for battery anode material. [78,79]

Global reserves

As far as global reserves are concerned, there are two regions which holds majority of the essential battery minerals viz. Australia and South America. Australia holds considerable reserve of all the battery minerals except for graphite, whereas, South America lacks only on Cobalt reserves.

[77] UNCOMTRADE and India Trade Statistics
[78] Himadri – Advanced carbon materials (access here)
[79] Epsilon – Advanced materials (access here)

Figure 45: Global battery essential mineral reserves - 2021



Source: Deloitte analysis, USGS Mineral Commodity Summaries 2021

To remove the impurities and increase core material concentration, mined minerals are further refined. The refinery location can either be near to the mining location itself or it can be situated far from it. China currently dominates the global refining industry. Almost all the battery minerals, irrespective of their mining geography, is sent to China for refining. As per BloombergNEF, China alone controls 80% of global battery raw material refining.[80]

4.2 Battery – Key components

A typical traction battery is manufactured using cells and modules. Modules group together cells in a frame to protect them from external factors such as shocks, heat, or vibration. These modules are then further grouped together along with control or protection systems.

Detailed flow of cell to battery conversion is provided below:

[80] China Dominates the Lithium-ion Battery Supply Chain, but Europe is on the Rise (access here)

Figure 46: Cell to battery conversion

Cell

It is the basic unit of a battery which exerts energy by charging and discharging.

STEPS

I. Voltage, Capacity and Internal Impedance are matched.
II. Group cells with similar operating parameters

Module

A module is a group of cells put into a frame to protect them from external shock, heat or vibration.

STEPS

I. Join cells in series strings
II. Join strings in parallel
III. Assemble modules and attach slave BMS
IV. Test the modules

Pack

Final shape of an EV battery consists of a group of modules along with control or protection systems including a BMS, cooling system etc.

STEPS

I. Stack modules in series and parallel combination to achieve final configuration
II. Place pack in enclosure
III. Attach master BMS
IV. Sent for final testing

Source: IESA

As mentioned above, once the **battery cells** are produced, they are grouped together to form **battery module**. In the battery module, cells are electrically connected using terminals and monitored using temperature sensors.

These modules are then are then grouped with protection systems such as battery management system (BMS) to form a **battery pack**.

Other than BMS, there are other ancillary components used in a battery pack such as contactors, bus bars, fuses, service plug and casing, sensors, terminals, and cooling channels.

Figure 47 illustrates all the key components of a battery pack. Details on these components are provided below.

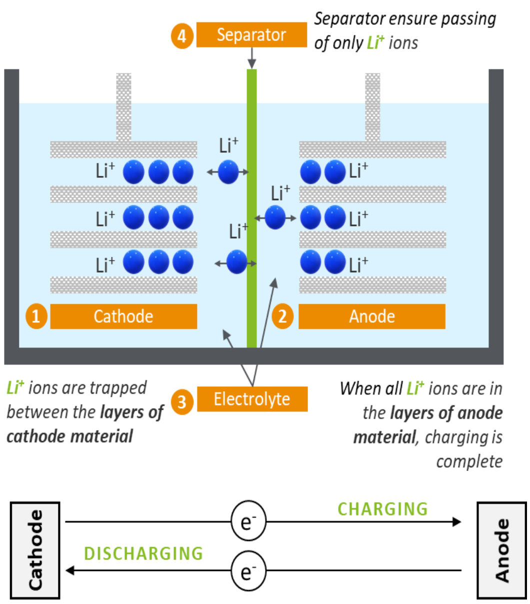
Figure 47 Traction battery pack

Note: Details of each battery component is provided in the table below

1.	**Battery Modules**	Battery assembly built by combining fixed number of battery cells; Protects the battery
2.	**Battery management system**	The purpose of the BMS is to guarantee safe and reliable battery operation. It monitors the voltage produced by individual battery cells in the stack and ensures that the battery's charge doesn't go above or below the threshold limits.
3.	**Contactors**	Contactors isolate the battery pack electrically from the vehicle when EV crashes or battery system fails
4.	**Bus bars**	Bus bars are responsible for electrically connecting the battery modules together and for connecting the modules to the contactors
5.	**Fuse**	Protects the battery pack components from damage due to power surges and faults
6.	**Service plug**	Used during servicing or maintenance to electrically isolate the battery pack from the vehicle
7.	**Casing**	Upper casing provides protection from fire, water, and dirt inflow while the lower casing supports the battery pack and protects it from damage.

Battery cell

Battery cell, the basic unit of a battery, is usually made of four components – anode (negative electrode), cathode (positive electrode), electrolyte, and separator which can differ in chemistry (except separator), yielding different cell characteristics. Besides these, other components such Copper and Aluminium foils are also be required.

Component	Details	Illustration
1. Cathode	Emits lithium-ion to anode during charging; Receive lithium-ion during discharging • *Key materials:* ***Lithium, Nickel, Cobalt, Manganese etc.*** • *Key players:* ***Umicore, Sumitomo Metal Mining, Easpring Material etc.***	
2. Anode	Receives lithium-ion from cathode during charging; Emit lithium-ion during discharging • ***Key materials:*** *Graphite (Natural or Synthetic), Lithium, Silicon etc.* • ***Key players:*** *Hitachi Chemical, Nippon Carbon Company, Posco Chemical, Shanshan, BTR etc.*	
3. Electrolyte	Passes lithium-ions between cathode and anode • ***Key materials:*** *LiPF6 (Lithium hexafluorophosphate), LiBOB (Lithium Bis(oxalate) Borate) etc.* • ***Key players:*** *Ube Industries, Mitsubishi Chemical, Soulbrain, Capchem Technology etc.*	
4. Separator	Prevents short circuit between cathode and anode, Pass lithium ions through pores in separator • ***Key materials:*** *Polyethylene, polypropylene, polyethylene-polypropylene etc.* • ***Key players:*** *Asahi-Kasei, Toray, SK Innovation, Semcorp, Putailai etc.*	

Material selection for Li-ion battery cell

Type of material has a significant impact on the performance characteristics of the battery. Based on the intended application and required performance, materials are selected for manufacturing.

Performance of Cathode and Anode influence the overall performance of the battery. Therefore, selection of suitable materials for production of these components is vital. The following table lists out the key materials used in the anode and cathode of a lithium battery and the impact of such materials in the batteries.

Table 52: Characteristics of key Cathode and Anode minerals

Sl. No	Cathode minerals	Anode minerals
1	**Cobalt:** It has a stabilizing effect, prevents cathode corrosion, and boosts the charge rate of a battery	**Graphite:** Graphite allows for higher energy density, rate capability, longer cycle life and batter safety performance.

Sl. No	Cathode minerals	Anode minerals
2	**Nickel:** Helps in delivering higher energy density. It also allows for greater storage capacity at a lower cost, thereby delivering a longer range for EVs	**Silicon:** Silicon has a low working potential and has higher energy density as compared to graphite
3	**Manganese:** Is mostly used as a stabilizing material in EV batteries. But it also has various natural ionic states and has the capacity to hold and discharge electrons.	
4	**Iron Phosphate:** This allows the battery to have high current rating, high specific power, long life cycle and good thermal stability	

Note: More details on performance characteristics of various Li-ion chemistries such as LFP, NMC, NCA is provided in Chapter 1.

Types of battery cells designs

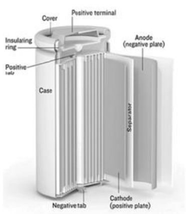
For a Li-ion battery, there are primarily three types of form factors: **Cylindrical, Prismatic and Pouch**. Each of the form factor has its own merits and limitations; however, they have different temperature distribution and heat transfer model, and their usage considerably influences the design of the product.

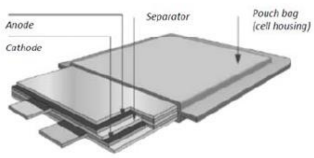
Out of all the cells, **cylindrical cells** are the most mature form factor. It is made up of sheet-like anodes, cathode, and separators that are sandwiched, rolled up, and packed into a cylinder-shaped can. These cells have **high mechanical stability,** and their round shape helps in **distributing the internal pressure** over the surface **evenly**. Although, the packing density of these cells is low (due to the circular cross-section), its thermal management is quite easy because of enough space for coolant to flow.

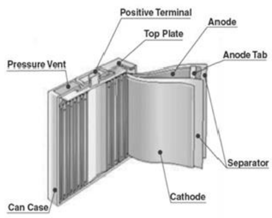
Quite similar to the cylindrical cells, components (anode, cathode and separator) of the **prismatic cells** are sandwiched and rolled up; however, here they are pressed to fit into a metallic or hard-plastic housing in cubic form. Due to its box-like shape, spaces are efficiently used while preparing battery packs; however, lack of spaces negatively impacts the thermal management capacity of the cell.

Contrary to cylindrical and prismatic cells, in **pouch cell**, electrodes (anode/ cathode) and separator are stacked with each other instead of sandwiched and rolled. These cells do not have rigid enclosure and use a thin aluminum polymer foil as cell container/ housing. The thin cell housing reduces the cell weight and results in the highest gravimetric energy density (Wh/kg).

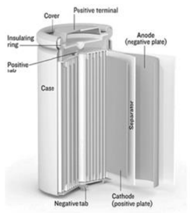
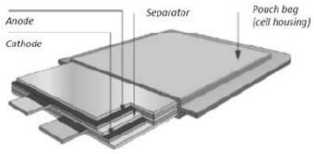
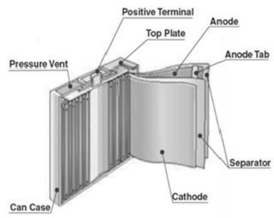
More details on all three types of cells are provided in the below table:







Parameters/ Cell designs	Cylindrical Cell	Prismatic Cell	Pouch Cell
Volumetric energy density at cell level	• Currently **highest** energy density at cell level	• Currently **lowest** energy density of the three cell formats	• **Medium** energy density at cell level
Volumetric energy density at module level	• **High** energy density similar to pouch cell	• Currently the **lowest** energy density of the three cell formats	• **High** energy density similar to round cell
Lifespan	• Independent of format	• Independent of format	• Independent of format

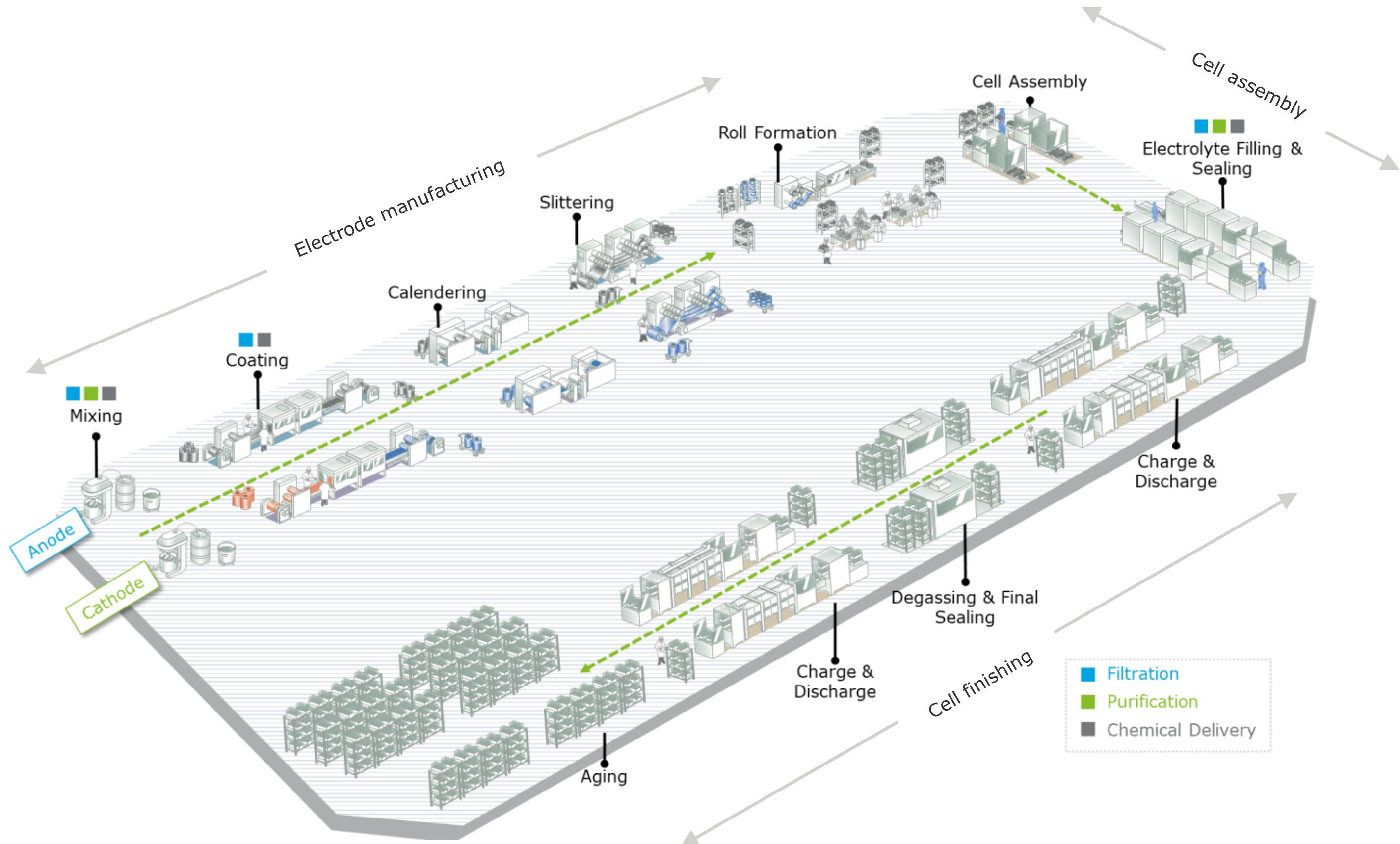
Parameters/ Cell designs	 Cylindrical Cell	 Prismatic Cell	 Pouch Cell
Housing	• Mainly nickel-plated steel	• Predominantly Aluminium	• Aluminium-plastic composite foil
Dimensions	• Typical size 21 x 70 (D x L, mm) but other formats also possible • Low packing density due to space utilization	• Less diversity than the pouch cell • Efficient packing of the cell compound • Tendency towards more elongated housings	• Many sizes • Efficient use of space due to • rectangular shape • Opposite or next to each other cell contacts
Mechanical strength	• High leak tightness • High stiffness • Mechanically robust • Robust under internal pressure due to degassing	• High leak tightness • High stiffness • Lower mechanical stability than the cylindrical cell	• Unstable housing • Inflates when pressure builds up
Thermal regulation	• Low heat dissipation	• A high volume compared to the surface area • Heat conducting Surface	• Good surface to volume ratio • Efficient temperature control
Typical energy content	• 10 – 18 Wh	• 80 – 450 Wh	• 65 – 300 Wh
Cost	• **Lowest** cost both at cell and pack level	• **Higher** cost than cylindrical cells	• **Higher** cost than prismatic cells
Select Manufacturers	• Panasonic (NCA chemistry)	• Samsung SDI, CATL, BYD	• LG Chem, SK Innovation

4.3 Traction battery – Manufacturing

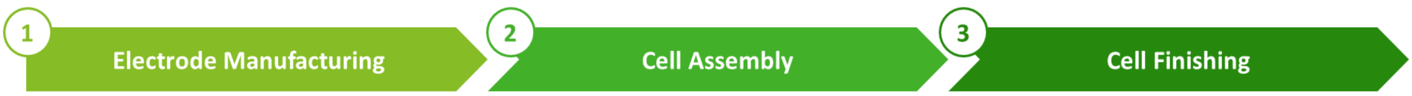
Cell manufacturing

Manufacturing lithium-ion cell is a highly capital-intensive business. Based on inputs from industry players, it is believed that the investment for setting up 1 GWh cell manufacturing facility in Indian can be to the tune of INR 1,200 - 1,500 crores and an estimated land requirement of ~3 – 5 acres.

Figure 48: Illustration of a lithium-ion manufacturing facility



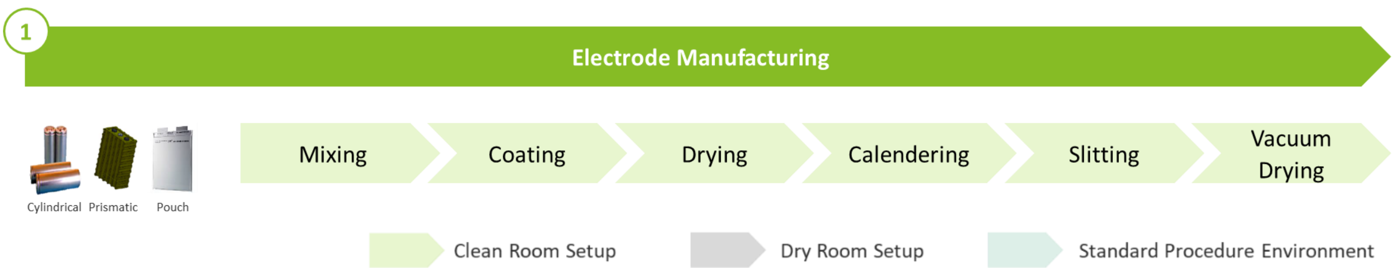
As illustrated above, the overall process of cell production can be divided into three key steps:



Of all these steps, electrode manufacturing processes remain constant for all the cell types whereas cell assembly and cell finishing vary based on the type of cell being manufactured. Breakdown of processes within each step is provided in the figure below:

1. Detailed break-down of electrode manufacturing process

Figure 49 Break-down of key Li-ion manufacturing processes – Electrode manufacturing

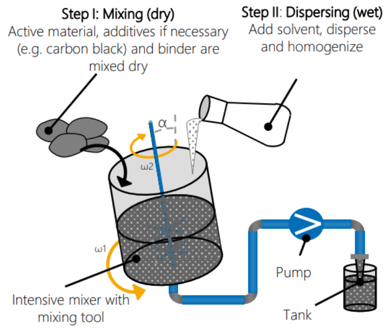


Source: Lithium-Ion Battery Cell Production Process - RWTH Aachen University (access here)

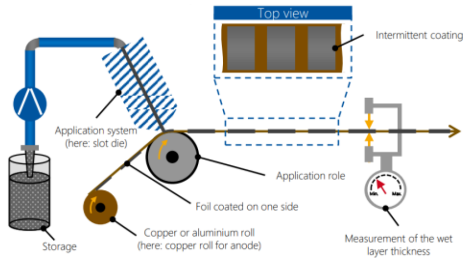
Further details on each of the key manufacturing processes under each step is provided below:

<table>
<tr><th>Process</th><th>Details</th><th>Representative illustration</th></tr>
<tr><td>Mixing (Pouch, Cylindrical and Prismatic Cells)</td><td>

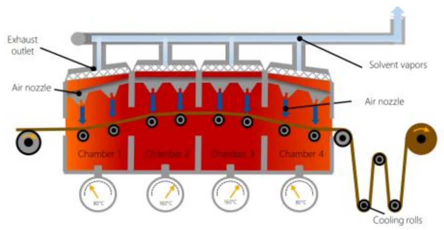
In this process, two or more than two raw materials are mixed together using a rotating tool (also known as slurry).
The raw materials used for mixing can be active materials, binders, conductive additives, solvent etc.

</td><td>
</td></tr>
<tr><td>Coating (Pouch, Cylindrical and Prismatic Cells)</td><td>

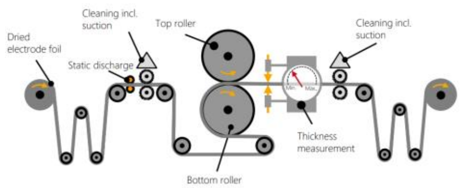
In coating process, a foil of either copper or Aluminium is coated either continuously or intermittently.
The coating is done using some application tools such as slot die, doctor blade, anilox roller etc.

</td><td>
</td></tr>
<tr><td>Drying (Pouch, Cylindrical and Prismatic Cells)</td><td>

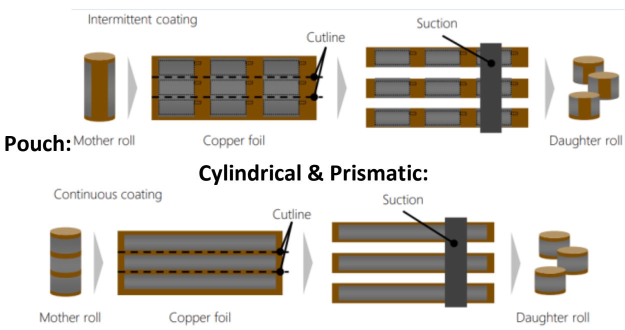
Once coating is completed, the active material is dried in a continuous process. The drying process is done either using roller systems or by floatation of air streams.

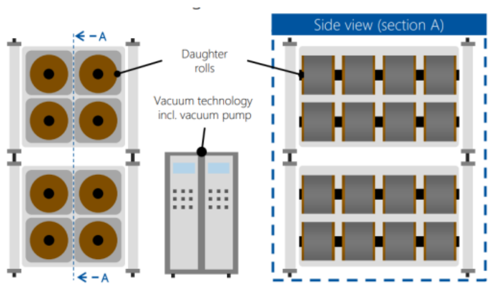
</td><td>
</td></tr>
<tr><td>Calendering (Pouch, Cylindrical and Prismatic Cells)</td><td>

In this process, coated foils are compressed using a pair of rollers. Rollers help in generating precise line pressure.

</td><td>
</td></tr>
<tr><td>Slitting (Pouch, Cylindrical and Prismatic Cells)</td><td>

In this process, a wide electrode coil (also known as mother roll) is divided into smaller electrode rolls (also known as daughter rolls).
Rolling knives are used to slitter the mother rolls.

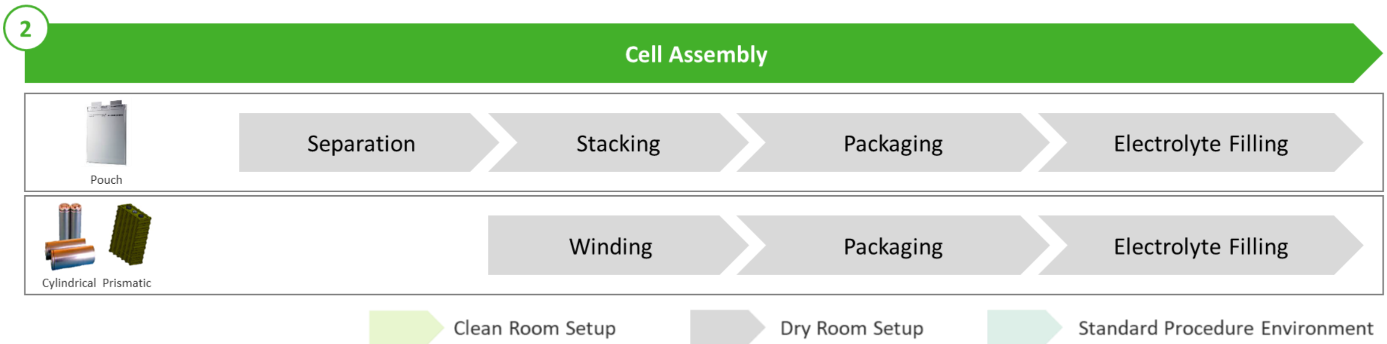
</td><td>
</td></tr>
</table>

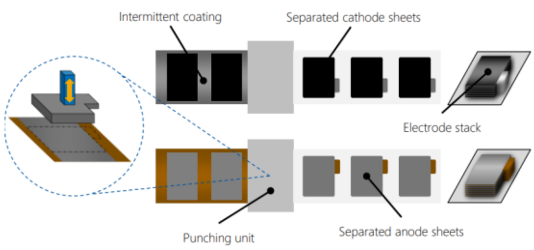
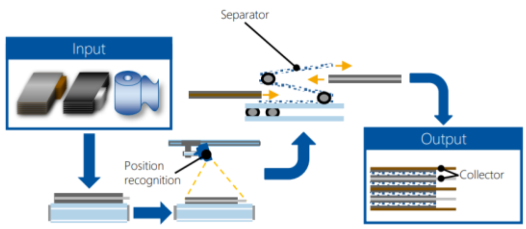
Process	Details	Representative illustration
Vacuum Drying (Pouch, Cylindrical and Prismatic Cells)	• After slitting, the daughter rolls are taken to a vacuum oven using a goods carrier. The rolls are kept in the vacuum oven for approx. 12 to 30 hours. • This process helps in removing the residual moisture and solvents.	

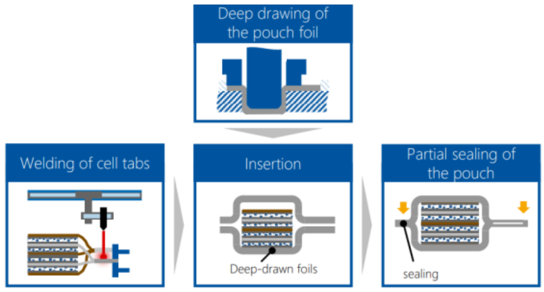
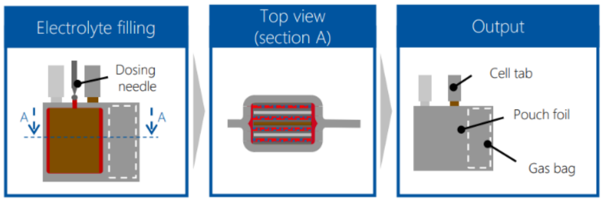
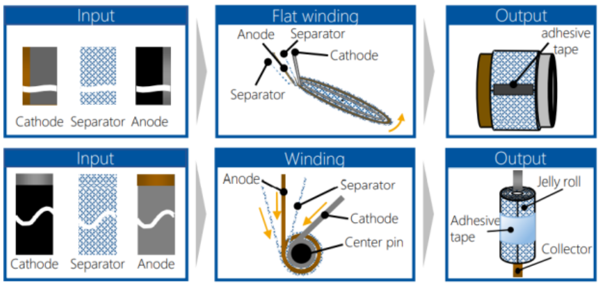
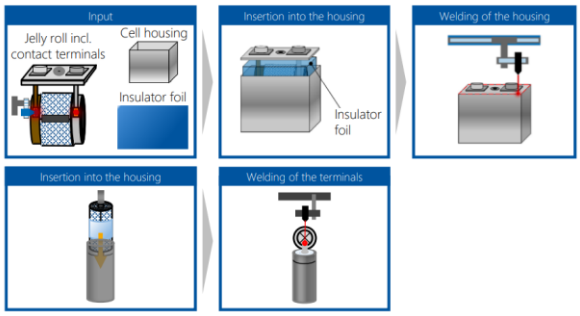
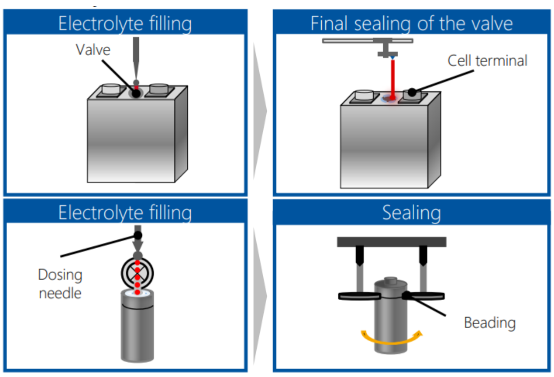
Source: Lithium-Ion Battery Cell Production Process - RWTH Aachen University (access here)

2. Detailed break-down of cell assembly process

Figure 50 Break-down of key Li-ion manufacturing processes – Cell assembly



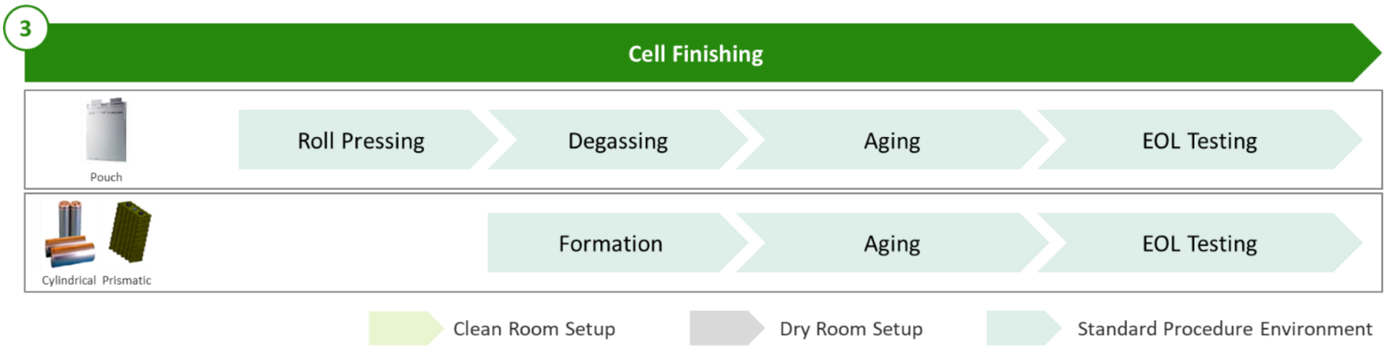
Process	Details	Representative illustration
Separation (Pouch Cell)	• In this process, the dried daughter rolls are unwound and fed to the separation tool which then separates anode, cathode and separator sheets from the daughter roll. • The cutting process is generally carried out with a shear cut in a continuous process.	
Stacking (Pouch Cell)	• In this process, the separated electrode sheets are stacked in a repeating cycle of anode, separator, cathode, separator, etc. •	

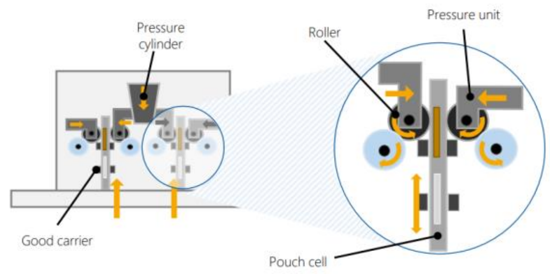
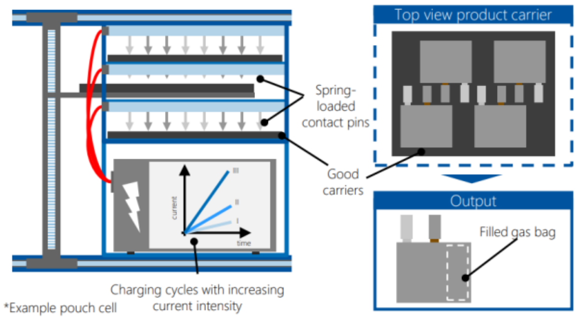
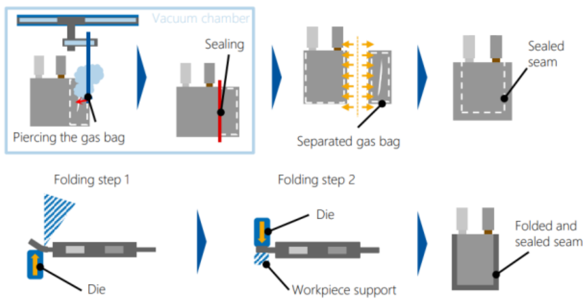
Process	Details	Representative illustration
Packaging (Pouch Cell)	• In this process, the current collector foils ((anode - copper and cathode – Aluminium), cell tabs are positioned in the pouch foil. • The pouch cell is then sealed gas-tight on the three sides (bottom side is left open to fill electrolyte).	
Electrolyte Filling (Pouch Cell)	• Once packaging is done, electrolyte is filled into the cell under vacuum with the help of a high-precision dosing needle.	
Winding (Cylindrical & Prismatic Cell)	• Once the cells are vacuum dried, they are wound around winding mandrel (for prismatic cell) or a centre pin (for cylindrical cell). •	
Packaging (Cylindrical & Prismatic Cells)	• In this process, roll prepared in winding process, is inserted into a metal housing (cylindrical housing for cylindrical cell, and prismatic housing for prismatic cell). • The housing for both the cells is finally sealed by welding process.	
Electrolyte Filling (Cylindrical & Prismatic Cells)	• In this process, electrolyte is filled in the cylindrical and prismatic cells using high-precision dosing needle. • Once the electrolyte is filled, the cells are then sealed (e.g., crimping, beading, wielding)	

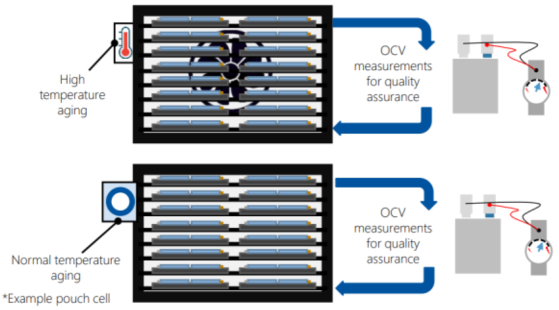
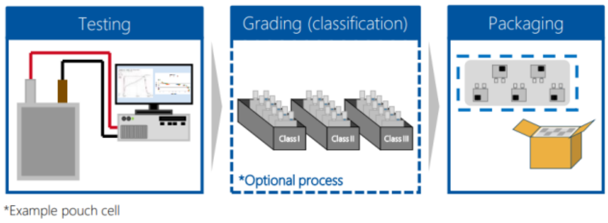
Source: Lithium-Ion Battery Cell Production Process - RWTH Aachen University ([access here]())

3. Detailed break-down of cell finishing process

Figure 51 Break-down of key Li-ion manufacturing processes – Cell finishing



Process	Details	Representative illustration
Roll Pressing (Pouch Cell)	• Roll pressing is required to ensure optimum distribution and absorption of the electrolyte in the pouch cell. • In this process, pouch cells are clamped in a good carrier and passed through two rollers using a servo motor.	
Formation (Pouch, Cylindrical and Prismatic Cells)	• In this process, manufactured battery cells are charged and discharged for the very first time. • To begin with, the cells are put in formation racks and then charged and discharged according to the pre-defined current and voltage curves.	
Degassing (Pouch Cell)	• Pouch cells have the tendency to release gases during the first charging cycle. These gases are generally stacked up into a dead space (also known as gas bag). • In Degassing, the gas bag is pierced in a vacuum chamber. The released gases are then sucked off and the cell is then sealed under vacuum.	

Process	Details	Representative illustration
Aging (Pouch, Cylindrical and Prismatic Cells)	• In this process, manufactured cells are checked if they can retain all their characteristics even after placing on shelves in specific conditions (high temperature/ normal temperature) for the period up to three weeks. • The check is usually carried out as a quality assurance process.	
EOL Testing (Pouch, Cylindrical and Prismatic Cells)	• Prior to the final packaging of the cells, they go through the end-of-life (EOL) testing. In this step, cells are discharged to their nameplate capacity. Testing criteria used to test the cells is specified by the manufacturer.	

Source: Lithium-Ion Battery Cell Production Process - RWTH Aachen University (access here)

Battery module & pack manufacturing

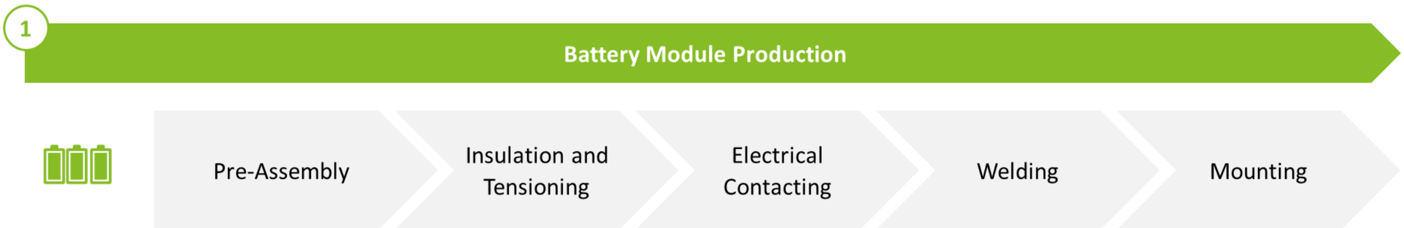
Once the cells are manufactured by the OEM, these are either directly converted into batteries at their facility itself or shipped to their customers for manufacturing their own batteries.

Conversion from cells to battery includes a step of producing modules (although currently companies are looking to skip the need of developing modules before developing battery pack). A schematic of conversion from cell to battery pack is presented below:

Similar to the process of cell manufacturing, we will breakdown the process of battery module and pack assembly.

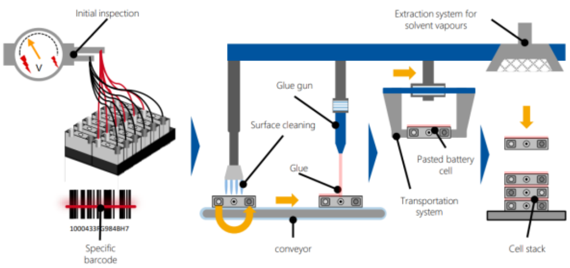
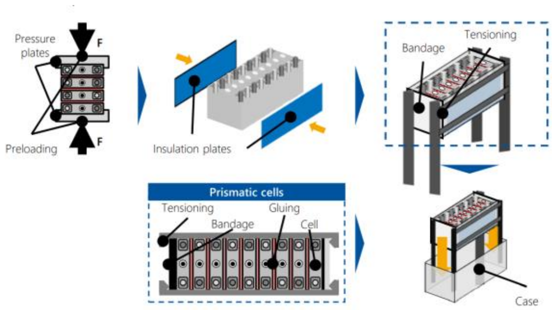
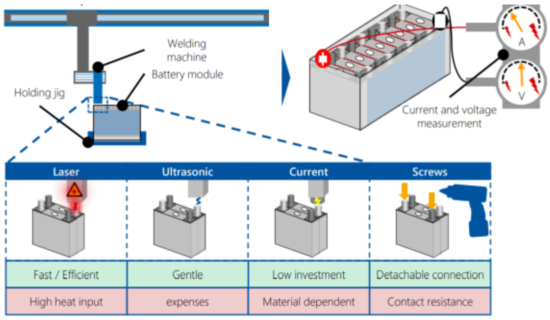
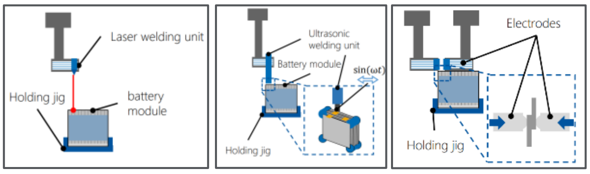
4. Detailed break-down of battery module manufacturing process

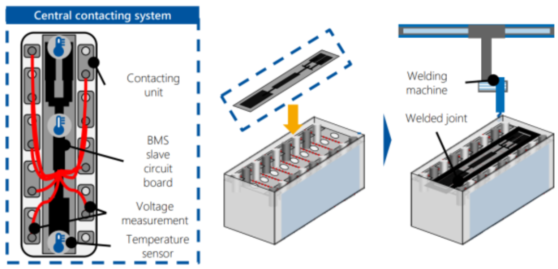
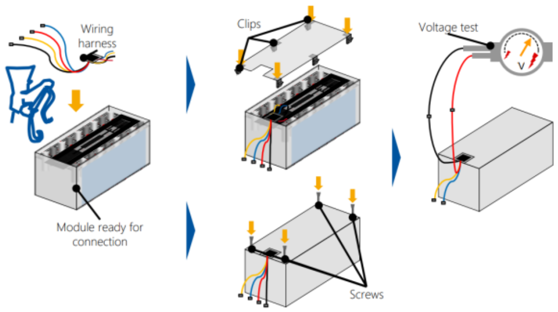
Figure 52: Break-down of battery module production processes



Source: 1 Battery Module and Pack Assembly Process - RWTH Aachen University (access here)

Detailed processes of battery module and pack manufacturing is provided below:

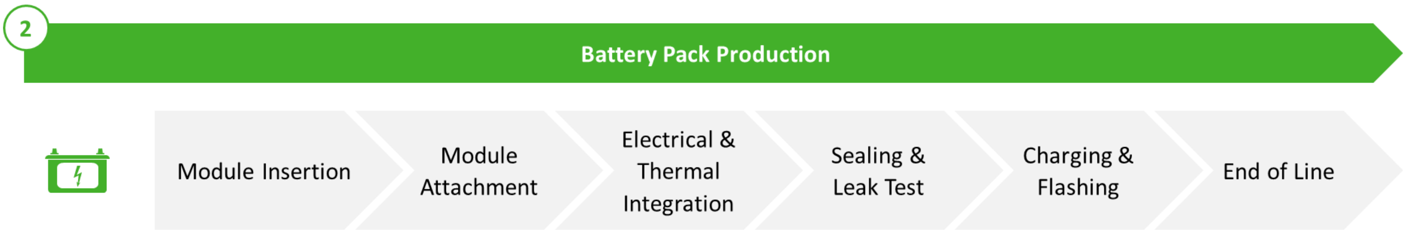
Process	Details	Representative illustration
Pre-assembly (Battery Module)	• In this process, cells are screened and sorted as per their performance. Once the cells are identified, their surfaces are cleaned, and then joined using a liquid or solid adhesive. • It is ensured that the stacking is done in a pre-defined way.	
Insulation and Tensioning (Battery Module)	• In this process, cells are insulated with each other using plastic plates or foils. • Also, cells are pressured by the clamping device to give defined shape and reduce the swelling due to charge/ discharge.	
Electrical Contacting (Battery Module)	• In this process, cells are connected to form one of more parallel strings. This contact is done by either ultrasonic welding, laser welding or screw connections.	
Welding (Battery Module)	• Electric contacting is done by welding. Welding can be done through various forms as mentioned below: • **Laser welding:** A laser optic heats the current collector and the contact plate until they are fused. This process offers high flexibility. • **Ultrasonic welding:** Uses interfacial friction and acoustic absorption to generate heat. The process offers high joining precision. • **Resistance welding:** Generates heat using electrical resistance.	 Laser Welding | Ultrasonic Welding | Resistance Welding

Process	Details	Representative illustration
Mounting of the Slave Circuit Board **(Battery Module)**	• Cell grouping is placed on the slave circuit board of the BMS and joined using welding/ screwing. • Other components such as cables, temperature sensors etc. are also connected/ welded with the slave circuit board.	
Mounting of the housing cover (Battery Module)	• In this process, final mounting of the housing cover is done. • At first, power and other cables at fitted. Then wiring of the controller is ensured. After that, final mounting of the lit, fixing with screws or clips is done. • The prepared module is then transported to manufacture battery packs.	

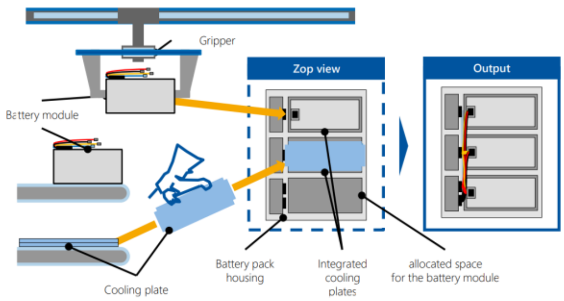
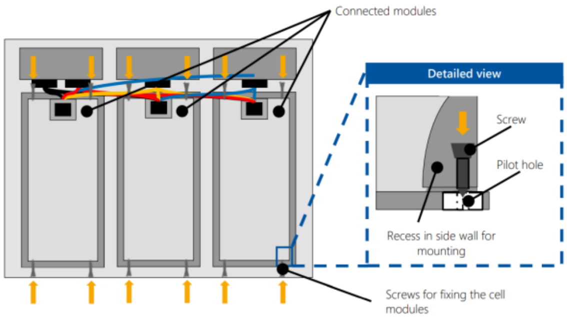
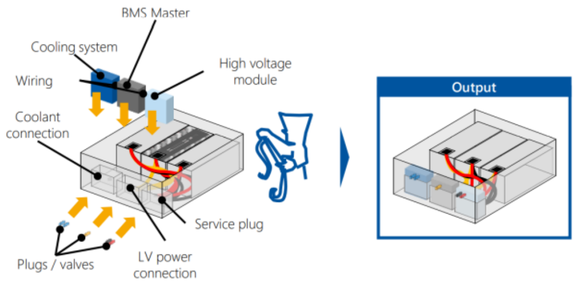
Source: Battery Module and Pack Assembly Process - RWTH Aachen University (access here)

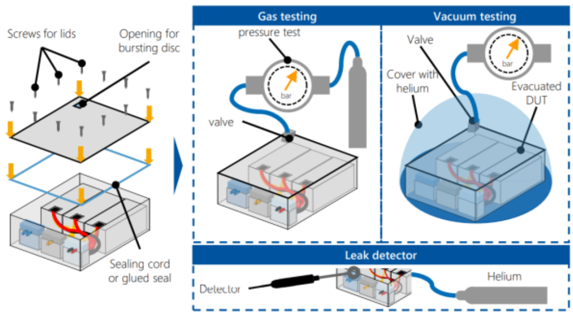
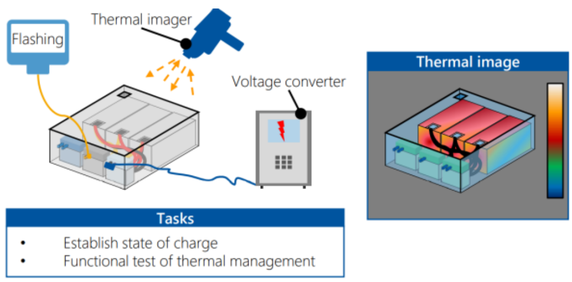
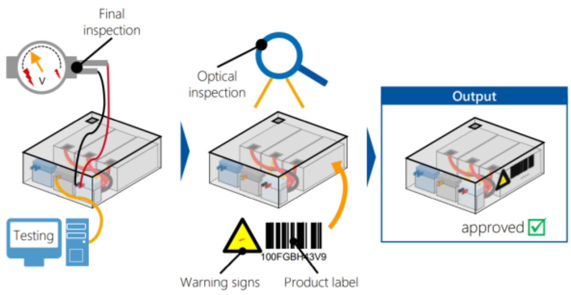
5. Detailed break-down of battery pack manufacturing process

Figure 53: Break-down of battery pack production processes



Source: 2 Battery Module and Pack Assembly Process - RWTH Aachen University (access here)

Process	Details	Representative illustration
Insertion of the Cell Modules (Battery Pack)	• In this process, battery modules are inserted into the pack housing using grippers. • A cooling plate is also mounted at the bottom of the battery modules to cool the modules during the complete operation.	
Attachment of the Modules (Battery Pack)	• In this process, the battery modules inserted in the pack housing are fixed by the means of screws. • Screws help in ensuring rigidity in the overall structure and protect against possible vibrations during the operation.	
Electrical & Thermal Integration (Battery Pack)	• In this process, multiple components such as cooling system, fuses, relay, current measuring system, insulation monitoring, BMS etc. are integrated in the pack housing.	

Process	Details	Representative illustration
Sealing & Leak Test (Battery Pack)	• In this process, rubber or glued seals are applied at the edges of the housing cover. • The upper part of the cover is also connected with the battery pack housing using screws.	
Charging & Flashing (Battery Pack)	• In this process, a desired consistent state of charge of all the cells is established. • Also, BMS is connected to a computer and flashed through a system analysis program.	
End of Line (Battery Pack)	• In this process, the final inspection of the battery pack is done. • Charging/ discharging of the battery as per defined profiles, functionality of BMS and sub-components, and all associated operations of the battery is tested. • Once approved, the battery is shipped to the customer for end-use.	

Source: Battery Module and Pack Assembly Process - RWTH Aachen University (access here)

4.4 Analyzing the levelized cost of cell manufacturing

In this section, we will analyze and compare the cost of various battery cell technologies manufactured by leading OEMs for electric vehicle application. The objective of the analysis will be to break down the cost of these battery cells and determine the potential reason for their different cost structure.

Box 6: What impacts the cost of a cell?

There are multiple factors that can influence the cost of a battery cell – some of these factors are independent of the manufacturer whereas some depends upon the manufacturer, the location of its plant, utilization etc.

Manufacturer independent factors: (i) One of the key aspect that influence the cost of a cell is the selection of its design – **cylindrical** cells are economical than **prismatic**, whereas **pouch** cells are the costliest of all due to their structural complexity and additional manufacturing steps such as stacking, pressing, degassing etc. (refer section 0); (ii) Another factor influencing the cost of the cell is the selection of cathode and anode materials. NMC cathodes tend to have higher cost than LFP cathodes as they use costly rare earth minerals such as **Nickel** and **Cobalt**. Similarly, anodes using **natural graphite** will be cheaper than anode made of **synthetic graphite** or **silicon**.

Manufacturer dependent factors: The dependent factors are mostly the manufacturing cost which is greatly influenced by aspects such as **plant capacity, line utilization, equipment efficiency** etc. Manufacturer who ensures maximization in these aspects will always have cost advantage over others.

Li-ion cell chemistries and cost-heads

To analyze and compare the levelized cost, cells manufactured by three leading global OEMs were considered. The selected cells differ in their chemistry as well as in their design.

OEM	**CATL**	**LG Chem**	**Panasonic**
Chemistry	NMC 811	NMC 622	NCA
Design	Prismatic	Pouch	Cylindrical
Capacity	180 Ah	50 Ah	5Ah

For each of the cell, we will analyze two aspects: breakdown of (i) **manufacturing cost** *(cost of electrode manufacturing, cell assembly and cell finishing)*, and (ii) **cell cost**

The manufacturing cost of the cell will be broken-down into the three steps detailed in Section 4.3 viz. electrode manufacturing, cell assembly, and cell finishing. The cost of cell will also be categorized into three heads viz. material cost, manufacturing cost, and other overheads.

Manufacturing cost breakdown:	**Cell cost breakdown:**
1. Electrode manufacturing	1. Material cost
2. Cell assembly	2. Manufacturing cost
3. Cell finishing	3. Overheads *(includes cost heads such as Selling, General, and Administrative Expense (SG&A), R&D and warranty, scrap etc.)*

Li-ion cell – Cost breakdown

CATL – NMC 811 – Prismatic

CATL supplied this cell to Dongfeng D60 EV. The EV battery size was 58kWh with almost 480km range.

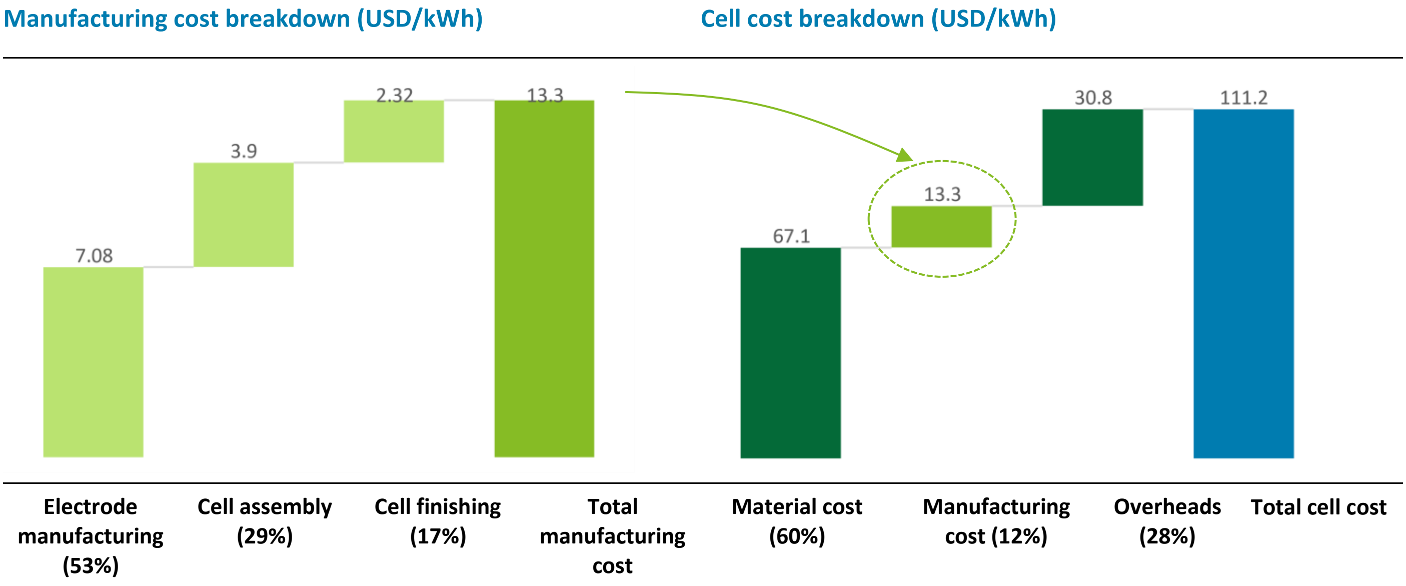
Cell Details:

Particular	Details
Capacity	180 Ah
Energy density	244 Wh/Kg

Particular	Details
Anode material	Graphite (60:40 - Natural:Synthetic Graphite)
Cell cost	USD 111.20/kWh

Cost breakup:

Below represents the share of in cost breakup of manufacturing and final cell cost for CATL – NMC 811 – Prismatic cell:



Source: P3 automotive GmbH, UBS Evidence Lab

Cost breakdown – Takeaway:

- CATL has achieved high gravimetric loading (~354 g/cm^2) of the cathode and anode materials which leads to **higher active material cost**
- The high cost of active material is however compensated by using **low amount of standard electrolyte** and high share of **natural graphite**
- CATL uses **lean housing design** for its prismatic cell which leads to further decrease in overall housing cost

LG Chem – NMC 622 – Pouch

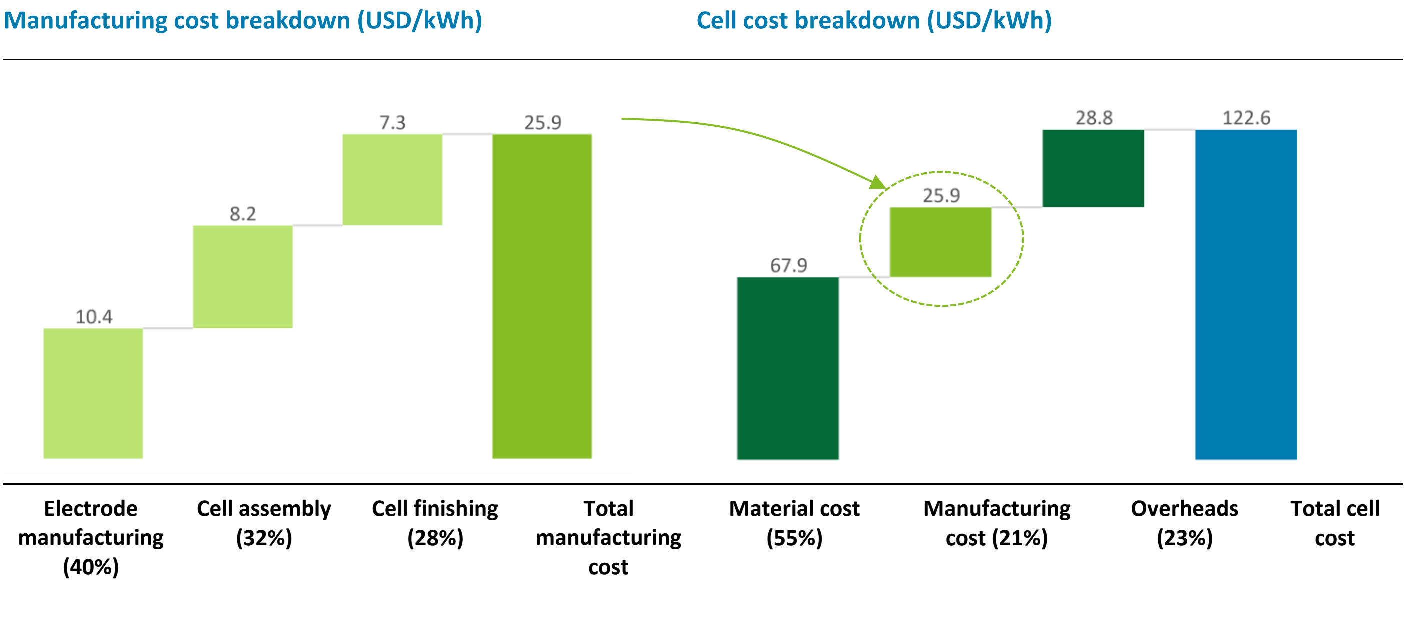
Samsung supplied this cell to Bolt EV. The EV battery size was 63 kWh with almost 383 km range.

Cell Details:

Particular	Details
Capacity	60 Ah
Energy density	267 Wh/Kg
Anode material	Graphite (60:40 - Natural:Synthetic Graphite)
Cell cost	USD 122.60/kWh

Cost breakup:

Below represents the share of in cost breakup of manufacturing and final cell cost for LG Chem – NMC 622 – Pouch cell:



Source: P3 automotive GmbH, UBS Evidence Lab

Cost breakdown – Takeaway:

- LG Chem's NMC 622 has **high material cost** largely due to its cathode active materials (i.e., high share of Cobalt)
- The cell also uses the **blend** of **natural and synthetic graphite** which further increases the material cost
- Similar to CATL, LG Chem also uses **lean housing design** reducing its overall housing cost

Panasonic – NCA – Cylindrical

Samsung supplied this cell to Tesla EV. The EV battery size was 77 kWh with almost 499 km range.

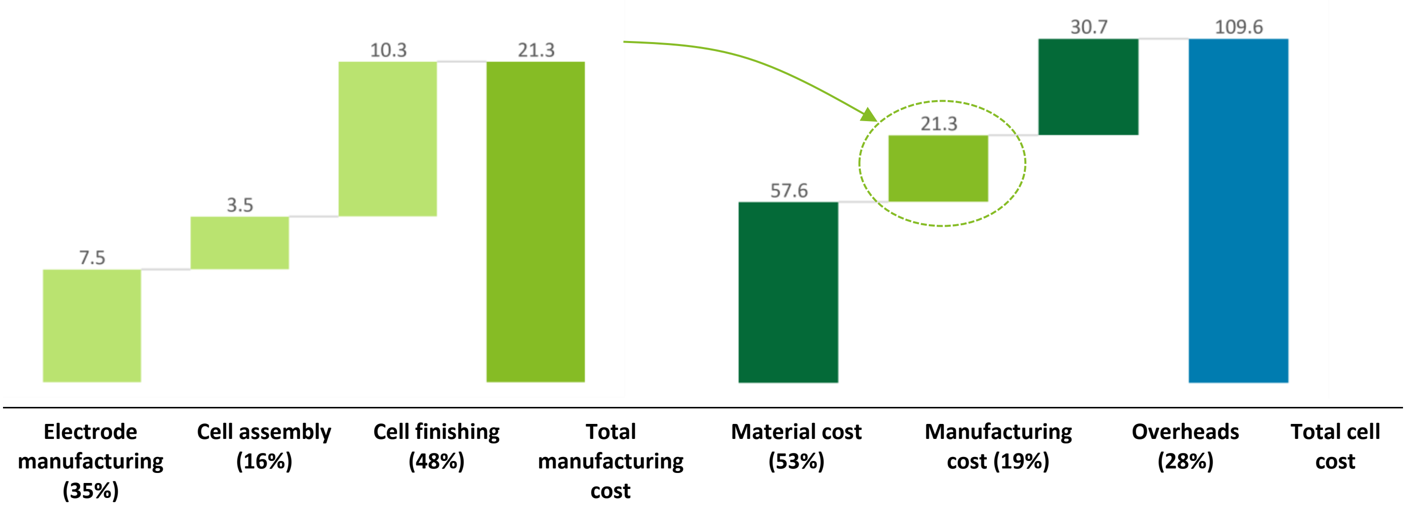
Cell Details:

Particular	Details
Capacity	5 Ah
Energy density	257 Wh/Kg
Anode material	Graphite (52:41:7 - Natural:Synthetic Graphite:SiOx)
Cell cost	USD 109.60/kWh

Cost breakup:

Below represents the share of in cost breakup of manufacturing and final cell cost for Panasonic – NCA – Cylindrical cell:

Manufacturing cost breakdown (USD/kWh) **Cell cost breakdown (USD/kWh)**



Source: 3 P3 automotive GmbH, UBS Evidence Lab

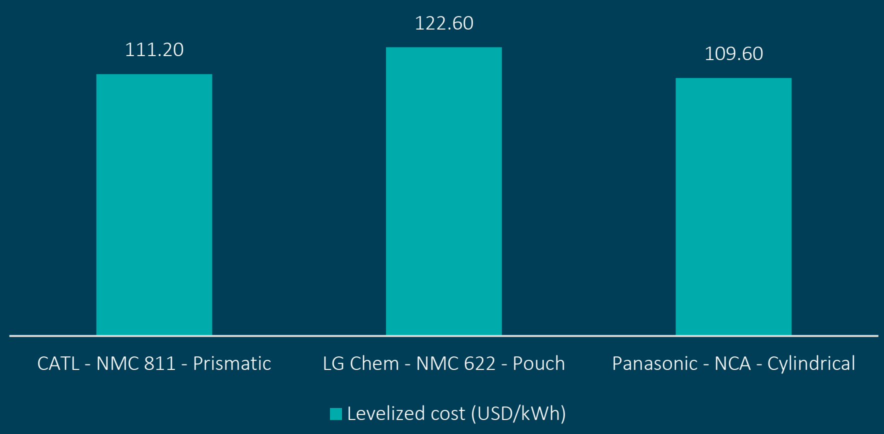
Cost breakdown – Takeaway:

- Panasonic's NCA cell uses very **low Cobalt** content that significantly reduces its cathode active material cost (lowest among the competitors)
- The company however uses **doping** of natural graphite i.e, combining synthetic graphite and **silicon** which increases the anode active material cost of the cell
- Housing cost of Panasonic-cylindrical cell is also significantly higher than other OEMs – this is largely because of the **cell's small size** and round format
- The company also does **rigorous testing** of the cells which significantly increase its end-of-line testing cost

Levelized cost of cell – Conclusion

The result of the levelized cost assessment suggested that the cost of Pouch cell manufactured by LG Chem is the highest among the three cells. Prismatic cells generally are costlier than cylindrical cells; however, CATL has successfully managed to reduce its manufacturing cost due to its higher scale. Also, the NCA cells supplied by Panasonic to Tesla has anode produced from the doping of artificial graphite and silicon which are costlier than natural graphite (60% share) used in CATL NMC 8111 cell.

Figure 54 Levelized cost of cells (USD/kWh)



Final cost comparison output:

Prismatic cell of CATL < Cylindrical cell of Panasonic < Pouch cell of LG Chem

Breaking down the levelized cost, it was observed that the manufacturing cost of the LG Chem-pouch cell was the highest. This was largely due to the fact that pouch cells usually have additional manufacturing processes such as separation, stacking, pressing, degassing etc. (Figure 49).

Within the overall manufacturing cost, the cost of manufacturing electrode was highest for CATL-NMC-prismatic cells (~53%) followed by LGC-NMC-pouch (~40%). It was the cell assembly cost, where LGC-pouch cell has the highest share (~32%) (due to additional stacking and separation processes). The cell finishing cost of Panasonic-cylindrical cells was observed to be the highest which was mostly due to the rigorous testing leading to the high cost of end-of-line testing.

Figure 55 Manufacturing cost breakdown comparison

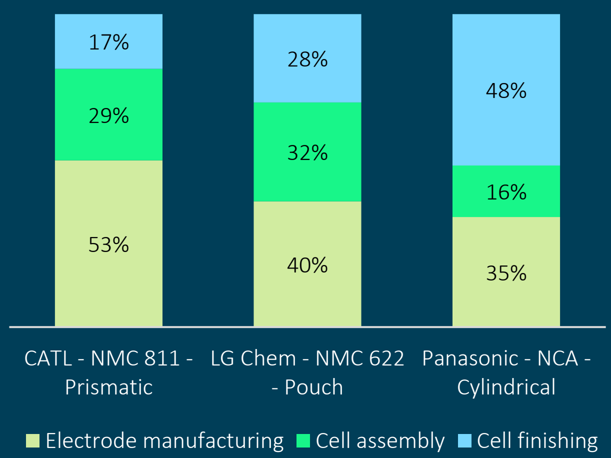
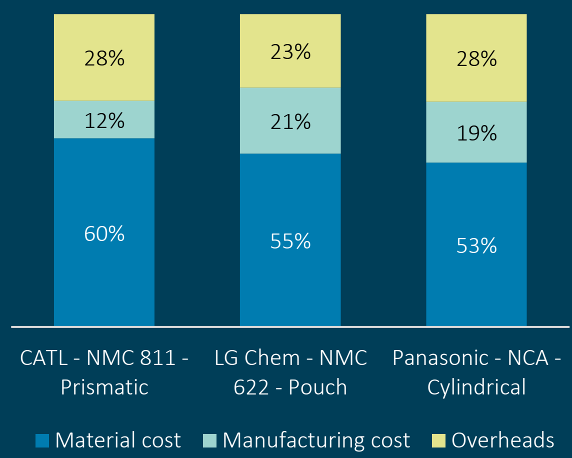


Figure 56 Cell cost breakdown comparison



As far as the breakdown of cell cost goes, it was observed that material cost is the highest contributor, followed by overhead costs, for these leading OEMs. The average range of material cost is ~53% - 60%. Whereas the overhead contributes between 23% - 30%. Cost of manufacturing contributes the least in the overall levelized cost of the cell.

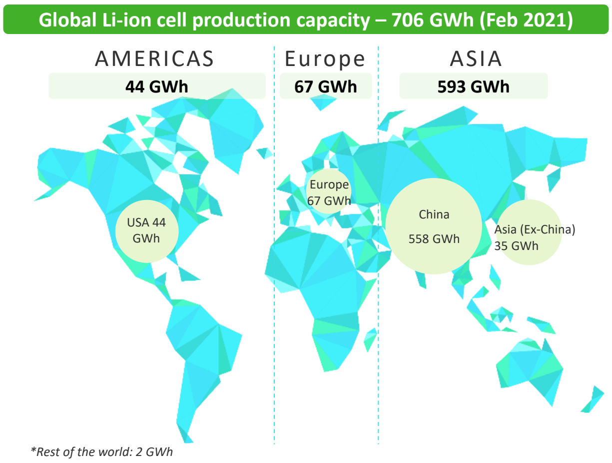
4.5 Global battery manufacturing industry

Battery manufacturing industry has grown tremendously in the last few years. As of 2021, global Li-ion manufacturing capacity stood at 706 GWh compared to 57 GWh in year 2015 – achieving an overall CAGR of ~52%.

Global Li-ion battery industry is currently oversized – at the end of 2020, Li-ion battery demand was 526 GW against the operational capacity of around 700 GWh[81]

Regional deployment of battery manufacturing facilities suggests Asia's sheer dominance over the rest of the world. Close to 84% of global lithium-ion cell manufacturing is in Asia – almost all of which (~79%) is present in China (figure alongside). Other than China, South Korea and Japan are the other two Asian countries having considerable battery manufacturing capacity.

Figure 57 Global battery manufacturing capacity (2021)



Source: Benchmark Mineral Intelligence, S&P Global Market Intelligence

Figure 58 Country-wise Li-ion manufacturing capacity (GWh, 2021)

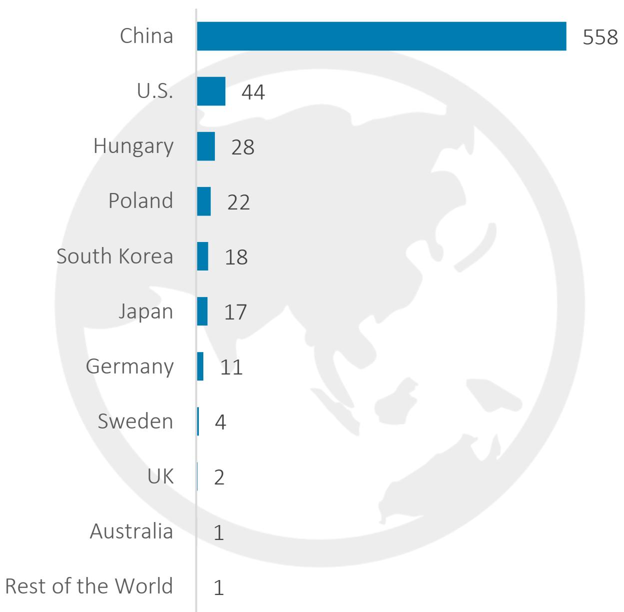
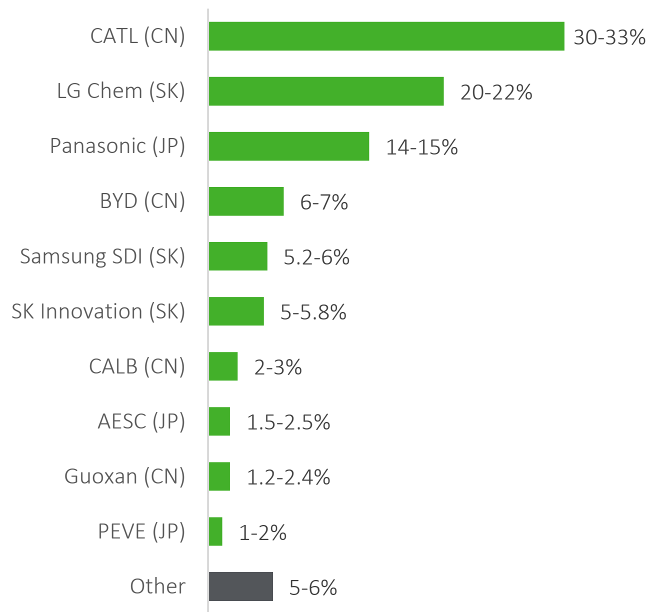


Figure 59 Leading battery OEMs globally (% share, 2021)



Note: 37 GWh Tesla Gigafactory is included in Panasonic's share; CN- China; SK-South Korea; JP-Japan
Source 1 Benchmark Mineral Intelligence, S&P Global Market Intelligence, SNE Research, Deloitte analysis

China's dominance in battery manufacturing is quite evident as almost all the global leaders in battery manufacturing have their facilities located in China. However, recent trends have indicated increased focus on Europe and USA from these players.

Below table lists global leaders in battery manufacturing, their production capacity, existing presence, and future plans.

[81] S&P Global Market Intelligence

Table 53 Global leaders in battery manufacturing and their future plans

Sl. No.	Battery OEM	Presence	Battery Chemistry	Production capacity (GWh) (2020)	Future plans (non-exhaustive)
1	**LG Chem**	South Korea, Poland, US, China	Lithium-ion and lithium-ion polymer (NMC)	81	• 15 GWh/year factory in 2022 (Europe) • 32 GWh/year factory in 2023 (China)
2	**BYD**	China	Lithium-ion battery (NMC/LFP)	62	• 20 GWh/year and 30 GWh factories in 2023 (China) • 10 GWh/year factory (date to be determined)
3	**CATL**	China	Lithium-ion battery (LPF, NMC)	53	• 100 GWh/year factory in 2021 (Erfurt, Europe) • 98 GWh/year factory (date to be determined) to be launched
4	**SK Innovation**	South Korea, China, Hungary	Lithium-ion battery (NMC)	42	• 7.5 GWh/year factory in 2021 (Europe) • 10 GWh/year factory in 2022 & 12 GWh/year in 2023 (USA)
5	**Tesla**	USA	Lithium-ion batteries (NCA)	35 (In JV with Panasonic)	• 100 GWh/year factory in Texas (USA) and Germany (Europe)
6	**Samsung SDI**	South Korea, Hungary, China	Lithium-ion battery (NMC)	30	• Plans to setup new manufacturing capacity in Hungary; production size not disclosed
7	**Panasonic**	Japan, US, China	Lithium-ion battery (NCA)	23 (Excl. Tesla)	• Expansion of Tesla giga-factory in Nevada to 35 GWh/ year by 2023
8	**CALB**	China	Lithium-ion batteries (NMC and LFP)	10	• Plans to setup new manufacturing capacity in Europe; production size not disclosed

Source: CIC energiGUNE, IHS Markit, Deloitte analysis

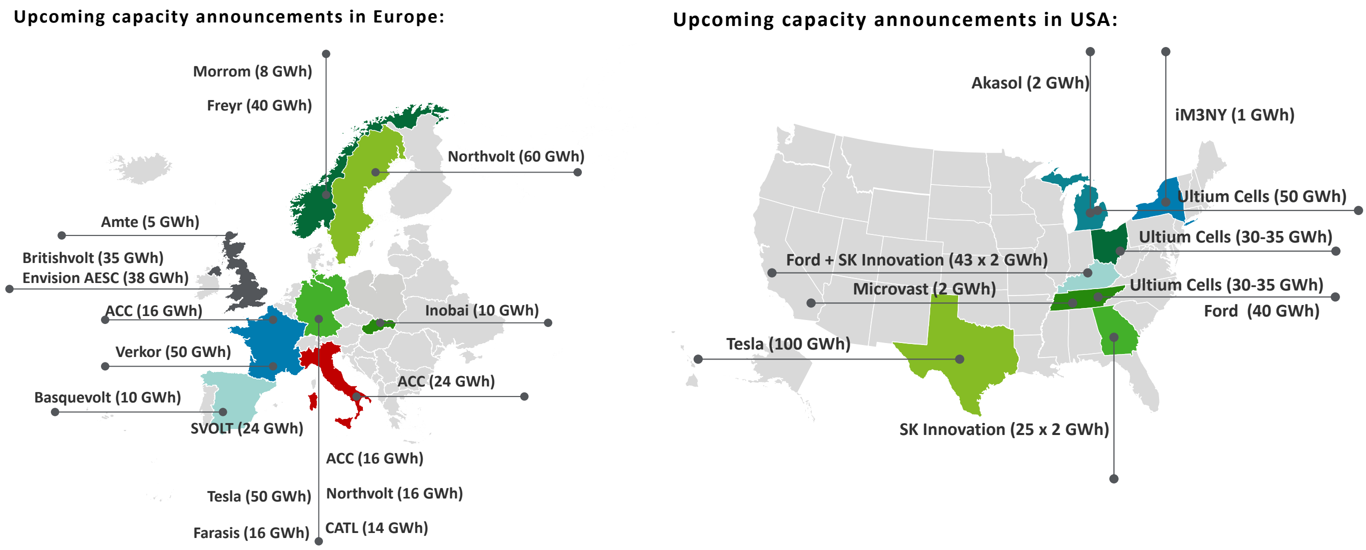
As the market for EVs is progressing, globally there has been a continuous push to increase the battery manufacturing capacity. In a forecast done by Clean Energy Associates (CEA)[82], Li-ion cell production capacity is expected to reach ~4,800 GWh by 2030 out of which, close to 3,100 GWh will be from China alone. However, other regions such as Europe and USA will also have significant manufacturing capacities by then.

By 2030, emergence of Li-ion cell production capacities in the US and Europe is expected to reduce China's global Li-ion cell manufacturing share to 66% from existing 79%

In the below figure, OEM-wise major announced capacity additions till 2030 in Europe and USA is provided:

[82] Global Demand for Energy Storage Expected to Exceed 100 GWh in 2025 (access here)

Figure 60 Upcoming battery manufacturing capacity announcements in EU and USA



Source: CIC energiGUNE (Mar 2022), Deloitte analysis (List non-exhaustive)

Detailed list of OEMs, location, planned capacity and expected completion year is provided in the below table:

Table 54 Region-wise planned battery manufacturing capacity by 2030 (non-exhaustive)

Sl. No.	Region	Company	Location	County	Capacity (GWh)	Year
1.	**Europe**	**CATL**	Erfurf	Germany	14	2022
2.	**Europe**	**Farasis**	Bitterfeld	Germany	16	2022
3.	**Europe**	**Amte**	Thurso	Scotland	5	2023
4.	**Europe**	**SVOLT**	Uberherrn	Germany	24	2023
5.	**Europe**	**Freyr**	Mo I Rana	Norway	40	2023
6.	**Europe**	**ACC Automotive Calls**	Douvrin	France	16	2023
7.	**Europe**	**Morrom**	Arendal	Norway	8	2024
8.	**Europe**	**VW Northvolt**	Salzgitter	Germany	16	2024
9.	**Europe**	**Inobai**	Bratislava	Slovakia	10	2024
10.	**Europe**	**ACC Automotive Calls**	Kaiserslautern	Germany	16	2025
11.	**Europe**	**ACC Automotive Calls**	-	Italy	24	2025
12.	**Europe**	**Britishvolt**	Blyth	England	35	2027
13.	**Europe**	**Basquevolt**	-	Spain	10	2027
14.	**Europe**	**Northvolt**	Skelleftea	Sweden	60	2030
15.	**Europe**	**Tesla**	Grunheide	Germany	50	2030
16.	**Europe**	**Verkor**	South France	France	50	2030
17.	**Europe**	**Envision AESC**	-	England	38	2030

Sl. No.	Region	Company	Location	County	Capacity (GWh)	Year
18.	**USA**	**Tesla**	Austin	Texas	100	2021 (proposed)
19.	**USA**	**SK Innovation**	-	Georgia	25	2021-2022
20.	**USA**	**Ultium Cells (GM-LG Chem JV)**	Lordstown	Ohio	30-35	2022
21.	**USA**	**Microvast**	Claksvile	Tennessee	2	2022
22.	**USA**	**GM-LG Chem JV**	Spring Hill	Tennessee	30-35	2023
23.	**USA**	**SK Innovation**	-	Georgia	25	2023
24.	**USA**	**Akasol**	Detroit	Michigan	2	2023
25.	**USA**	**iM3NY**	-	New York	1	2023
26.	**USA**	**Ultium Cells (GM-LG Chem JV)**	-	Tennessee	30-35	2023
27.	**USA**	**Stellantis + Samsung SDI**	TBD	TBD	40	2025
28.	**USA**	**Ultium Cells (GM-LG Chem JV)**	-	Michigan	50	2025
29.	**USA**	**Ford**	-	Tennessee	40	2025
30.	**USA**	**Ford + SK Innovation**	-	Kentucky	43x2	2026

Note: Capacity plans of BYD, CALB, Panasonic and GS Yuasa are still pending (for EU)
Source: 4 CIC energiGUNE (Mar 2022), Deloitte analysis

Curious case of China's dominance of Li-ion cell manufacturing

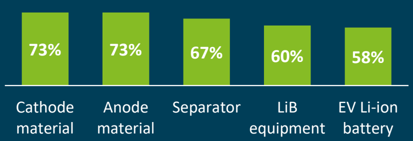
China already holds almost 73% share in the global lithium-ion cell manufacturing, its dominance in the Li-ion battery storage market can be attributed to three primary factors:

Primary factors for China's dominance in the Li-ion manufacturing industry:

1 Supply chain dominance

Chinese firms have presence in entire value chain of Li-ion battery which helps them gain strategic advantage over other competitors and optimize the cost of manufacturing

China's share of EV battery production (2018):



China's presence in Li-ion battery supply chain:

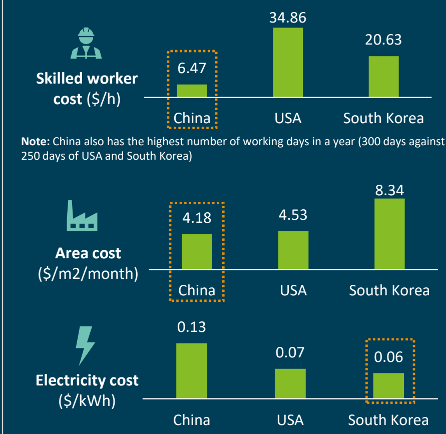
China holds significant presence in complete supply chain of lithium-ion cell manufacturing. Starting from mining of raw materials to their processing, anode and cathode manufacturing to cell production.

More details on this is provided in the next slide.

Source: HIS Markit, WEF, UBSe, Analyst report, Deloitte analysis

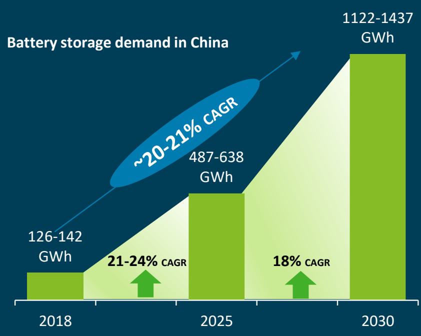
2 Cheaper cost of manufacturing

Compared to other countries, China holds locational advantage of **~$7/kWh** in cell manufacturing



3 High market demand

- China existing battery demand is already close to **70% of global demand**.
- China's battery demand is expected to reach **1122-1437 GWh** by 2030 at ~20-21% CAGR
- High market demand is an attractive proposition for battery manufacturers to establish their production facilities in China

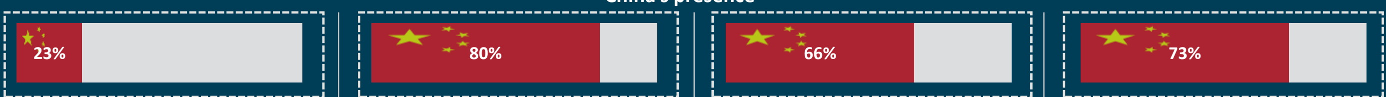


Dominance in supply chain is one of the key reasons for its competitiveness in the cost. Below figure provides an overview of end-to-end presence of China in the battery value chain.

China's presence across Li-ion manufacturing value chain:

Mining | Chemical processing | Cathode/Anode prod. | Cell manufacturing

China's presence



Mining

- **Graphite (65% Share):** High share gives China power to set world graphite prices.
- **Nickel (31% Share)**
- **Lithium (No mining):** However, China has been buying stakes in mining operations in Australia and South America where most of the world's lithium reserves are found
- **Cobalt (1% share):** However, 8 of the 14 largest cobalt mines in Congo are Chinese-owned
- **Manganese (6% share)**

Chemical processing

- China has **invested significantly** in its lithium carbonate and hydroxide, cobalt sulphate, manganese and uncoated spherical graphite refining
- Chinese companies control about **80%** of the **cobalt refining industry**
- **Lithium carbonates:** Second largest importer (2016-19)
- Largest importer of **Cobalt Ore, Manganese ore and Nickel ore:** from 2016 to 19

Cathode/Anode prod.

- **61% share** in global **cathode** production;
- **86% share** in overall **anode** (natural and synthetic graphite) production
- **100%** of **all-natural graphite** anode is made in China

Cell manufacturing

- **Present:** Out of total 455 GWh of battery production capacity globally in 2019, **333 GWh (~73%) is located in China**
- **Future:** Of the 136 lithium-ion battery plants in the pipeline till 2029, **101 are based in China**

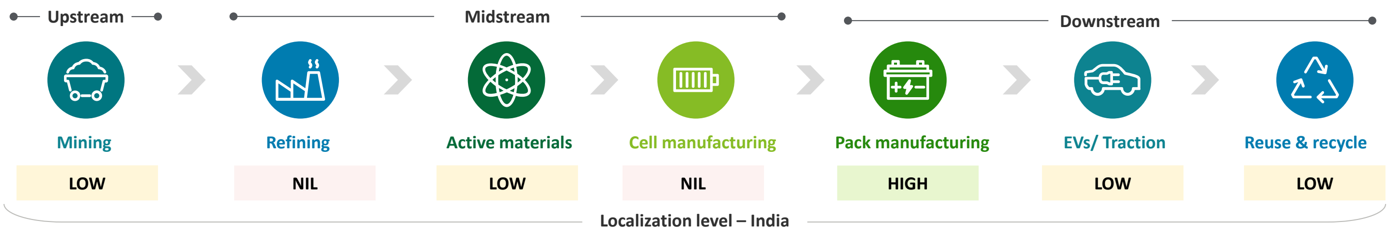
Based on its presence in the supply chain, China alone contributes to ~70-75% value in the overall value chain of Li-ion cell manufacturing

China's share in Li-ion battery supply chain, 2019

4.6 Developments in Indian Li-ion battery market

The existing Li-ion battery market of India is at infancy state; the country is yet to make its presence in most of the value chain areas. Figure 61 illustrates India's localization level in each of the value chain area; barring battery pack manufacturing, the country has no or limited presence in the value chain.

Figure 61: Li-ion battery value chain – India's presence



Details on the localization level is provided in the below table:

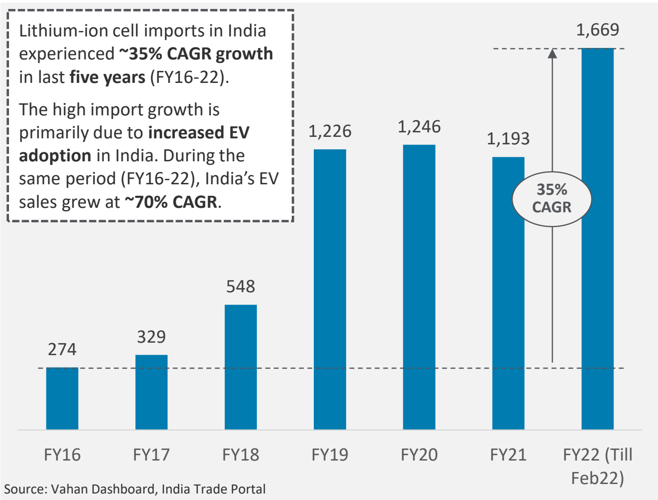
Sl. No.	Value chain	India's localization level	Remarks
1.	Mining	LOW	• Out of all the five critical battery minerals (Lithium, Nickel, Cobalt, Manganese and Graphite), India has considerable reserves for **Manganese and Graphite** only. • Existing mining of Manganese and Graphite in India is primarily undertaken for **non-battery applications.** • Graphite mined in India has **low carbon content** and is not suitable for battery application.
2.	Refining	NIL	• Battery mineral refining requires **high technological capability** – presently not available with any Indian player. • India currently **does not** have any battery **mineral refining capability**; however, with announcement of 50 GWh ACC manufacturing scheme and value addition requirement, there is an **emerging market** for **mineral refining** in India.
3.	Active materials	LOW	• Active material manufacturing require **high technological capability**. • For **active cathode materials** – India **does not** have any player operating in this space. • For **active anode materials** – there are few graphite manufacturing companies viz. **Epsilon and Himadri** which have **developed technology** to produce active anode materials for Li-ion battery.
4.	Cell manufacturing	NIL	• Cell manufacturing require high **technological capability** which is currently **not available** with Indian players. • India is currently **importing cells** from countries such as China, Hong Kong etc. • Govt. of India is **incentivizing advanced cell manufacturing** in the country; this step has ignited interest of several global & domestic players to **setup battery cell manufacturing** in India.
5.	Pack manufacturing	HIGH	• Battery pack manufacturing does not require high technological capability; India has **significant participation** in this space. • Indian battery pack suppliers/ manufacturers currently **import battery cells** from other countries and manufacture **modules** and **battery packs** using their **proprietary technology**. • Several Indian **EV OEMs** also have **in-house capability** of pack manufacturing.

Sl. No.	Value chain	India's localization level	Remarks
6.	Usage (EVs)	LOW	• **Promotion** of EVs is actively undertaken at **Central & State level** • From FY17 to FY22, EV sales have **grown** at **~50% CAGR** • However, looking at the overall automobile sales in the last six years (FY17-22), EVs accounted for **only 1%**
7.	Reuse & recycling	LOW	• Indian players have the required **technological capability** (Hydrometallurgy mostly) to extract raw materials from the spent batteries. • Battery market is **still picking up** in India, therefore market for recycling & reuse will take some time to flourish. However, several Indian players have already **started building capability** in battery recycling space.

EV battery cell manufacturing

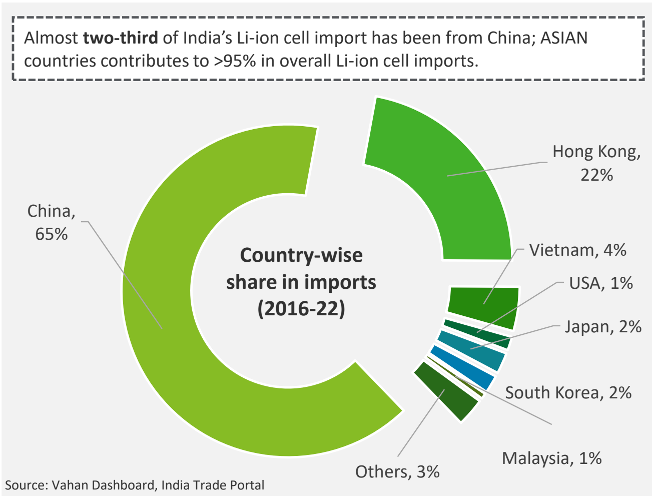
India currently lacks domestic manufacturing capability of Li-ion cells and is heavily dependent on catering its lithium-ion battery demand through imports. Most of the imports are from China which is not favorable for India considering the existing geo-political tension between the two countries.

Figure 62 Li-ion battery imports (US$ Mn) (HSN 850760)



Source: Vahan Dashboard, India Trade Portal

Figure 63 Country-wise import share (HSN 850760)



Source: Vahan Dashboard, India Trade Portal

Import of batteries is leading to **high cost of batteries** in Indian market thus delaying the large-scale adoption of EVs. Also, it poses **risk** of **supply of poor-quality batteries** in the Indian market.

In view of making India self-reliant for battery supply, Government of India announced the production-linked incentive (PLI) scheme i.e, the National Programme for ACC Battery Manufacturing which has an overall outlay of INR 18,100 Cr. The scheme plans to render subsidies to cell manufacturers and aims to establish 50 GWh of advanced chemistry cell production capacity in the country by 2027 through these incentives.

In March 2022, Government allocated proposed 50 GWh capacity to four players viz. **Rajesh Exports Limited (5 GWh)**; **Hyundai Global Motors Company Limited (20 GWh)**; **Ola Electric Mobility Private Limited (20 GWh)**; and, **Reliance New Energy Solar Limited (5 GWh).**[83]

With the proposed incentives in the PLI scheme, cost of cell manufacturing in India is expected to reduce up to USD 27/kWh[84]

Box 7: ACC Battery Storage Programme – The "Value addition" requirement

The production-linked incentive scheme on advanced chemistry cells is one of the marquee measures taken up by the Government to promote battery cell manufacturing industry in the country. As the capacities targeted under the programme have been allocated to the manufacturers, India may become home to 50 GWh cell manufacturing by 2025-2027. However, it was not only the cell production support that the Government offered under the programme, but it also ensured **development of the complete manufacturing ecosystem**.

In the programme, the Government included **"value addition"** element which basically means "manufacturing activity undertaken in India (either by the manufacturer or by the indigenous manufactures)". Manufacturer that will achieve higher value addition %, will be provided with the higher subsidy. Formula for subsidy calculation is provided below:

Subsidy amount = Quantity of cells sold during the period (kWh) x Effective subsidy per kWh (INR) x **Value addition (%)**

The value addition requirement is expected to create the domestic demand for value chain products (refinined minerals, active materials, cell components etc.) which will ultimately encourage investors/ value chain players to enter in other value chain areas in the country

In addition to the PLI scheme developments, industry players have also made several advancements/ announcements on their investment in India's battery storage industry. Some of such advancements/ announcements are provided in the table below:

Table 55: Advancements/ developments by industry players in battery space in India (non-exhaustive)

Sl. No.	Company	Partnerships	Battery Chemistry	Location	Details
1.	**TDS Lithium-Ion Battery Gujarat Private Limited (TDSG)**	Suzuki, Toshiba and DENSO (50%, 40% and 10%, respectively)	Lithium-ion	Gujarat	• Cell technology – Toshiba; module technology – DENSO • Target sector – EVs • Target to locally manufacture 30 million lithium-ion cells per year by 2025, with a production capacity of more than 1GWh. • 180 MILLION USD (Investment amount) has been invested between all three Japanese ventures for the lithium-ion battery manufacturing plant slated to be ready by 2020. • Planned investment for phase 2 production of lithium-ion batteries is INR3,715 Cr
2.	**Pinnacle India**	Philon, China	Lithium-ion	Maharashtra	• Battery cell technology – Phylion • Target sector – light passenger and commercial EVs

[83] ACC PLI – PIB release (access here)
[84] Considering actual cost of cell manufacturing in India is around $135/kWh (Based on industry inputs)

Sl. No.	Company	Partnerships	Battery Chemistry	Location	Details
3.	**Exide**	Exide (75%) and Leclanché SA (25%) JV – Nexcharge	Lithium-ion (LFP)	Gujarat	• Battery cell technology – Leclanché SA • Capacity – 1.5 GWh • Target sector – EVs, grid storage and other stationary storage
4.	**XNRGI India**	Own technology	Lithium metal battery	Gurugram	• Opened a 240 MWh battery plant in Gurugram in 2020, targeted at EVs • Plans to expand to GWh scale as demand picks up
5.	**BHEL ISRO**	MoU between ISRO and BHEL	Lithium-ion	Bangalore	• ISRO transferred its ion cell technology to BHEL • BHEL plans to set up GWh-scale manufacturing setup
6.	**Tata Chemicals**	MoU with ISRO	Lithium-ion (LFP)	Gujarat	• Plans to set up a 10 GWh lithium-ion battery plant • Target sectors – EVs and stationary storage
7.	**Renon India**	Ahamani EV tech	Lithium-ion (LFP and NMC)	Gujarat	• 200 MWh capacity, with target to expand to 1 GWh in the next few years • Target sectors – EVs, solar appliances, lights etc.
8.	**Li Energy**	CSIR technology	Lithium-ion (LFP)	Tamil Nadu	• Plans 1 GWh integrated manufacturing plant, to be set up in phases • Talks underway with Contemporary Amperex Technology Co. Limited to supply cells in the initial year
9.	**Greenko**	-	Lithium-ion	To be decided	• Announced US$1 billion investment plan for battery manufacturing
10.	**Exicom Okaya**	Lithium-ion (LFP)		-	• Assembles and supplies battery packs to 2-wheel, 3-wheel, e-rickshaws etc.
11.	**LG Chem**	M&M has collaborated with LG Chem	Lithium-ion (NMC)	Maharashtra	• Plan to develop high energy density lithium-ion cells
12.	**Amara Raja**	ISRO (Technology Transfer)	Lithium-ion	Tirupati	• ISRO has transferred its proprietary technology to manufacture lithium-ion cells to Amara Raja • Amara Raja has set up a development hub at Tirupati for the same
13.	**Grinntech**	-	Lithium-ion	Ambattur, Chennai	• Inaugurated 400 MWh per year manufacturing facility of Lithium-Ion batteries in 2021 – suitable for 2-wheelers, 3-wheelers, farm tractors and light vehicles.

Note: In addition to the above advancements, on 15th Jan 2022, technical bid of the ACC Battery Storage Programme was opened where 10 players expressed their interest in setting up battery cell manufacturing in India (more details)

Source: Deloitte analysis

4.7 Process of setting up a battery cell manufacturing facility in India

Setting up of battery cell manufacturing facility in India largely requires clearances at two levels: the first one being the 'environment and forest clearance' followed by 'other statutory and state-specific clearances or approvals'.

Figure 64 Stages in the Prior Environmental Clearance (EC) Process for New Projects

Details on these two levels is provided in the following sections:

1. Environment clearance and forest clearances

The environment clearance (EC) in India is conducted using a planning tool known as Environmental Impact Assessment (EIA). This tool helps the authorities in taking decisions on providing approvals to projects with potential environmental impact.

The Environment Impact Assessment (EIA) 2006 notification mandated "prior environmental clearance" for projects involving "handling of hazardous chemicals", and "hazardous waste treatment"[85] which may be a key process in battery cell manufacturing facility.

Based on the extent of impact and sensitivity of these projects, they are categorized into two categories: **Category A & Category B1**[85]. For category A, project appraisal is done by the Central Level Expert Appraisal Committee (EAC), and clearance is provided by MoEF&CC. For category B, appraisal is done by the State Level Expert Appraisal Committee (SEAC) and clearance is given by State Environmental Impact Assessment Agency (SEIAA).

The general process involved in obtaining prior environmental clearance is categorized into four stages:

Figure 65 Stages in the Prior Environmental Clearance (EC) Process for New Projects

The **screening** of the project is performed at the initial stage and is only applicable to Category B projects[85]. At this stage, the manufacturer needs apply for the prior environmental clearance using Form 1[86] to the State Level Expert Appraisal Committee (SEAC). The SEAC scrutinize the application and take decision on whether the project requires further environmental studies for preparation of an EIA for its appraisal prior to the grant of Environmental Clearance.

Once the screening is complete, the **scoping** stage of EC starts. In scoping, a detailed and comprehensive **TOR (Terms of Reference)** is determined by the Expert Appraisal Committee (EAC) addressing all the relevant environmental concerns for the preparation of draft EIA report and an Environmental Management Plan (EMP). As per the **TOR**, the manufacturer needs to conduct various studies in order to prepare final EIA report. While the studies may vary from project to project, below are some of the key studies that the manufacturer might need to undertake for obtaining environment clearance for the project:

[85] List of projects or activities requiring prior environmental clearance (access here)
[86] EC – Form-1 (access here)

Sl. No.	Key studies
1.	Pre-project baseline data collection: i. Ambient Air Quality ii. Micrometeorology iii. Noise Level iv. Surface & Ground Water Quality v. Soil Quality vi. Ecology & Biodiversity vii. Land use pattern viii. Socio-Economics environment
2.	Study on identification of existing potential sources of pollution in the project location
3.	Study on project solid waste generation and management including arrangements for hazardous waste management and e-waste
4.	Study on examination of soil characteristics, topography, rainfall pattern and soil erosion
5.	Study of surface water quality of nearby water sources and other surface drains
6.	Study on details of groundwater quality
7.	Study on preparation of detailed plan of treated water disposal, reuse, and utilization/management
8.	Study on estimated project water balance taking into account conservation measures, reuse, and recycling of treated effluents
9.	Study on individual and/or common facilities for waste collection, treatment, recycling, and disposal (all effluent, emission and refuse including MSW, and hazardous wastes)
10.	Study on environment impacts on project land
11.	Study of air quality and noise levels during construction and operation period
12.	Preparation of risk assessment & disaster management plan
13.	Study of Socio-Economic Impact & CSR from the project
14.	Study on availability of social infrastructure and future projections
15.	Study on anticipated environmental impacts and mitigation measures: i. impacts due to transportation of raw materials and end products on the surrounding environment ii. impacts on surface water, soil, groundwater, drainage due to project activities iii. impacts due to air pollution iv. impacts due to odour pollution v. impacts due to noise vi. impacts due to fugitive emissions vii. impact on health of workers due to proposed project activities
16.	Preparation of Environmental Monitoring Program (EMP)

After the scoping stage when the draft EIA report as per finalized TOR is prepared, **public consultation** process is conducted. In this process, the concerns of local people and others who have a stake in the environmental impacts of the project or activity are ascertained. Valid issues raised in public consultation is addressed in final EIA & EMP report.

Based on the final EIA and EMP report, EAC/ SEAC will **appraise** the project. After this, as per the recommendations of EAC/ SEAC, clearance for the project will be granted/ rejected by the MoEF&CC/ SEIAA.

For obtaining forest clearance, the manufacturer has to submit documents Form A (Part-I)/Form-B (Part-I)/Form-C (Part-I) etc.[87]. For land below 40 hectare, the proposal is submitted to regional office, whereas, for land more than 40 hectare, it is submitted to the office of MoEF&CC.

To facilitate the environment and forest clearance, Ministry of Environment, Forest and Climate Change (MoEF&CC) has created PARIVESH (Pro-Active and Responsive facilitation by Interactive, Virtuous and Environmental Single-window Hub)[88] portal as single window clearance for appraisal and granting environmental and forest clearances under EIA.

Battery cell manufacturers must obtain statutory environment and forest clearances for their manufacturing facility from PARIVESH portal.

2. Other statutory clearances and approvals

To setup a new manufacturing facility, the Department for Promotion of Industry and Internal Trade (DPIIT) has provided guidelines on necessary clearances[89]. In addition, for manufacturing of an advanced chemistry cell and handling its hazardous waste, guidelines on approvals and authorizations for the manufacturer is provided under Draft Battery Waste Management Rules, 2020[90], and Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016[91].

Summary of necessary clearances/ approvals for an ACC manufacturing facility as per DIPP, Battery Waste Management Rule, and Hazardous and Other Wasters Rule is provided in the below table:

Table 56 Clearances & approvals required for setting up a battery cell manufacturing facility

Sl. No.	Clearance/ approvals/ authorization	Agency concerned
1.	**Incorporation of Company**	Registrar of Companies
2.	**Registration/IEM (Industrial Entrepreneur Memorandum/Industrial license**	District Industry Center for Small Scale Industries(SSI) /Secretariat of Industrial Assistance (SIA) for large and medium industries
3.	**Allotment of land**	State Directorate of Industries (DI) /State Industrial Development Corporation (SIDC)/Infrastructure Corporation/Small Scale Industrial Development Corporation (SSIDC)
4.	**Permission for land use (in case industry is located outside an industrial area)**	a. State DI b. Department of Town and Country c. Planning d. Local authority/District Collector
5.	**NOC and consent under Water and Air Pollution Control Acts**	State Pollution Control Board
6.	**Approval of construction activity and building plan**	a. Town and country planning b. Municipal and local authorities c. Chief Inspector of Factories d. Pollution Control Board e. Electricity Board

[87] Form A (Part-I)/ Form-B (Part-I)/ Form-C (Part-I) (access here)
[88] PARIVESH Portal (access here)
[89] DIPP – List of approvals (access here)
[90] Battery Waste Management Rules, 2020 (access here)
[91] Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016 (access here)

Sl. No.	Clearance/ approvals/ authorization	Agency concerned
7.	**Sanction of Power**	State Electricity Board / State Power distribution utility or company
8.	**Tax Registration**	a. State and Central GST Department b. State Department of Revenue
9.	**Extraction of Minerals (if applicable)**	State Director of Mines and Geology
10.	**Code Number for Export and Import**	Regional Office of Director General of Foreign Trade
11.	**BIS certificate (if product is covered under compulsory certification)**	BIS
12.	**Authorization for generation of battery wastes***	State Pollution Control Board (SPCB) or Pollution Control Committee (PCC) of Union territories
13.	**Authorization and registration for battery waste recycling (if applicable)***	Central Pollution Control Board (CPCB) or designated agency
14.	**EPR (Extended Producer Responsibility) Authorization (if applicable)***	Central Pollution Control Board (CPCB), State Pollution Control Board (SPCB),
15.	**Registration of workers involved in recycling, preprocessing of hazardous waste^**	Department of Labour in the State

*Directed in Draft Battery Waste Management Rules, 2020; ^Directed in Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016

The Production linked incentive (PLI) schemes for battery storage and auto are expected to significantly promote domestic manufacturing of EV value chain components. These schemes are in line with the national ambition of '**Aatma Nirbhar Bharat'** (Self-reliant India) which was announced in May 2020. The primary motive of the Aatma Nirbhar Bharat initiatives is to substitute imports using domestic products.

The key highlight of the PLI scheme is – it provides subsidy on **'sales'** made by the manufacturers. This implies that the domestic market should be capable of absorbing the products. The existing policy landscape towards demand creation does not compliment the support provided under PLI schemes for domestic manufacturing.

Absence of desired market may limit the growth of domestic manufacturing in the country; **promising measures to promote demand** can be expected in near future. With PLI scheme in place, **outlook** on development of domestic battery manufacturing ecosystem is also **promising**.

Battery Swapping

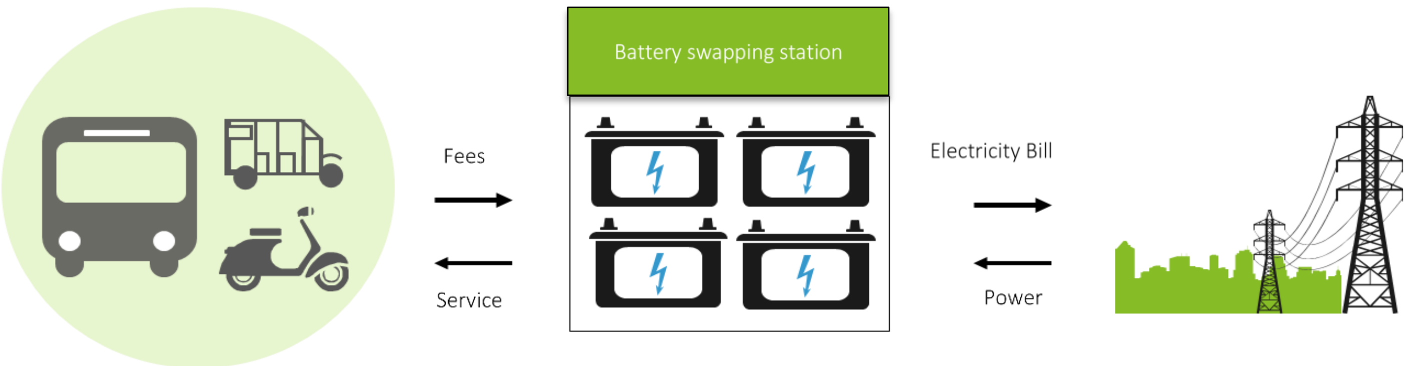
Chapter 5. Overview on battery swapping infrastructure

The EV revolution faces some big challenges in the form of range anxiety, longer charging times, higher vehicle costs, battery longevity and replacement costs. The battery of an electric vehicle constitutes approximately 40% of the upfront cost of an EV. This high upfront cost of EV is a key barrier to its widespread adoption. Removing the battery from the vehicle and providing the same through a service can lower the cost of an EV and offer a better value proposition to users. Such a model can ensure that upfront prices of EVs are at par or even lower than the ICE vehicles. Battery swapping provides such a method of decoupling of batteries from EVs and reducing their upfront costs.

Battery swapping is a process in which a depleted battery of an EV is exchanged with a fully charged battery at a swapping station. The battery swapping station acts as a battery aggregator that offers the infrastructure where depleted batteries are charged and then offered to EV drivers in replacement of the discharged battery. This approach takes care of battery longevity, reduces replacement costs, and effectively eliminates longer charging times. This approach could further be integrated with EV OEMs and users can simply lease batteries from battery swapping stations instead of owning them. This would reduce the vehicle cost as batteries are the major contributors of the cost of EV encouraging users to buy the EVs at lower costs and lease the battery at cheap rates.

A large network of battery swapping stations will also eliminate the range anxiety helping users to travel long distances without worrying about the battery range. A typical battery swapping station consists of a bulk charger which has an enclosed locker system housing 10-30 batteries. The bulk charger can charge all the batteries at once.

Figure 66: Typical arrangement at Battery swapping station (BSS)



In addition to the above, battery swapping allows entities to focus on their core competence viz.

- Vehicle OEM can focus only on designing and manufacturing EVs.
- Battery OEMS can manufacture batteries.
- Swapping or charging service companies can provide desired services to consumers.

5.1 Overall attractiveness / feasibility of battery swapping for different vehicle segments

Battery swapping, as a proposition, holds significant value when some or all of the following scenarios are met:

1. where EV users want to decrease their waiting time and avoid waiting for 1-2 hours for charging solution
2. where EVs have significant distance to be travelled during a day
3. where public charging options are not suitable or adequately available

4. where customers are price sensitive regarding upfront cost of the EV
5. where users who do not have access to personal / private charging

As per NITI Aayog & RMI, India can achieve an EV sales penetration of 70% for commercial cars, 30% for private cars, 40% for buses, and 80% for 2 and 3 wheelers by 2030. Although there is a substantial scope for electrification of all segments of vehicles, however it becomes important to demarcate feasibility of battery swapping for each vehicle-segment. Following section assesses the technical feasibility of each vehicle segment for battery swapping:

Two wheelers

Two-wheeler segment is generally represented by users who would be taking short and definite trips. This would comprise personal vehicles, commercial vehicles and fleet operators. While users of personal vehicles would prefer to have personal / residential or own charging stations, commercial vehicles and fleet operators have to travel long distances during the day. Such users do not have adequate time available during the day for charging and hence would not like to be subjected to long waiting hours for charging their vehicles. Users of e-2Ws who travel to their place of work might still prefer public charging station, however public charging stations have primarily catered to the 4W segment. Hence, it is expected that this would be an ideal segment for battery swapping.

- India is the biggest two-wheeler market in the world, but currently not many electric two-wheeler models in the country support the battery-swapping model. Sun Mobility is one of the leading providers of battery-swapping services in India, and by the end of 2021, it aims to set up 100 battery-swapping stations in Bengaluru. Sun mobility has also set up quick interchange stations in Delhi NCR, Amritsar, Chandigarh, Vijayawada, Kozhikode, and Thiruvananthapuram. Additionally, Hero MotoCorp announced a strategic partnership with Gogoro in April 2021 through which Gogoro will establish a battery-swapping network in India and Hero will provide e-2w that will work on Gogoro batteries. A cost comparison of battery swapping, point charging, and ICE two-wheelers in India by International Council on Clean Transportation[92] in November 2021 revealed the following results:
  - If 50% of the central government's FAME II incentive were also offered to BEV two-wheelers with the battery-swapping option, then after incentives, these vehicles would become cheaper in terms of upfront cost than those with point-charging mode and would be comparable to the gasoline two-wheeler
- BEV two-wheeler with battery swapping incurs less TCO and cost per km values than the gasoline two-wheeler across all use cases.
- As the average daily distance traveled increases, the BEV with battery-swapping option gives better economic results relative to the point-charging and gasoline vehicle options.[93]

It is thereby clearly inferred that battery swapping could be an attractive proposition for two-wheelers going forward. Moreover, following factors would lead to increasing two-wheeler adoption in the country:

- Two-wheelers make for a more pocket-friendly option due to their lower upfront and upkeep costs.
- The perks of owning a two-wheeler are not only easy affordability but extend to economical insurance solutions and toll tax exemptions as well.
- Those who own two-wheelers have to face less difficulty in crowded and congested roads as opposed to four-wheeler owners.

However, there are certain challenges in this segment viz. lack of standardization in batteries, OEMs focusing on product differentiation as well as consumer behavior which may hinder battery swapping. However, with entry of several players in the e-2W segment for last mile services, this segment may be attractive for battery swapping.

[92] Cost comparison of battery swapping, point charging, and ICE two-wheelers in India (access here)
[93] International Council on Clean Transportation (access here)

Three wheelers

Three-wheelers represented ~80% of the total EV sales in India in 2021 and are expected to lead the same in future as well.[94] However, currently this segment is largely dominated by unorganized players. In addition to this, there has been limited adoption of battery swapping infrastructure for this category of market. There have been few players viz. Sun Mobility, Echargeup Solutions, Amara Raja Batteries Ltd. who have started limited operations in battery swapping for three wheelers recently.

In addition to this, three wheelers represent a large scope of last mile connectivity wherein the vehicle would cater to short and frequent trips on same routes. While there could be some e-3W which may resort to private charging options at night hours, there is a scope for battery swapping for the same as it has the same characteristics of commercial 2Ws.

Moreover, this segment requires charging on the go. Most e-2Ws use lead acid batteries which usually have a life of 6-7 months after which they have to be replaced. Replacement costs around INR 25000-28000 (EUR 296 – 332) for e-rickshaws. Such replacement provides an opportunity for players who are providing conversion kits to make the vehicles compatible to Lithium-ion chemistry and be used for swapping.

With a large number of 3Ws prevalent in cities and towns, presence of fleet operators in this segment and a largely unorganized market with several OEMs in this space, it can be assumed that electric three wheelers represent a substantial business opportunity for battery swapping. Hence, this segment may also be attractive from the perspective of Public Charging.

Four wheelers and buses

Public transportation has the potential to influence the development of any city / town. A good public transport is accessible to all and has the power to bridge the gap in mobility. There can be different modes of public transport like commercial vehicles, fleet operators, app-based cab services, buses, trams, etc. Currently, commercial four wheelers and buses are the dominant form of public transport in India.

Commercial four wheelers ply for larger distances (intra-city and inter-city) and would need adequate level of battery charge for the same. Commercial four-wheeler vehicles would be represented largely by fleet owners, private taxi players, light, and medium goods vehicle, etc. which would need instant access to charged batteries since they would like to focus on their core capabilities only. Electric Buses and other large public / goods transportation vehicles would also ply for larger routes (intra-city and inter-city) and need availability of substantial level of charge. However, at present since batteries in such segments are not standardized, there could be limited adoption of battery swapping to start with. As and when standardization is done across batteries, this segment could also witness significant uptake of swapping. However, commercial four-wheelers and buses are generally parked in demarcated locations with access to private charging infrastructures. Hence this segment may witness lesser uptake of swapping to start with. However, it represents a substantial business opportunity for swapping in the future.

Personal four-wheeler segment may not be a feasible market for battery swapping as such users would like to charge their vehicles either at residential / private locations or at commercial public chargers during the day. Moreover, as this segment is represented by cost-conscious consumers, safety would be an important consideration which would lead to such users not relying much on swapping as a solution.

Lot of municipal authorities and state-level public transportation authorities are going electric. Electric buses have huge batteries and low amount of time for charging. This makes battery swapping an attractive option for them.

In addition to this, financial viability of a battery swapping station is also dependent on its utilization. This would necessitate the installation of such stations at routes which has high footfalls and vehicle availability. Such locations could be shopping complexes, malls, commercial and industrial hubs, expressways / highways / arterial roads, metro locations, airports, etc. which are generally catered to by commercial three / four wheelers as well as intra-city and inter-city buses.

Considering the above-mentioned factors into account, it is evident that commercial e-2W, e-3W and e-buses would be the most technically feasible segments to look at for battery swapping business.

[94] Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India (access here)

Table 57 Key aspects of market segment w.r.t. Charging needs and feasibility for battery swapping

	Electric Two wheelers (Commercial)	Electric Two wheelers (Private)	Electric Three wheelers	Electric Four wheelers (Commercial)	Electric Four wheelers (Private)	Electric buses
Key aspects of market segment w.r.t. Charging needs	• Long trip duration • Long distance to travel • Requires less waiting time • Less technical complexity of charging • High requirement of fast charging • May not have access to private charging	• Short trip duration • Short distance to travel • Can afford medium-high amount of waiting time • Less technical complexity of charging • Less requirement of fast charging • Has access to private charging	• Largely unorganized market • Short trip duration with fixed trip length • Frequent trips during the day • Less technical complexity of charging • May not have access to private charging	• Organized market • Larger trip lengths • Requirement of fast charging at commercial / business locations • Requirement of fast charging • Has access to private charging	• Organized market • Smaller trip lengths • Requirement of fast charging at commercial / business locations • Requirement of fast charging • Has access to private charging	• Long trip duration • Long distance to travel • Requires less waiting time • Requirement of fast charging / special plug points • Has access to own charging depots
Feasibility for battery swapping						

Least feasible Highly feasible

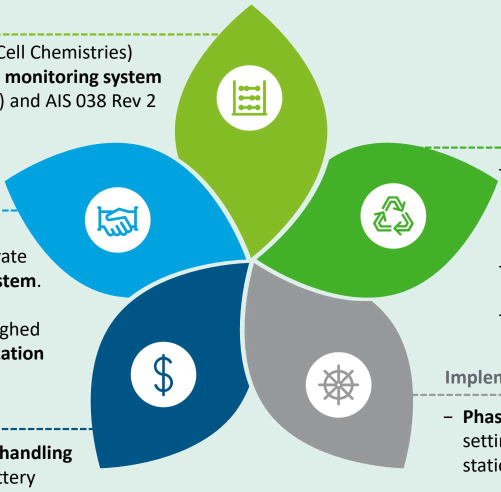
Based on the analysis, it is understood that battery swapping would be technically most feasible for commercial electric 2Ws and 3Ws as well as e-buses. There have been several players in the battery swapping business focusing on these segments as is highlighted in section **5.7**. It is expected that more such players would enter into this space fueled by the substantial potential for battery swapping in these identified segments. Policy incentives should hence be focused on driving increased adoption of swapping in these segments particularly.

Box 8: Draft Battery Swapping Policy

Battery swapping has been identified as one of the key catalysts for improving the adoption of electric vehicles in the two- and three-wheeler segments. The primary reasons being its ability to supplement reduction of upfront costs. Apart from reducing the upfront cost of EVs, it provides key advantages in relation to charging through time saving, efficient space management, and cost effectiveness.

Identifying such advantages, the Hon'ble Finance Minister in her budget speech of 2022-23, announced that the Union Government will introduce a Battery Swapping Policy and interoperability standards to improve efficiency in the EV ecosystem. NITI Aayog released a Draft Battery Swapping policy through inter-ministerial discussions and releases the draft policy in April 2022. Some of the salient features of the policy are mentioned below:

Key features of the Draft Battery Swapping Policy:



Technical and Operational Requirements

- Support batteries using ACC (Advanced Cell Chemistries) and suggests **implementing IoT enabled monitoring system** for tracking. will be as per AIS 056 (2020) and AIS 038 Rev 2 (2020) **Testing, certification**

Business Models

- **Business model agnostic** and **encourages collaboration** amongst stakeholders to innovate and **create a sustainable and scalable ecosystem**.
- Key **role of battery providers** has been highlighed to **enable technology** to **promote standardization**

Fiscal Support

- **Initiates subsidies and responsibility** of **handling** and **coordinating** the **conflicts** to the battery providers who comply **with technical and operational requirements**;
- States the **differential GST rates** on lithium-ion batteries and equipment.

Battery Re-use and Recycling

- Address **concerns related to battery life** and **resale value; regulations for minimum performance and durability** to be developed by BIS/ relevant authority
- **Encourages development of power bank** to **store RE for EV charging**, other applications
- **Emphasises on Battery Waste Management Rules** for **EPR** and **EOL** batteries handling

Implementation of Battery Swapping Services

- **Phased rollout** based on **population of cities** and setting up **specific nodal agencies** for battery swapping stations
- Roll out in cities with **40+ lacs population in Phase 1 (1-2 Years)** and major cities with population of 5+ lacs as per 2011 census
- Identifed **BEE (Bureau of Energy Efficiency)** as the **implementation agency** of battery swapping networks across countries.

Although the policy is wide in its reach, investors would avoid taking such risks as battery swapping is a niche business because 76 per cent of Indian consumers prefer charging at home, said a Deloitte survey. Also, the policy is silent on an 18% tax on charging, and equally silent on the timeline of the tax cut and little clarity on financing the vehicles without batteries as the sale of individual frame and motor by third party is reluctant and possess the risk for investors.

The policy is a welcome step for the battery ecosystem and provides a clear sense of direction of government's intent without being too prescriptive about solutions. The clear phasing out and setting specific responsible agencies streamlines the efforts for technical and safety prioritization sets the heads-up for investors. The draft has been open for comments and it is expected the concerns mentioned would be cohesively addressed in the final version.

5.2 Battery swapping technology

Battery swapping station – categorized based on extent of human intervention

Battery swapping can either be done manually or through an automated method. Both methods are explained in detail below.

Manual swapping

The manual swapping stations requires the users to remove/place the battery themselves. Manual battery swapping stations are the most popular ones currently. These battery swapping stations occupy minimal space and are modular. The station consists of a bulk charger which has different lockers where batteries are housed individually. The locker system has gained prominence due to the increasing vulnerability of battery theft. The batteries housed in the locker needs to be placed and removed manually (by hand). They are mostly used for 2W and 3W battery applications since the battery pack sizes are smaller in these applications.

The manual swapping stations use batteries with weight less than 9 kgs to ensure the handling by one or two people. Certain vehicles can have options to use multiple battery packs to further increase range and power.

PROS

- **Is cost effective** as it does not use labour, robots or complex mechanical components for its operation
- **Easier to scale up due to lesser investment:** This form of swapping is easier to operate and involves less investment

CONS

- **Slower adoption rate:** Users need to service the vehicle themselves. Hence, the adoption rate could be lower as compared to other battery swapping technologies
- **Safety concerns:** If the battery swap is not executed properly, a short circuit might happen, thereby causing fire
- **Limited segments:** By virtue of the battery weight, this technology would see adoption in 2W and 3W segments and not much in 4W and e-buses.

Robotic / Automated swapping

This form of battery swapping is semi or fully automated. A robotic arm is used to facilitate the swapping procedure. The robotic arm removes the depleted battery packs from the car and replaces them with charged battery packs. The depleted battery packs are further placed on shelves where they are recharged.

These battery stations are mostly suited for 4W and e-bus applications as their battery packs are heavier and larger, hence requiring mechanical assistance. The battery swapping stations can either be under floor swapping (platform type) or side mounted swapping. Under the floor swapping is mostly used for cars as their batteries are mounted on the floor. Side mounted battery swapping is used by e buses as the e buses have lots of space of either side to facilitate battery swapping.

PROS

- **Faster adoption:** Users do not have to manually place batteries and hence it is more user friendly
- **Safety:** Limited human intervention is required as the entire process is mechanised. Hence, this technology is safer than the manual process.

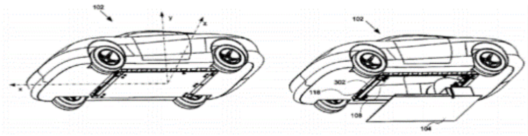
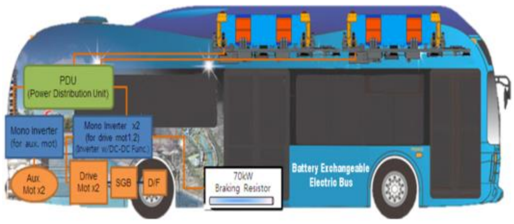
CONS

- **Expensive and complex:** Requirement of robotic metal arms and other mechanical components make the system expensive. The system is relatively more complex to manage.

Owing to it ease of use and technological simplicity, manual swapping technology is generally adopted for e-2W and e-3Ws. This is quite visible in various 2W and 3W swapping players globally as well as in India. In these segments, typically the driver or any individual can easily install the battery from the battery station. However, for commercial e-4W and e-buses, typically robotic / automatic swapping is preferred owing the larger battery sizes and less appetite for a longer waiting time. Battery swapping service providers need to take this into account while setting up their stations.

Battery swapping station – categorized based on location of battery and robotic arm's application point

Following are the various swapping technologies, classified according to the location of the battery in the vehicle and the robotic arm's application point:

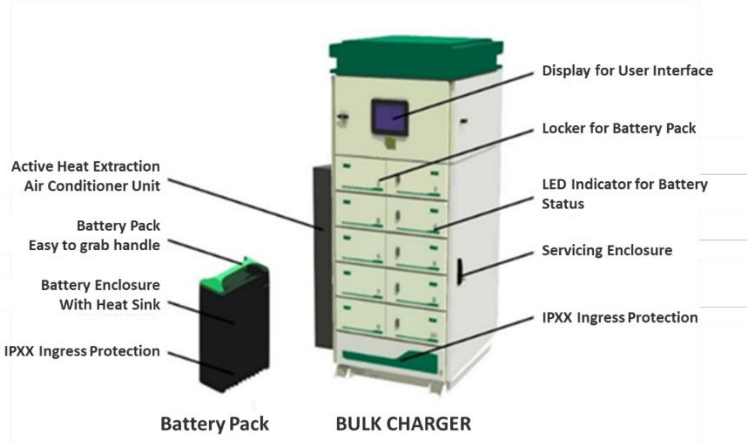
Type of swapping	Illustration
Bottom swapping Bottom swapping is carried out for vehicles with a battery that is located at the bottom of the vehicle. The swapping station is designed such that the vehicle is parked on an elevated platform and the batteries are switched from the bottom using a robotic arm and other accessories that are usually located below ground level.	
Top swapping This form of battery swapping is more widely seen with electric buses, where the batteries are mounted on top and the rooftop opens as the bus arrives in the station, the rooftop opens, and the swapping is completed by means of the robotic arm.	
Sideways swapping This is commonly seen in vans and other vehicles where the sideways configuration is the most suitable.	
Rear swapping This is seen in vehicles where the battery is mounted backwards. This is typically observed in cars and vehicles which have high boot space.	

Battery charging technologies for swapping station

How a battery swapping station is different from an EV charging station?

Battery swapping stations are not much different from a typical charging station except for the bulk charger. Battery swapping stations have an onboard bulk charger in which batteries are stored and charged as shown in the figure alongside. The Bulk charger can hold multiple batteries in it which can charge at the same time thus reducing the wait time of charging.

Figure 67: Illustration of a typical battery pack and Bulk Charger



There are a lot of similarities between Battery swapping stain and Charging station. All the components used in charging stations are also included in battery swapping stations, but the charging speeds are tuned down to reduce heating and increase battery longevity.

Battery swapping stations are specifically designed to hold and charge batteries. It allows electric vehicles to immediately swap their discharged battery pack with a fully charged one. This helps in eliminating the delay involved in conventional electric vehicle charging.

In addition to the components, the biggest difference in swapping stations and charging stations is their business model. In charging stations, the operator is selling energy at a cost, but in swapping stations generally the operator is giving Battery as a service (BaaS), where they lease out batteries to electric vehicle owners and charge them monthly fee and charging cost whenever they swap a battery.

Bulk charger for charging batteries in a Battery Swapping Station:

Bulk charger is an advanced and most predominant battery charging technology used by global battery swapping players at their stations. The bulk charger allows multiple battery packs to charge at once helping operator to achieve quick turnaround of batteries for swapping.

Operation of a bulk charger is complex and requires a lot of factors to take into consideration – one of which is safety of the station and user. Multiple batteries charging at a same time dispenses a lot of heat and therefore increases safety risks. To tackle and avoid these risks, certain safety measures are considered by the manufacturer/ operator:

- **Shock protection:** To provide protection from shock, manufacturers use non-conductive materials so that the users can touch the bulk charger without any risks involved. They generally use rubber gaskets to insulate the charging devices with the bulk chargers.
- **Current leakage:** Manufacturers uses sensors on the body of the bulk charger which inform the operator/ user in case of current leakage in the bulk charger.
- **Voltage fluctuations:** For voltage fluctuation, manufacturers generally install surge protector.
- **Fire protection:** Suitable temperature sensors around all batteries and chargers are installed. These sensors have a power cutoff facility in event of a fire breakout.

In addition to the safety features, the bulk charger has other components such as user display unit and IoT modules.

Component	Details
User Display Unit	The user display unit is used as an enabler to provide the user a hassle-free swapping experience. The display unit shows the user information on available charged batteries, corresponding compartment location and payment methods.
IoT Module	There are two types of usage of IoT modules in a battery swapping station: i) One IoT model is installed in the bulk charger which makes sure all the relevant data is transferred to operator such as data on payment, battery usage, charging, cooling etc., and ii) Another type of IoT module tracks the geo-location and usage of the battery pack. The usage of the battery pack is monitored throughout its lifecycle.

Charging options for a battery swapping station:
Charging options for battery swapping station can be primarily categorized into three types:

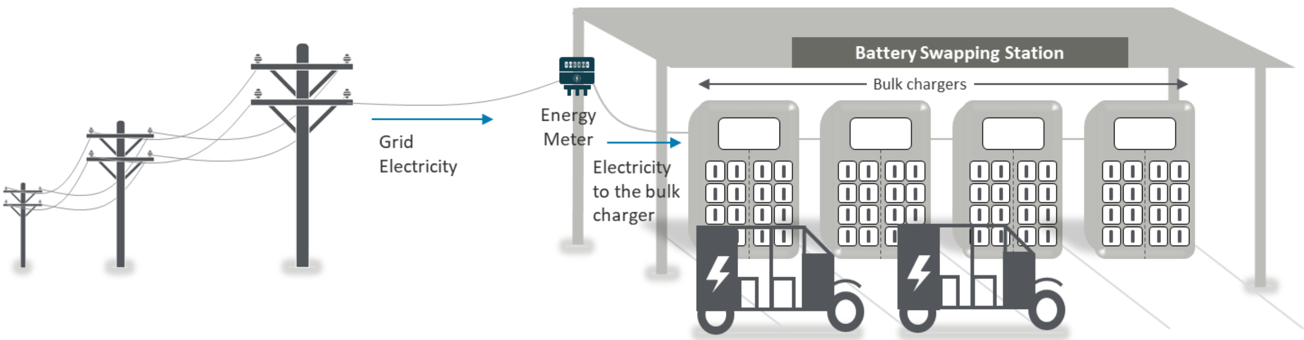
Bulk Charging from grid	**Power from Solar PV** *(mostly Solar Rooftop)*	**Hybrid charging** *(from both grid and solar PV)*

More details about each of the charging option is provided in the below sections:

a. Bulk Charging from grid

A bulk charger can charge multiple battery packs at the same time. The bulk charger can draw power from the grid to charge the batteries all at the same time. It is the most important component in the battery swapping station. However, charging of multiple batteries at the same time will generate a lot of heat, due to which cooling solutions are used in such a system.

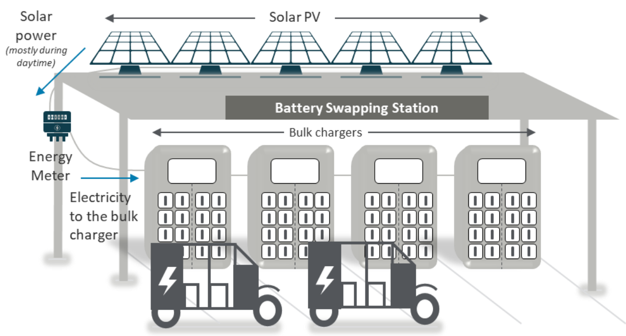
Figure 68 Bulk charging from grid – Illustration



b. Charging from solar rooftop

Roof top solar systems can be used to charge batteries, but in order to meet the energy demands of the EV, the surface area of the roof charger needs to be much bigger than the vehicle itself (5-10 times). Since sunlight is essential for the operation of this system, the batteries can only be charged during daytime. With evolving technologies, such a charging system will get more prominence. Such charging systems are more viable economically as compared to those systems which use power from the grid. The mismatch between energy generation and consumption can be curbed by deploying net metering at the swapping stations.

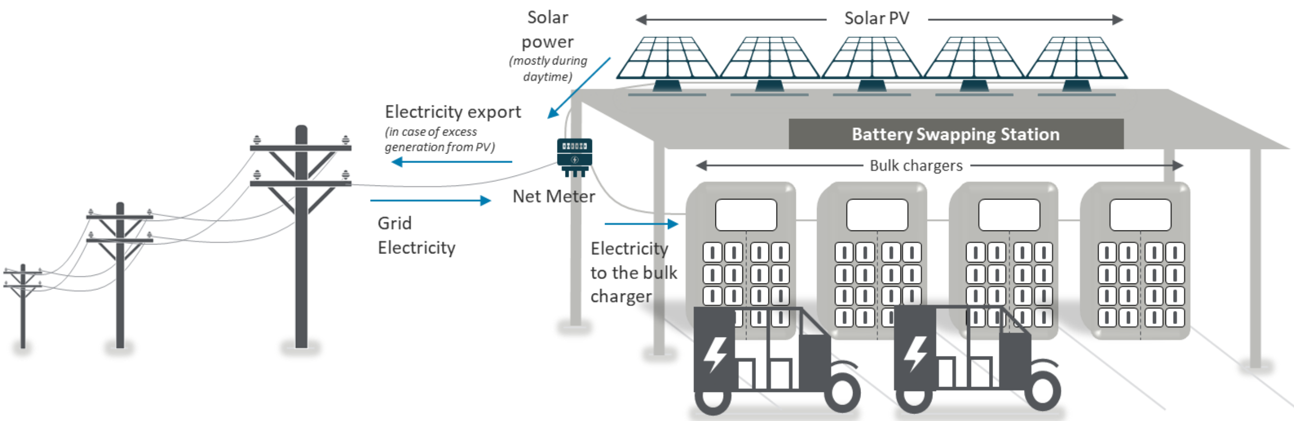
Figure 69 Bulk charging from solar rooftop – Illustration



c. Hybrid charging

Hybrid system uses grid as well as solar based charging to charge the batteries. During daytime, the batteries can be charged from solar power. But solar power may not meet the charging needs of the swapping station. Hence the power generated from the solar rooftop can be fed into the grid using net metering. The power from the grid then charges the battery. Based on the solar power fed into the grid, the battery swapping station operators could be offered reduction in their electricity bill.

Figure 70 Hybrid swapping station – Illustration

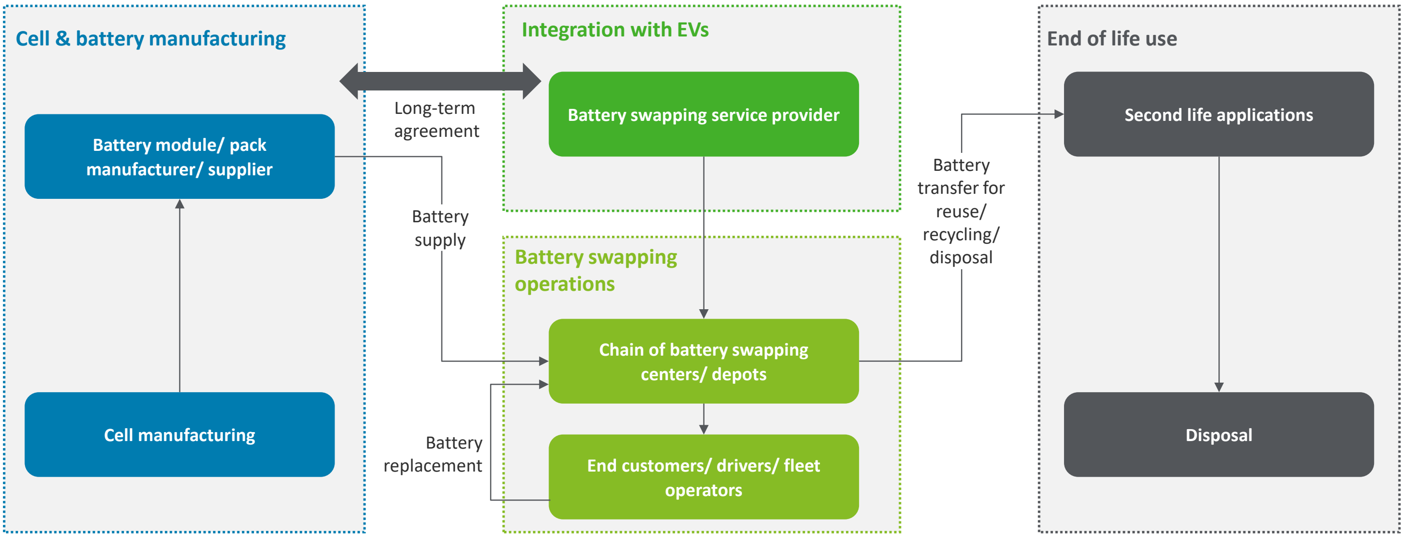


5.3 Battery swapping supply chain

Batteries store the energy that drives an EV, similar to the way a fuel tank stores the energy that drives a conventional ICE vehicle. In a battery pack, the simplest unit is a cell. A cell contains chemical materials from which the chemical energy is converted to electrical energy. A series of cells put together form a module. A series of modules packed together form a battery pack. It is this battery pack which is then sourced from OEMs by swapping station operators and solution providers.

In this section, the entire supply-chain system of a battery is reproduced starting from cell / battery manufacturing to its utilization in a swapping station and subsequent disposal. A schematic overview of the supply chain is reproduced herewith:

Figure 71 Battery swapping supply chain

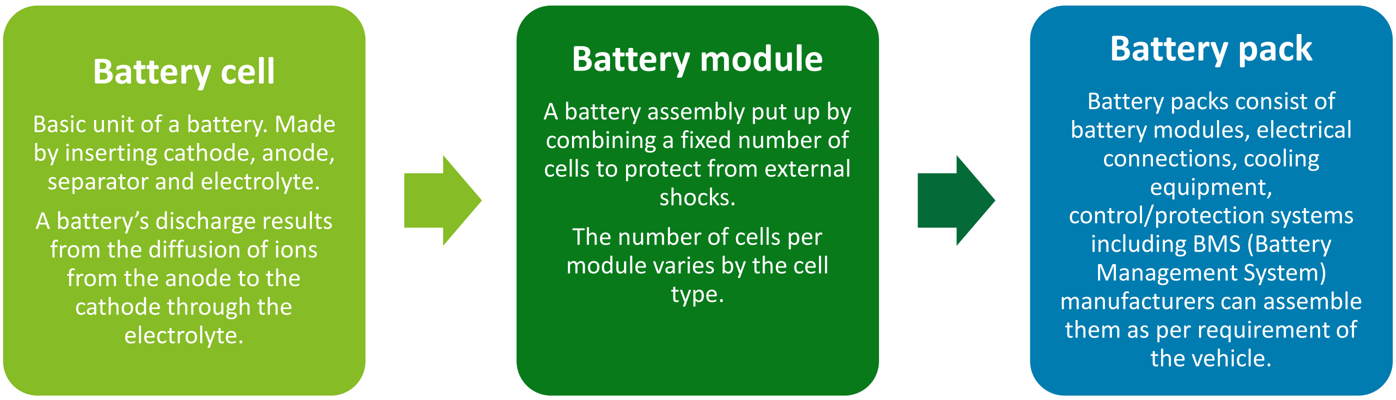


Cell and Battery pack Manufacturing

Manufacturing a battery can generally be broken down into three different stages as shown in figure below. A battery is a device that converts chemical energy into electrical energy and vice-versa. A battery cell is the smallest packaged form a battery can take and is generally on the order of one to six volts.[95] A battery module consists of several cells generally connected in either series or parallel. A battery pack is then assembled by connecting modules together with some safety devices and electronics in control in a Battery Management System (BMS), a cooling system etc.

These three stages can be conducted in the same place or broken up into two or (theoretically) three locations. The battery pack is the ultimate component which goes into several applications. Following are the various stages of cell to battery pack manufacturing.

Figure 72 Stages of manufacturing of EV batteries



Integration of battery packs with EVs

For vehicles with non-swappable batteries, the EV manufacturer takes on the complete responsibility of maintaining a charging network and supplying home chargers compatible with the vehicle's charging standards. For vehicles with swappable batteries, there is a requirement of a higher level of involvement for the battery pack manufacturer. This also provides an opportunity for EV makers to vertically integrate and move into the manufacturing of their own swappable battery packs. For instance, Gogoro has succeeded in forming tie-ups with some of the largest 2-wheeler manufacturers in India and China for manufacturing electric

[95] Source: A Guide to Understanding Battery Specification, MIT Electric Vehicle Team (click here)

scooters compatible with the Powered-by-Gogoro-Network (PBGN). Nio (China) is a manufacturer of electric passenger cars that is working on developing a battery swapping ecosystem involving its own battery packs, vehicles, and robotic battery swapping stations (BSS).

In India, several battery swapping solution providers have long-term tie-ups with battery manufacturers for sourcing of batteries and some have their own indigenously developed battery manufacturing capabilities.

Box 9. Partnership – Battery swapping solution providers & battery manufacturers

1. **Sun Mobility Pvt Ltd.** has partnerships with various vehicle manufacturers, energy and infrastructure providers, fleet operators, and smart city authorities. The company has partnered with Piaggio to provide smart batteries, interchange stations and smart network for electric 3Ws. In addition to this, it has also partnered with SmartE, a 2W and 3W fleet operator to provide swappable batteries for 2W, 3W. SmartE's fleet of electric three-wheelers makes use of SUN Mobility's solution and will be deployed at SmartE Park & Charge Hubs across the Delhi-NCR.

2. **Amara Raja** has launched its battery swapping station in Tirupati for e.3Ws. The lithium-ion battery packs, EV battery charging, and swapping stations are designed and developed in the state-of-the-art R&D facilities of Amara Raja.

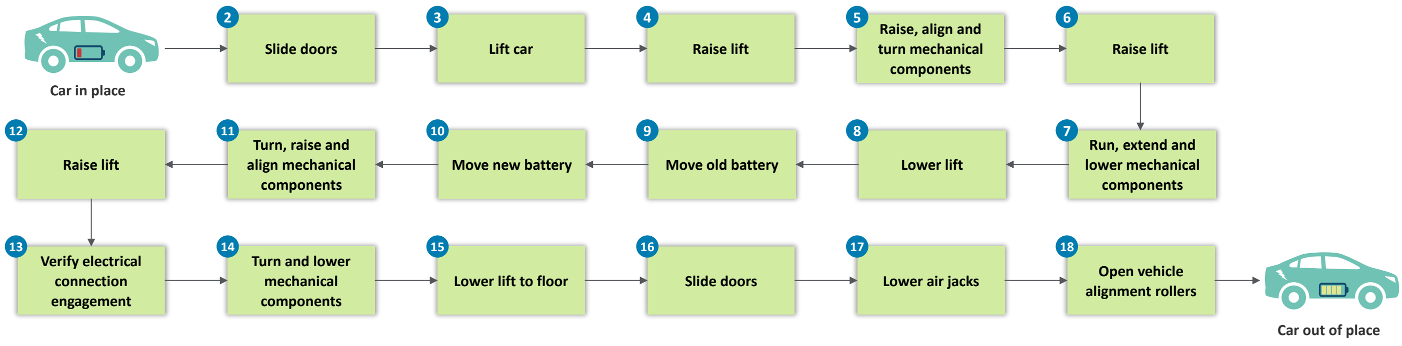
Source: (1) Economic Times (click here), (click here), (2) Economic Times (click here)

Battery swapping station (BSS) operations

The swapping station operates on the FIFO: First in First Out principle. The vehicle arriving first will be given priority to avail the swapping services. To attend the demand of all the vehicles approaching the BSS, it is deemed necessary that the discharged batteries are charged immediately after swapping to ensure the availability of charged batteries for other customers. To participate in the battery swapping, an electric vehicle should be compatible and have a battery architecture designed for the swap. The EV can even plan the battery swap and give an affirmation to the station to ensure the availability of a battery pack. Upon showing up at the swapping station, the EV ascends a slight incline which also indicates the beginning of the swap.

The vehicle is then positioned accurately in a particular direction. This is followed by turning off the power of the vehicle to ensure safety. For an electric vehicle with battery positioned in its bottom, the horizontal doors present underneath the vehicles are further opened after the vehicle is lifted. This allows access to the battery which sits underneath the vehicle. The battery lift is used to support the battery for removal. The battery lift is raised to touch the underside of the battery pack, Once the lift is placed securely within the battery pack, the fastener removal is initiated. At this point a battery transport system (battery conveyer shuttle) is brough underneath the battery lift. The used/depleted battery (currently present on the battery lift) is brought down on to the battery transport system where it is replaced by a new one fetched from the battery rack. The new battery is then raised up to be positioned underneath the vehicle. The battery lifts then position and secure the battery again. The fasteners are locked in and the doors are shut. The vehicle is then lowered and powered back on.

Figure 73 Battery swapping procedure flow chart



Source: IET (access here), Polytechnic University of Turin (access here)

Once the swapping is completed, the vehicle is then immediately monitored for its state of charge (SOC), state of health (SOH), battery life, battery age, remaining charge and number of charging and discharging cycles undergone. The owner will be notified of this information and the charges incurred.

The setup and operation of BSS involves operators to undertake several processes as mentioned below.

Battery charging management

Discharged batteries are either charged at the swapping service station itself or centrally collected and charged at a dedicated charging facility. Generally, **battery charging can be done at the same location as the swapping facility**, with the help of portable or fixed chargers. An example of an individual battery charger for swappable batteries is shown alongside. The specifications for fixed battery chargers are quite similar to those of portable EV chargers since each one of them charges the same set of batteries at a time and hence they have similar wattage and current ratings. In the bulk chargers, there are many dockets where the individual batteries are placed for charging. The typical area required for installation of a bulk charger for 20 batteries is about 1 square metre (sqm). In the case of individual charging, 1 sqm is also typically the standard area requirement for a charger.

Figure 74 Illustration of a battery charger

It is also possible to develop a **hub-and-spoke model** for battery swapping. In this case, centralized charging is done in a remote location, and the swapping facilities only dispense the charged batteries. In such cases, a high tension (HT) grid connection may be needed, based on the number of batteries. The ancillary infrastructure includes the suitably rated transformer, circuit breaker, and cables. The charged battery dispenser for 20 batteries can be installed in an area of 1 sqm.

Box 10: Gogoro is a Taiwanese e-2W manufacturer that has grabbed headlines for its battery swapping network. The company, with assistance from Panasonic, manufactured portable lithium-ion batteries that weigh 9.8 kg each. A typical battery swapping station has the appearance of a vending machine and holds a minimum of 10 batteries. The company has successfully deployed their battery swapping infrastructure in the Asian and European markets. It also provides individual battery chargers to users.

Battery inventory management

Each battery provided to customers at swapping stations is individually tracked, and users can exchange batteries as often as they desire. The batteries used are lock smart, i.e., a given battery will only work with a specific vehicle. This step is necessary to avoid battery theft. Industry players have developed innovative solutions that utilize artificial intelligence, Internet of Things (IoT), GPS tracking, and facial recognition to maintain speed and reliability of battery swapping services and to improve the customer experience.

Monitoring and tracking of battery status

Some battery swapping solution providers provide interconnected, intelligent systems compatible with electric two-wheelers and three-wheelers. A smart network developed by the provider monitors the battery and nearby station and is IoT enabled and linked to a mobile application. The Smart Network provides real-time feedback to customers and fleet owners. It is also used for tracking, health monitoring, diagnostics and anti-theft capabilities of the batteries. The network is capable to detect the batteries state of charge and automatically locate the closest station.

Box 11: Sun Mobility, a Bangalore-based start-up has come up with a pay-as-you-go battery service system running on Microsoft Cloud. Users can stop at a swapping station before their battery runs out of power. They can then replace the depleted batteries with fresh ones, without waiting for hours. Users just need to pay to swap batteries rather than owning a battery. The batteries and the swap stations are connected to the Cloud using Microsoft Azure and built-in solutions like Azure IoT Hub, Azure Data Factory, CosmosDB, Azure Databricks that shares battery performance data with Sun Mobility.

End of life

Compared to primary batteries which are designed to be used only once, a rechargeable battery is designed to last for a long time, over and over again. However, a rechargeable battery degrades over time and all such batteries will cease to work. Thus, a battery that is used daily in a power tool might reach end-of-life in a few months to few years. The time taken for a battery to reach end-of-life depends on the application it is used in, apart from the chemistry. The life of battery in different EV segment are as follows:

- E-2w – ~2-4 years
- E-3W – ~9-11 months
- E-4W – ~10 years
- E-bus – ~8 years

Batteries from EVs have huge potential to be used in other applications. Several vehicle manufacturers from Europe have installed used batteries in various energy storage systems, ranging from small residential systems to large grid-scale storage solutions. Time-shift management (charging when cheaper power generation source is available and discharging when tariff is higher), frequency response, power back-up, demand side response etc. are some of the applications of refurbished Li-ion batteries. Refurbished batteries can also be used for Vehicle to Grid and Grid to Vehicle applications to reduce stress on the grid and to manage peak demand.

A wide range of strategies have been developed to process used EV batteries. Some companies have partnered with energy companies, third party vendors and start-ups, for sale of refurbished batteries while others have established dedicated energy companies, using the refurbished batteries for their own use. While refurbished batteries are kept as whole packs in larger energy storage systems, other packs are disassembled to enable custom-built second life products.

In addition to second life, there are procedures for recycling of batteries. The recycling processes used, and their efficiencies, vary widely. Most of the recycling processes today are hydrometallurgical using different types of liquids to separate various elements of the batteries. Pre-processing usually involves shredding or cutting and smelting or pyrolysis. The efficiencies of recycling are dependent on to the recycler's upstream and downstream options. Limited access to used batteries for recycling (upstream) and limited buyers for extracted materials makes it difficult to obtain an efficient process.

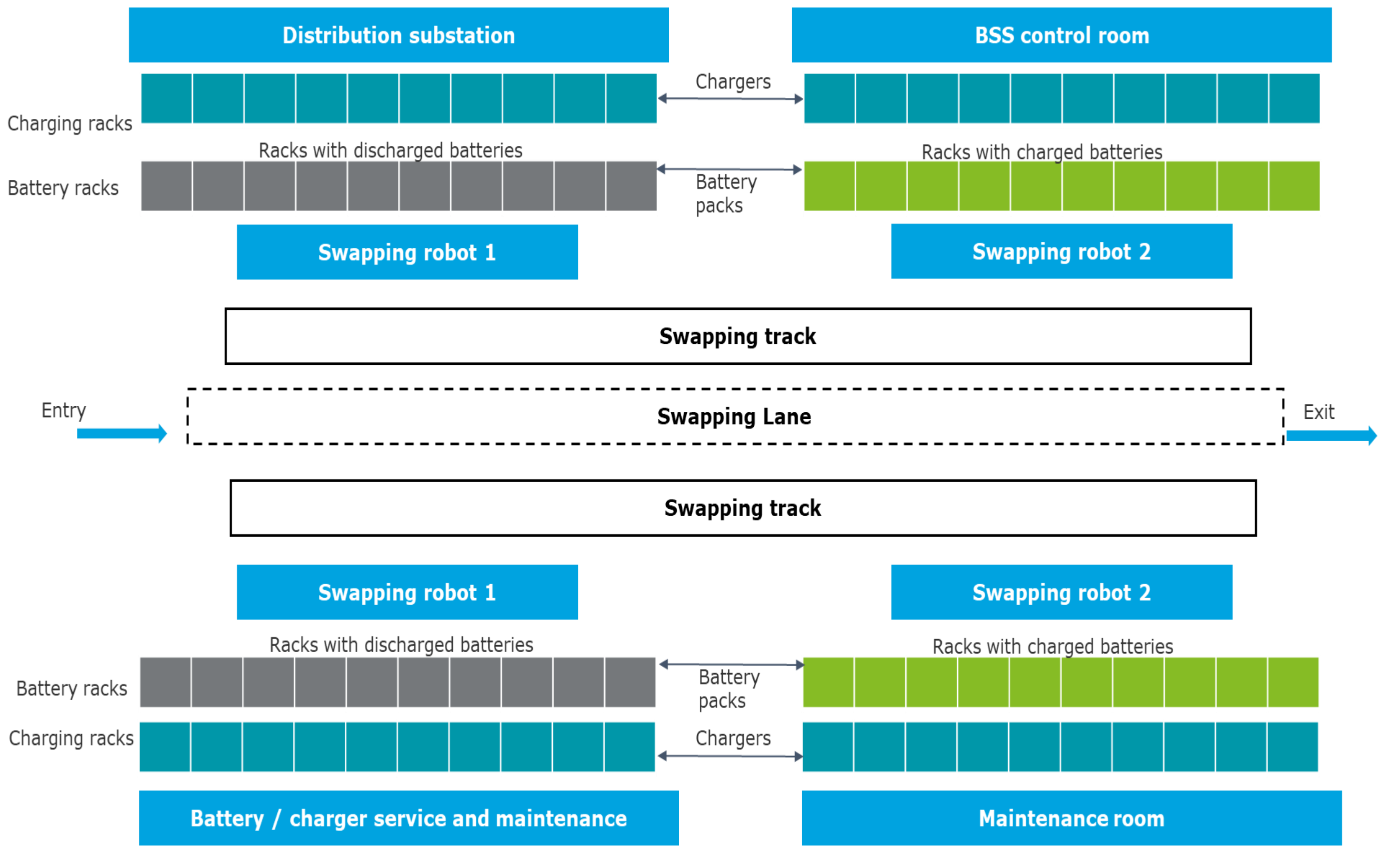
Apart from setting up recycling facilities, China has passed regulations holding vehicle manufacturers responsible for recovery of batteries. China Tower, a large telecom tower operator from China has announced in 2018 to replace Lead acid batteries used in the tower with retired EV batteries.[96]

5.4 Key components of battery swapping infrastructure

The battery swapping stations (BSS) will operate successfully when there is continuous communication between the different components of the system including the EV, swapping station and information system. The key components of the battery swapping station are further highlighted in figure below.

[96] Source: Lithium battery reusing and recycling: A circular economy insight (Mario Pagliaro, Francesco Meneguzzo)

Figure 75 Illustration of the key components of a battery swapping station



Source: IET (access here)

The swapping station operates on the first-in-first-out principle, i.e., the vehicle arriving first will be given priority for their swapping services as compared to those who arrive later. To attend the demand of all the vehicles approaching the swapping stations, it is necessary that the batteries must be charged immediately after swapping so that they are available to other arriving customers. This integrated operation of stations will optimise the vehicle for its route, allowing the vehicle to maximise its journey with minimal lag. Battery charging factories and BSS serve as a base for the current EV battery swapping systems.

The battery swapping station consists of mechanical, structural, and electrical components. Distribution transformer, AC-DC converters, vehicle batteries, battery chargers, robotic arms, maintenance, and control systems and charging and battery racks are the key components of the battery swapping station. These components are further listed out and elaborated in Table 58.

Table 58 Key Components of a battery swapping station

Sl. No.	Component	Description
1	**Converters**	• Charging of battery packs directly from grid would require a DC step down converter. A typical AC-DC converter can be positioned in two configurations. The first configuration involves a central AC-DC converter which is directly connected to the distribution transformer which provides power to all the chargers. Second configuration involves, placing AC-DC converters locally at each point where chargers are located providing DC power. • Both the configurations are feasible but generally, the latter one is preferred because it provides the advantage of operability even if any one of the converters is not in operation state. Also, the centralised AC–DC converter will be a very large one in terms of size, weight, and cost which might raise issues during installation.

Sl. No.	Component	Description
		• In addition to the above, the swapping station would also include DC-DC converter. This is a critical component since the same is used to convert power from the high voltage (HV) bus to the Low Voltage (LV) bus to charge the LV batteries.
2	**BSS Control Room**	• The BSS control room monitors the power distribution substation. It also controls, regulates and monitors the overall functioning of the battery swapping station
3	**Charging Rack**	• The charging racks are equipped with Electric Vehicle Supply Equipment which are capable of slow and/or fast charging methods. The charging rack has slots, and each slot is capable of charging the discharged battery packs.
4	**Battery rack**	• The battery rack houses the discharged and fully charged batteries. The swapping robots take the discharged batteries from the EV to place it in discharged batteries section and replace it with the compatible fully charged batteries stored in the battery racks.
5	**Swapping Track**	• The swapping track facilitates any safety check, logistics and manual and/or automating unscrewing/ screwing of the battery of the EV
6	**Swapping Lane**	• Stationary/moving lane from the entry point to the exit point where the EV's are housed for the swapping robots to swap the batteries
7	**Swapping Robot**	• The swapping robot facilitates the removal of the discharged battery from the EV, fetching the compatible battery from the battery racks and installation of the battery pack on the EV through any battery swapping method on any swapping lane
8	**Battery/Charger Maintenance Room**	• The battery/charger maintenance room facilitates the maintenance and/or repair of the battery and/or charger as and when required
9	**BSS Maintenance Room**	• BSS maintenance room facilitates housekeeping and/or maintenance for the ideal/optimal operation of the battery swapping station as and when required
10	**Power Distribution Substation**	• Battery swapping station (BSS) is heavily dependent on the distribution grid for supply of power. BSS acts as a new high-power consumption load for the power distribution system which feeds in power to the BSS for charging of the batteries.

Source: MDPI (access here), IET (access here), Polytechnic University of Turin (access here)

5.5 Component wise costing in batteries swapping infrastructure

On the basis of few assumptions, the estimated cost of setting up a battery swapping stations for different vehicle segments is reproduced below.

The key assumptions for e-4-wheelers are:

Table 59 Key assumption for setting up a battery swapping station for e-4 wheelers

Assumptions	Unit	Value
Number of Batteries	-	100
Battery size*	kWh	14
Battery cost	₹/kWh	14,000.00

Assumptions	Unit	Value
Charger cost	₹	30,000.00
Number of chargers	-	22
Swapper cost per unit	₹ Lakhs	2.50
Number of Swappers	-	2
Other Infrastructure cost (building, air-conditioning, IT, safety, electrical connection, etc.)	-	~ (cost of chargers + swappers)

Source: SSEF, IIT Madras, WRI India

*Tata Nexon EV2

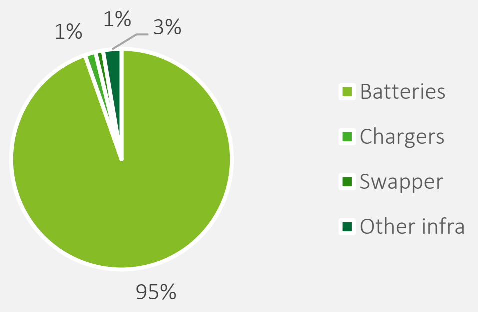
We have assumed that the battery swapping station has invested in 100 batteries, with each battery of the capacity of around 14 kWh. Each battery can be swapped 1.3 times per day. This is known as the swap factor. Thus, the swapping station will have the capacity to serve 130 (100 X 1.3) vehicles per day.

Considering a time taken for charging of 2 hours and at 50% utilization, the number of chargers installed by the battery swapping station is 22 and it has two swappers to change the degraded batteries with the fully charged batteries. Other infrastructure costs include cost of civil structure, air-conditioning system, IT systems, safety equipment, electrical equipment, etc. Based on our general understanding of the costing of battery swapping stations, we have assumed that the cost of other infrastructure would be almost equal to the cost of chargers plus the cost of swappers.

Table 60 Component wise cost of setting up battery swapping station for e-4 wheelers

Sl. No.	Components	₹ (in Lakhs)
1.	Cost of Battery	196
2.	Cost of Chargers	6.6
3.	Cost of Swappers	5.0
4.	Other Infrastructure cost	12
	Total Cost	**220**

Figure 76 Component wise cost breakup % for e-4 wheelers



Similarly, on the basis of few assumptions we have prepared an estimated cost of setting up a battery swapping stations. The key assumptions for e-2/3-wheelers are:

Table 61 Key assumption for setting up a battery swapping station for e-2/3-wheelers

Assumptions	Unit	Value
Number of Batteries	-	100
Battery size*	kWh	3
Battery cost	₹/kWh	14,000.00
Charger cost	₹	6,000.00
Number of chargers	-	27

Assumptions	Unit	Value
Other Infrastructure cost (building, air-conditioning, IT, safety, electrical connection, etc.)	-	~2 x (cost of chargers)

Source: SSEF, IIT Madras, WRI India

*Mahindra Treo

We have assumed that the battery swapping station has invested in 100 batteries, with each battery of the capacity of around 3 kWh. Each battery can be swapped 1.6 times per day. Thus, the swapping station will have the capacity to serve 160 (100 X 1.6) vehicles per day.

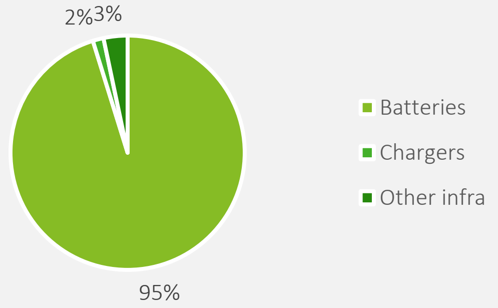
Considering a time taken for charging of 2 hours and at 50% utilization, the number of chargers installed by the battery swapping station is 27. There will be no need of automatic swappers since manual process is generally utilized for 2/3/ wheeler swapping station.

Other infrastructure costs include cost of civil structure, air-conditioning system, IT systems, safety equipment, electrical equipment, etc. Based on our general understanding of the costing of battery swapping stations for e-2/3-wheeler, we have assumed that the cost of other infrastructure would be almost twice the cost of chargers.

Table 62 Component wise cost of setting up battery swapping station for e-2/3 wheelers

Sl. No.	Components	₹ (in Lakhs)
1.	Cost of Battery	42
2.	Cost of Chargers	1.62
3.	Other Infrastructure cost	3.6
	Total Cost	**47.2**

Figure 77 Component wise cost breakup % for e-2/3 wheelers



Similarly, on the basis of few assumptions we have prepared an estimated cost of setting up a battery swapping station for e-buses. The key assumptions for e-buses are:

Table 63 Key assumption for setting up a battery swapping station for e-buses

Assumptions	Unit	Value
Number of Batteries	-	100
Battery size*	kWh	55
Battery cost	₹/kWh	14,000.00
Charger cost	₹	40,000.00
Number of chargers	-	33
Swapper Cost	₹ Lakhs	15.00
Number of Swappers		4

Assumptions	Unit	Value
Other Infrastructure cost (building, air-conditioning, IT, safety, electrical connection, etc.)	-	~ (cost of chargers + cost of swappers)

Source: SSEF, IIT Madras, WRI India

*JBM Ecolife 12 m Bus

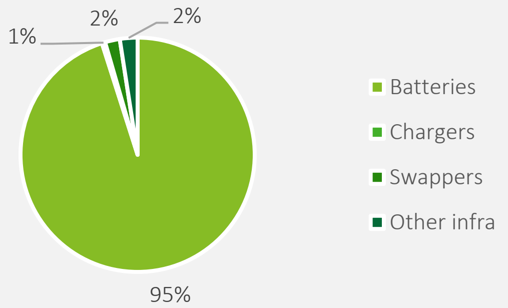
We have assumed that the battery swapping station has invested in 100 batteries, with each battery of the capacity of around 55 kWh. Each battery can be swapped 3 times per day. Thus, the swapping station will have the capacity to serve 300 (100 X 3) vehicles per day.

Considering a time taken for charging of 1.5 hours and at 50% utilization, the number of chargers installed by the battery swapping station is 33 and it has four swappers to change the degraded batteries with the fully charged batteries. Other infrastructure costs include cost of civil structure, air-conditioning system, IT systems, safety equipment, electrical equipment, etc. Based on our general understanding of the costing of battery swapping stations, we have assumed that the cost of other infrastructure would be almost equal to the cost of chargers plus the cost of swapper.

Table 64 Component wise cost of setting up battery swapping station for e-buses

Sl. No.	Components	₹ (in Lakhs)
1.	Cost of Battery	770
2.	Cost of Chargers	13.2
3.	Cost of Swappers	60
4.	Other Infrastructure cost	72
	Total Cost	**915.2**

Figure 78 Component wise cost breakup % for e-buses



5.6 Business models for battery swapping

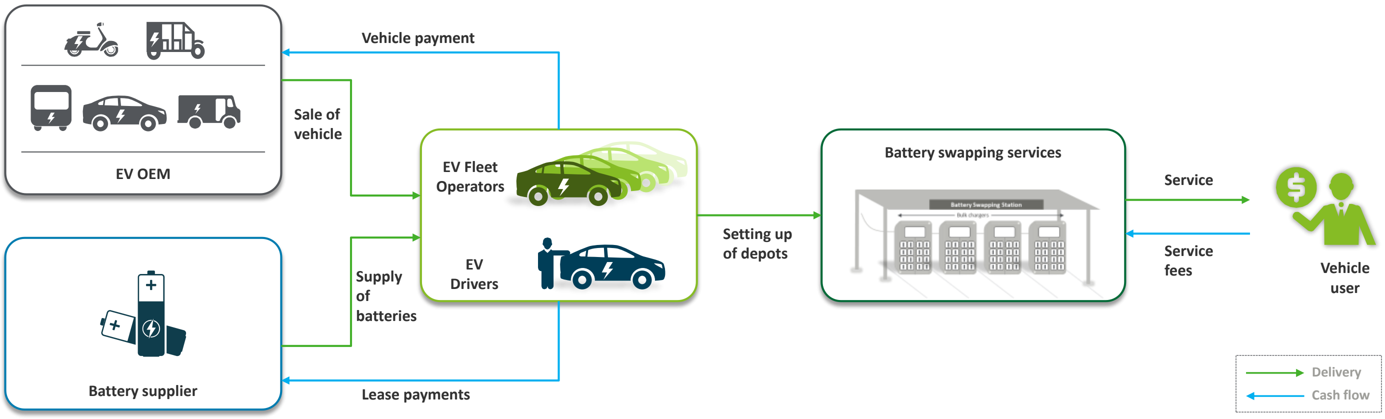
There could be various business models in which the Battery Swapping could develop as shown below in these scenarios:

1. **Fleet Operator Driven Battery Swapping Services Business Model**
2. **Battery Swapping Services Provider Driven Business Model**
3. **OEM Driven Business Model**

Fleet operator driven battery swapping services business model

In this model, fleet operators who may want to set up a 2W/3W/E-rickshaw infrastructure network drive the battery swapping business. They may either may have their own vehicles or just set up a network to cater to a host of drivers. Since fleet operators own the vehicles, they can decide on the type of vehicles and batteries. Long-term agreements are drawn between them and vehicle OEM's as well as battery suppliers since the overall volume of batteries is high considering the extensive network of such operators.

Figure 79 Fleet Operator Driven Battery Swapping Services Business Model



Fleet operators set up battery swapping services infrastructure and decide on the source of technology for swapping and the batteries as well. They also operate the battery swapping business on a day-to-day basis.

Following are the key pros and cons of such a model:

PROS

- Fleet operators have the **flexibility to decide** on source of technology and batteries
- Fleet operators can **use** the **swapping stations exclusively** for their fleet of vehicles with **no interruption**

CONS

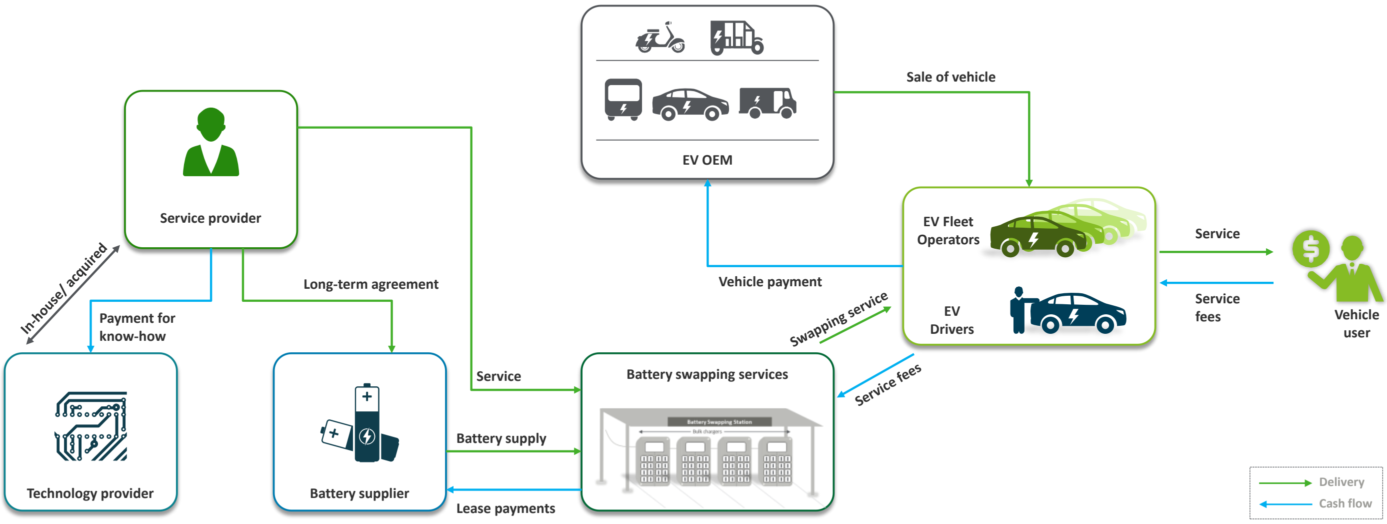
- Fleet operators have to **develop technical knowhow** of operating battery swapping stations and entering into agreements with several upstream players
- Fleet operators have to **undertake huge capital investment** in the same. Any decrease in ridership due to factors beyond control of the operator would affect the financials

Box 12: Ola Electric piloted a battery swapping station in Nagpur for its fleet of vehicles. It has established 31 battery swapping stations across 4 hubs in Delhi and Gurgaon. It is also working with power utility companies in Delhi to build a network of charging and swapping stations and provide existing and future electric vehicle users with easy access to charging. The EV Battery Swapping Stations will be set-up at mutually identified locations across East, Central, South and West Delhi, areas where BYPL and BRPL operate. Electric vehicles (two & three wheelers and E-Rickshaws) will be able to avail of these services at these stations in the initial phase.

Battery swapping services provider driven business model

This model is primarily driven by battery swapping services provider. This could be an independent entity who may want to set up a 2W/3W/e-rickshaw infrastructure network- They usually have a technology-based solution (IoT/cloud-based solution, smart chargers & smart battery). They may have their own in-house batteries or may source from a long-term supplier based on their specifications, in exchange for recurring lease payments.

Figure 80 Battery Swapping Services Provider Driven Business Model



The battery swapping services provider is responsible for the complete roll out of the business and they have full control of the operations. They may acquire swapping technology from a third-party provider, or it may be developed in-house. Battery supplier provides the batteries on lease to the swapping centres owned by the service provider. Individual EV users or fleet operators can access these swapping centres.

Following are the key pros and cons of such a model:

PROS	CONS
• **Faster adoption:** Service provider can easily scale up considering that it can leverage its technical strength in the business • **Reduced risk for fleet operators:** Provides fleet operators and normal drivers to rely entirely on the BSSP's assessment of the battery/brand and the technology. • **Provides for different players to focus on their core competencies**	• Service provider needs to **tie up with technology** providers, **battery OEMs**, etc. increasing its own **business and commercial risk** • **Standardization across vehicles** is critical to ensure service provider achieves economies of scale

There could be various variants of this model viz:

- Service provider could lease batteries from battery OEMs. In this case, there is a revenue sharing agreement between the battery swapping service provider and battery OEM. Swapping company does not invest in capex cost. This is particular adopted in the unorganized market where batteries are not standardized, and it does not make business sense to purchase the batteries upfront.
- Service provider could alternately purchase the batteries upfront from a battery OEM and then undertake swapping at the designated swapping centres / stations. This could be relevant in the organized sector where service provide deals with standardized batteries

Box 13: Sun Mobility is a battery swapping solution provider and is present across 14 cities in India. It has inked partnership with battery manufacturers, technology providers, software providers, etc. for operating its network of swapping stations. The company focuses on the shared mobility segment and deploys its energy infrastructure and swapping services to primarily service electric two-wheelers and e-buses. Sun Mobility provides battery swapping services for e-buses in collaboration with Ashok Leyland in Ahmedabad. The company purchases batteries from battery OEMs and utilizes the same in its swapping centres.

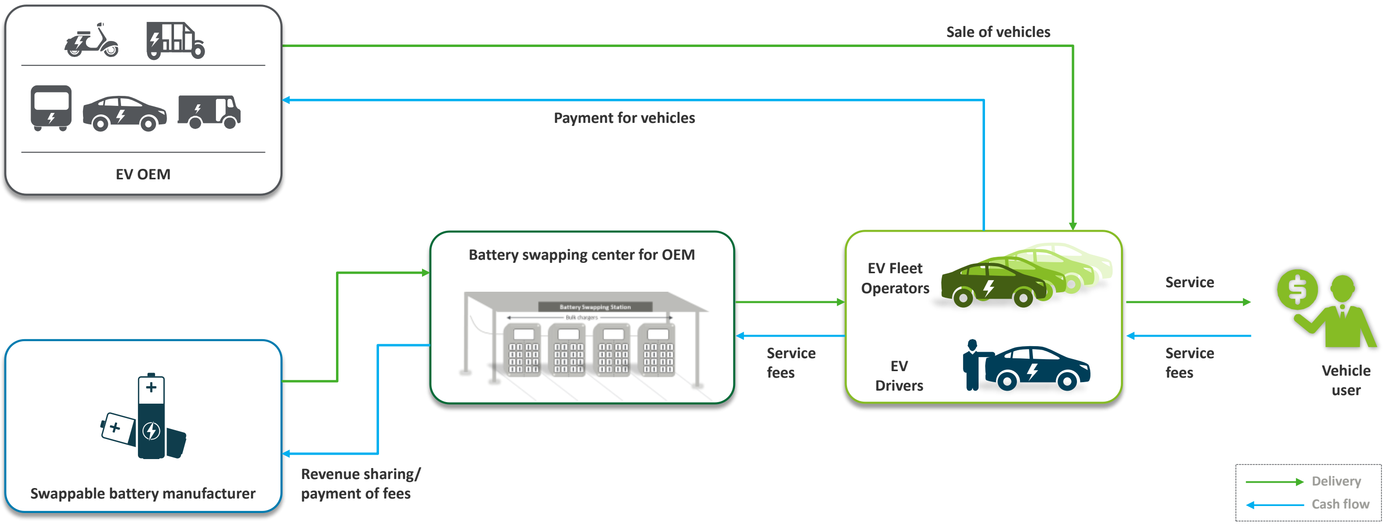
E-chargeup, another battery swapping service provider, does not purchase the batteries. It, however, has partnerships and agreements with battery OEMs for leasing of batteries through an appropriate revenue sharing mechanism.

OEM Driven Business model

This model is primarily aimed at providing a swapping infrastructure tailored to a particular OEM. In this model, a swappable battery manufacturer provides swappable battery packs customized to each OEM's specifications. The swapping service provider forms tie-ups with the vehicle OEM for providing a network of swapping points for its own vehicles.

In an improved model, the vehicle OEM can vertically integrate to manufacture battery packs. These battery packs will be customized for its own fleet. The vehicle OEM can also set-up its own swappable ecosystem / stations.

Figure 81 OEM driven business model



Following are the key pros and cons of such a model.

Box 14: Gogoro has succeeded in forming tie-ups with some of the largest 2-wheeler manufacturers in India and China for manufacturing electric scooters compatible with the Powered-by-Gogoro-Network (PBGN). In addition, Gogoro's technology, including its swappable smart batteries, will be used in scooters made by Dachangjiang Group (DCJ), one of China's biggest motorcycle makers, and Yadea, one of China's top electric two-wheel companies. DCJ and Yadea will jointly invest INR 3750 (EUR 44.5) million in an operating company to develop new two-wheel vehicles with their own branding that use the Gogoro Network, including its batteries, drivetrains, controllers and other components.

Nio (China) is a manufacturer of electric passenger cars that is working on developing a battery swapping ecosystem involving its own battery packs, vehicles, and robotic battery swapping stations (BSS).

PROS	CONS
• Provides **customized swapping network** for a particular OEM • Providers **more control and flexibility** • Swapping centre does **not have to maintain** batteries of different make and specification • Gives **competitive advantage** to the OEM as the swapping network is **customized** to it only	• Vehicles of any other OEM **cannot use** the swapping facility since the facility is customized to a select OEM only. • Requires OEM to develop **technological competence** and knowhow • May **not lead to economies of scale**

Choosing an **appropriate model** is left to the decision of the concerned player. Since it has been understood that battery swapping is technically most feasible for commercial vehicles in the 2W, 3W and 4W segment, the fleet operators may choose to set up and operate the swapping stations themselves.

However, in case they want to focus on their core competence only, they may choose to utilize the services of a battery swapping service provider. The primary element which would drive such decision is extent of control which the operator can have and its choice of choosing batteries as per its requirement. At present, lack of standardization in batteries may lead to fleet operator owned model to come up. With increasing standardization in batteries, it is expected that many more service providers will dive into this business and offer services to a large scale of users.

Moreover, in the service provider business model, importance has to be given to the state of standardization of batteries. In case of lesser prevalence of standardized batteries and where there are a lot of unorganized players in the market, service provider should not resort to upfront purchase of batteries. This is because it is not preferable to undertake high capital investment on a specific technology / make of battery. Rather a leasing model can be adopted for batteries with certain revenue sharing agreements. However, in case of higher prevalence of standardization, service providers can resort to upfront purchase of batteries from OEMs.

Key partnerships required in battery swapping business

For Battery swapping business to be successful, the provider of swapping solution needs to partner with energy providers, utility companies, transportation companies/logistics company, EV OEMS and battery manufacturing companies. Following is a brief overview of the key actors involved and the relationships among them.

Energy Providers (utility companies)

Power distribution companies have a vast network of sub-stations as well as access to end consumers. Partnering with such entities can enable swapping service providers understand the optimal locations for integration of such stations. A key element of battery swapping is to ensure charged batteries are always available. Hence, the siting of a swapping station has to take into account availability of electrical infrastructure, sufficient spare capacity in distribution lines / transformers for absorbing the charging load, etc. Partnering with utilities can enable service providers to understand optimal locations where swapping stations can be located. In addition, service providers need to adhere to mandatory requirements specified by utilities for availing grid connection for battery charging.

Power distribution utilities need to work with charging operators to apply a controlled strategy for charging and discharging of the batteries since batteries can also act as a source of grid stability. From the power system perspective, battery swapping stations can be treated as a large flexible load, fulfilling the role that would otherwise need to be filled by utility-scale battery energy storage systems. A BSS emulates an energy storage station that has the ability to absorb as well as inject power. By controlling the charging and discharging time of batteries, the potential peak demand caused by EVs during peak hours can be flattened.

Additionally, as the EV penetration increases, more customers will resort to swapping at designated locations. If such stations are placed in commercial spots, the utility may need to augment the distribution network in that area to cater to the charging load.

Additionally, if enough customers utilize battery swapping as an alternative to residential charging, upgrades to distribution lines closer to residential areas can be avoided.

EV OEMS

Swapping service providers need to tie-up with select OEMs to cater to their fleet of vehicles. For example, SUN Mobility has partnered with Piaggio to provide smart batteries, interchange stations and smart network for electric 3Ws. It has also partnered with Ashok Leyland for refuelling/swapping of its electric bus. This would ensure that service providers have long-term business certainty.

In addition to the same, a different partnership can also be explored wherein, EV OEMs need not acquire battery packs and the customers can lease battery packs from battery swapping stations who will be directly acquiring the batteries from battery manufacturers. There shall be a close collaboration for design and specifications with EV OEMs in order to ensure standardization and compatibility. In such a scenario, the cost of EVs would drastically reduce as the battery is still the major contributor to the cost of EV. Customers need to only pay a service/ subscription fees to battery swapping stations for the batteries. Hence there will be a reduction in upfront cost.

Battery manufacturers

Battery swapping stations need to stock up batteries on a regular basis to meet the demand. Instead of selling batteries to EV OEMS, battery manufacturers can sell / lease batteries to battery swapping stations' owners. This would require drawing up contractual agreements and payment terms.

Technology providers

Battery swapping service providers need to tie-up with the following:

- Swapping technology providers to gain technical knowhow of swapping technology
- Software solution providers to develop a smart network. Such systems can ensure that batteries, EV OEMs, Battery OEMs interact with each other for tracking health and status of batteries. Solutions also need to be developed for EV users to track nearby swapping stations, charge level of batteries, booking / reserving batteries for swapping, undertaking payments, real-time visualization, etc.

Fleet operators

Fleet operators represent a large market for battery swapping. Such players are typically involved in commercial operators and hence, a long-term tie-up with the same can ensure adequate utilization of swapping stations. Several battery swapping players in India and globally have undertaken such tie-ups.

All the above stakeholders thus play an important role in ensuring seamless operations of battery swapping. Several battery swapping players have entered into partnerships with these players to ensure effective business operations and exploit the strengths of one another. It is hence paramount that potential battery swapping players do a strategic evaluation of possible partnerships in this space to increase the scale and profitability of their business.

Types of payment models

As seen above, there are several business models which can be adopted. In each of the business model, the mode by which charges would be levied from users can vary. Following sections highlight two key payment modes which are prevalent across all battery swapping service providers.

Pay per use / Pay-as-you-go

In this payment model, charged batteries are provided to the users / customers. EV user pays for the energy charges corresponding to the battery capacity which is used for running. This model does not assume a fixed monthly or annual fee, instead with pay-per-use model a customer makes a single purchase at a fixed price based on usage.

In this model, a critical component is to measure the energy consumed by the vehicle. This is possible because the batteries could be IoT-enabled, and a cloud-based network can measure the energy consumption by the user. For instance, drivers can access mobile applications to load the vehicle wallet with credits. The Driver app connects to vehicle battery pack via a smart platform / Bluetooth to display parameters like the state of charge, distance to empty, nearest swapping station location, vehicle payment transactions, etc. Using the available credits, the driver can reserve a battery and make a swap transaction at the station.

PROS

- Individual drivers prefer to pay as per their usage, owing to the **lack of a fixed usage pattern** of their vehicles
- Advantageous for **cost conscious user** in the 2-wheeler and 3-wheelers sector since such riders generally do not prefer driving for longer distances and do not need many battery swaps

CONS

- **Increased unpredictability** for users and swap station operators as maintenance, roadside assistance, and service expenses are not included
- Swap station operators will charge **higher rates per charge** for pay-per-use compared to subscription-based models

Box 15: Case study: SUN Mobility Pay-as-you-go model

Sun Mobility's pay-as-you-go battery as a service system uses a digital platform built on Microsoft Azure. It enables the customers to replace the batteries of their e-vehicles at the swapping stations – similar to refueling at a petrol station. They can also use an app, which connects with their EV's battery and gives them real-time information on their battery's performance and the nearest swap station.

The batteries as well as swap stations are connected to the cloud using Microsoft Azure and built-in solutions like Azure IoT Hub, Azure Data Factory, CosmosDB, Azure Databricks, among others, that transmit battery performance telemetrics back to SUN Mobility, thereby enhancing their services.

Battery-as-a-service (subscription model)

In this payment model, Batteries are charged fully by the Swapping service provider. An EV user signs up for a battery rental plan in which it pays monthly fees in return for access to a battery swapping on regular basis. In an electric vehicle battery swapping subscription service, a consumer can subscribe for one or more battery swapping. Monthly fees may also include roadside assistance and maintenance apart from battery charging costs.

PROS

- **Maintenance, roadside assistance**, and service expenses of the battery are included within the subscription
- **Subscriptions** may include **additional offers of** flexible battery upgrade options and assurance of battery performance
- Requires only a **one-time payment** from the user

CONS

- Might be **uneconomical** for users that resort to charging of batteries at home
- Customers are locked into the BSS operator's ecosystem, even if competing charging options from other service providers might be available

The similarity for both the payment models is in terms of the the lease payment made by the customers for the batteries. These payments ensure that the battery swapping operator receives the payments for covering the capital expenditure incurred in procuring batteries.

Box 16: Battery-as-a-service – Case studies

Case study 1: Better place company, California

***Better Place** company, based in California, had started battery swapping stations and network for charging stations in 2008 in various countries viz. US, Japan, Netherlands, Australia, etc. They implemented a model where in customers entered into subscription to purchase driving distance similar to mobile telephone industry from which customers contract for minutes of airtime. The payments by consumers covered the electric "fuel" costs including battery, daily charging, battery swaps as well as profits and cost of capital.*

The model relied on a smart grid software platform to shift the recharging time of batteries during off peak hours. The actual time for battery switching took around 3-5 minutes in these stations through a fully automated process

Case study 2: E-chargeup Solutions subscription based model

In December 2019, E-ChargeUp Solutions set up two electric three-wheeler battery swapping stations at Noida. These swap stations serve more than 50 registered EVs, which ply over 7,500 km per day under their offered subscription plans. Furthermore, the company has plans to open 500 more battery swap stations across the country in order to support over 50,000 EVs. Also, the company is targeting 1.7 million e-rickshaws through this model in coming years, where it will offer battery swapping and related services to the vehicle owners

The service provider charges Rs 220 for a single swap in a 12-hour period, and Rs 400 for unlimited charges or battery swaps for the same e-rickshaw in a 24-hour period.

Competitive pressures and strive for differentiation in services will drive the appropriate payment models which service providers would adopt. For a consumer who does not want to get into regular payment cycles, a subscription-based model can be adopted. However, a pay-as-you-go model involves more consumer interaction with the battery set-up and transparency in his consumption. Hence, different players around the world have resorted to various innovative payment models as per their priorities and consumer behaviours.

5.7 Key battery swapping players

There are various swapping solution providers in India, some in the form of startups, and some which are new arms of existing businesses. To have a better understanding of the same, we have segregated them into Indian and global companies. Some of the notable players are mentioned in following section.

Detailed business overview of Indian battery swapping players

Sun Mobility

Sun Mobility is a joint venture between Maini Group and SUN Group. It is the most prominent player in India's battery swapping space and caters to electric two-wheelers and electric three-wheelers. In Sep 2020, Bosch acquired 26% stake in the firm[97].

Through its open-architecture Energy Infrastructure Solution, which includes Smart Batteries that can be swapped at Quick Interchange Stations powered by its Smart Network, it is enabling EVs for mass adoption, especially in shared mobility segments. The company focuses on shared mobility segment and has partnered with various OEMs and third parties to deploy its energy infrastructure and swapping services.

The company offers battery swapping station that works on a pay-as-you-go model. These stations are interconnected, and some are powered by renewable energy and tracked by a Smart Network. The stations are offered for two-wheelers and three-wheelers, which include ebikes, electric autos, and e-rickshaws. Furthermore, it enables the vehicles for a fast swap in around one minute.

[97] Source: Economic Times (click here)

Table 65 Business overview of SUN Mobility

Company – SUN Mobility	
Location / presence	• Operational in 14 Indian cities
Present capacity (number of swapping stations)	• 65
Swapping offerings	
Vehicle segments catered to	- 2W - 3W - Shared mobility
Key strategic moves and partnerships	
India	• Aggressive expansion into e-2W and e-3W segment in the country • Bosch, a leading provider of technology and services in the mobility ecosystem globally, acquired a 26% in SUN Mobility, through its investment vehicle Robert Bosch Investment Nederland B.V. This investment will allow SUN Mobility to continue to develop and deploy its market leading battery swapping solutions across India and make in-roads at a global level. • Partnering with power distribution companies, OMCs for increasing access to consumers at lesser costs. • Entered into a strategic alliance with Ashok Leyland, flagship of the Hinduja Group. The objective is to make inroads into battery swapping for e-buses. • In 2019, launched e-buses in Ahmedabad with automatic swap station equipped with robotic arm. The smart swappable batteries weigh at 600 kgs to improve efficiency and free up space for more passengers. The quick interchange station just takes under 2.5 mins for swapping batteries for e-bus. The QIS station for e-bus can carry out 300 swaps per day. • In 2020, launched its swapping operations in Chandigarh and Bengaluru
Tie-ups and partnerships	**Vehicle manufacturers:** • Partnered with Piaggio to provide smart batteries, interchange stations and smart network for electric 3Ws • Partnered with Ashok Leyland for refueling/swapping" of its electric bus in under 4 minutes **Service provider:** • SUN Mobility's Smart Network uses Microsoft's technology to connect the Sun Mobility Smart Batterytm And Sun Mobility Quick Interchange Station (Qis) with end users through a mobile application. **Fleet operator:** • Partnered with SmartE, Zypp electric & Uber to provide swappable batteries for 2W, 3W. The fleet of electric two & three-wheelers make use of SUN Mobility's solution • Partnered with Zyngo's fleet of e-loaders to utilize swapping services at IOCL retail outlets in Gurugram, Delhi, Noida and Ghaziabad
Future Plans	• To power 1 Mn EVs by 2025 • To set up 100 EV battery swap stations across Bengaluru by end of 2021 • To cater to 500 e-loaders by end of 2021 in Delhi - NCR

Source: Sun Mobility Website

Battery Smart

Battery Smart operates a network of over 160+ battery swapping stations providing Li-ion batteries on a pay-per-use basis for the drivers of electric two and three-wheelers through an asset-light network of partner swap stations. Battery Smart's battery-as-a-service model enables interoperable battery swapping for electric vehicles in under two minutes. With over 160 swap stations operational in the Delhi-NCR region, the company has completed 3 lakh battery swaps and powered 10 million emission-free km to date by servicing more than 1200 active e-rickshaws. It undertakes ~5000 swaps per day.

Table 66 Business overview of Battery Smart

Company - Battery Smart	
Location / presence	• Presently in and around Delhi NCR
Present capacity (number of swapping stations)	• 160+
Swapping offerings	
Vehicle segments catered to	• Electric three-wheelers • Electric two-wheelers
Key strategic moves and partnerships	
India	• The IoT-enabled batteries on its network and the data generated are being utilized for network planning and ensuring EV users have access to two-minute swaps within a 1km radius with zero wait time.
Tie-ups and partnerships	• Grip Invest, a digital platform for facilitating new-age investments signed an INR 150 (EUR 1.78) million lease financing deal with Battery Smart for electric vehicles. Through this deal, Grip Invest plans to lease 4,000 batteries for e-rickshaws, enabling the battery network provider to leverage an asset-light business model and save operational costs
Future Plans	• The company has plans to tie-up with major OEMs of four-wheelers for e4W swapping business • The company plans on scaling its operation to serve 10,000 electric vehicles daily and expanding to three new states by end of 2022.

Source: Battery Smart Website

Lithion Power

Lithion Power is a **start-up** focusing on "Battery as a service" operation and provides lithium-ion batteries for e-bikes and 3 wheelers. It has a network of Lithion Swapping Points (LSP) predominantly in Delhi NCR. At present it has ~10 swapping stations in Delhi NCR and plans to enter into few more cities in the future.

The company has developed battery management systems, telemetry units, etc. to continuously send data to a server/cloud on 24 x 7 basis, irrespective of whether the vehicle is running on the ground, or if it is parked. So, we get data 24 x 7 about what is the state of affairs of the battery, and we do this on the daily basis. The BMS also has a GSM and GPS module to track the location of batteries.

Table 67 Business overview of Lithion Power

Company – Lithion Power	
Location / presence	• Presently in and around Delhi NCR
Present capacity (number of swapping stations)	• ~10
Swapping offerings	
Vehicle segments catered to	• Low- to medium- power commercial vehicles such as e-rickshaws and bikes • Shared mobility
Key strategic moves and partnerships	
India	• More focused on B2B and not on B2C

Company – Lithion Power	
	• Developed in-house BMS for e-bikes and e-3Ws.
Tie-ups and partnerships	• Partnering with e-commerce platforms for last-mile deliveries
Future Plans	• Expand operations to multiple tier II and III cities • Plans to invest around $1billion along with its partners to create battery swapping solutions on daily lease or rental.

Source: Lithion Power Website

Amara Raja Power Systems Ltd.

Amara Raja Power Systems Ltd. is part of the Amara Raja group. The company is offering battery swapping station for on-the-go charging solution for 2 and 3-wheeler EVs, with swapping time under 2 minutes. The company claims that it provides smart and efficient charging which ensures good health and longer life of batteries. The swapping stations comes with touch screen, RFID authentication and digital payment which would provide hassle free operation to the customers.

The swapping stations are available in 20, 12, 8 and 4 channel variants. The battery slots are provided with rollers for smooth movement of Batteries (Rack in/Out). The swapping stations provide charging for battery ratings from 1.5kWHr to 3kWHr, with charging rates ranging from 0.5 to 2C. the swapping stations are for both outdoor and indoor operations.

Table 68 Business overview of Amara Raja

Company – Amara Raja	
Location / presence	• Andhra Pradesh
Present capacity (number of swapping stations)	• NA
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• Amara Raja has launched EV battery swapping stations and e-Autos fleet in Tirupati • Amara Raja has developed the lithium-ion battery packs and EV swapping stations in its own state-of-art R&D facility.
Tie-ups and partnerships	• E-auto fleet and EV battery swapping stations initiative has been launched in collaboration with Tirupati Municipal Corporation, as a part of its smart city program.
Future Plans	• It has added lithium-ion battery pack manufacturing facility of 500MWH capacity at its Tirupati manufacturing unit. • Amara Raja plants to offer lithium-ion battery packs and charging/ swapping stations for fleet operation as an end-to-end package to its customers

Source: Amara Raja Website

VoltUp

VoltUp is a start-up which provides lithium-ion battery swapping solutions for two-wheelers and three-wheelers EVs. VoltUp through its smart swapping network is deploying a network of connected VoltUp stations with smart batteries and building mobile technologies, hardware and leveraging data to enable an innovative mobility solution to transform commute by e-vehicles. It claims that its batteries are not only cheaper but also, are made in the highest quality energy density making it more efficient for longer duration than common Li-ion batteries and Lead acid batteries.

Table 69 Business overview of VoltUp

Company – VoltUp	
Location / presence	• Mumbai, Maharashtra
Present capacity (number of swapping stations)	• 6 battery swapping stations in Jaipur and 3 battery swapping stations in Kolkata
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• VoltUp works on a pay-as-you-go business model, where customers have to pay initial subscription fees and then pay as per usage. There are no swap limits or any other charges. • The company is committed to taking care of the battery maintenance and servicing over the entire life of the battery.
Tie-ups and partnerships	• VoltUp has partnered with HPCL to set up 50 battery swapping centres across India.

Source: VoltUp Website

ESmito

ESmito is a startup up founded in 2018 which provides SaaS & IoT enabled battery management products and solutions for electric vehicles. It offers hardware and software-enabled solutions for clients. It offers services like charging solutions, fleet management, battery swapping solutions & more with features like data analytics and reporting, automated payments management, battery health predictions, etc.

Table 70 Business overview of Esmito

Company – Esmito	
Location / presence	• Chennai, Tamil Nadu
Present capacity (number of swapping stations)	• NA
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• Esmito is among the top battery swapping companies that provide swapping solutions by its IoT enabled cloud-based software integrated battery swapping technology. • They are working towards setting up more common standards in the automobile industry. • Esmito Solutions has been awarded the “Enterprise Mobility Management Solution of the Year” at the 5th ISV Virtual Summit & Awards 2020.
Tie-ups and partnerships	• Esmito is housed at IIT Madras Research Park.

Source: ESmito Website

Numocity

Numocity is a Bangalore-based start-up with experience in delivering solutions in the e-Mobility market globally. Their digital technology platform is designed and built for scale and flexibility in the emerging e-Mobility industry. Numocity offers comprehensive end to end digital technology platform for EV charging Battery swapping and Smart Grid integration.

Table 71 Business overview of Numocity

Company – Numocity	
Location / presence	• Bangalore, Karnataka
Present capacity (number of swapping stations)	• NA
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• Numocity is creating a smart and scalable energy delivery ecosystem for EVs across the world. • It mainly offers fixed charging infrastructure, battery swap management, and actionable intelligence for fleet management for the electric mobility infrastructure.
Tie-ups and partnerships	• Numocity has collaborated with Wipro to provide innovative solutions across the value chain. • Rebright Partners, Ideaspring Capital and ABB Technology Ventures are key investors in the company.

Source: Numocity Website

Charge-up

Charge-up is a New Delhi based start-up founded in 2019. It offers battery swapping model called 'Battery-as-Service (BAAS)' to e-rickshaws. The company follows a subscription-based model wherein drivers sign up for a battery rental plan, minus any upfront costs.

Table 72 Business overview of Charge-up

Company - Charge-up	
Location/ presence	• New Delhi
Present capacity (number of swapping stations)	• 18
Swapping offerings	
Vehicle segments catered to	• E-rickshaws and e-loaders
Key strategic moves and partnerships	
India	• Charge-up is rapidly expanding its battery swapping system network and aims to target the e-rickshaws, e-2/3 wheelers and other LCVs segment.
Tie-ups and partnerships	• It has announced raising an undisclosed amount in a Pre-Series A funding. The funding round was led by MapmyIndia with participation from a group of High Net worth Individuals (HNIs). • Chare-up plans to use the investment in marketing for customer acquisition and building the tech stack.
Future Plans	• Charge-up has stared operations primarily with e-rickshaws and e-loaders in Delhi and plans to expand the coverage to all categories of electric 2 & 3 wheelers across India. • Charge-up plans to install 3000 EV battery swapping stations by 2024 and aims for 1 station every 2 km in Delhi.

Source: Sun Mobility Website

Source: Charge-up Website

RACEnergy

RACEnergy is an electric vehicle-based start-up from Hyderabad established in 2018. Its vision is to accelerate the adoption of electric mobility in India by focusing on public transportation, specifically the two-wheeler and three-wheeler segment. Its unique battery swapping stations and swappable batteries are provided as a service through a network of swapping stations.

Table 73 Business overview of RACEnergy

Company - RACEnergy	
Location / presence	• Hyderabad, Telangana
Present capacity (number of swapping stations)	• NA
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• RACEnergy has a business strategy for creating the demand for swapping solutions by retrofitting ICE 2 wheelers into electric. • It is also working with multiple OEMs to bring out electric 3Ws on its proprietary swapping platform. • RACEnergy also claims to be developing a unique electric powertrain for three-wheelers.
Tie-ups and partnerships	• New & Renewable Energy Development Corporation of Andhra Pradesh (NREDCAP) and RACEnergy has setup battery swapping stations in Tirupati to pilot five retrofitted electric autos. • It has raised a seed round of USD 1.3 million led by Micelio Fund and GrowX ventures, along with investments from Huddle, Prophetic Ventures, BITSian Angels, among others. • The funds are planned to be used to enhance R&D, scale the company's swapping technology and infrastructure, and fulfil the pre-orders received in Hyderabad and surrounding tier-II cities
Future Plans	• RACEnergy had showcased its first prototype in 2019 and aims to set-up India's largest network of battery swapping infrastructure across various cities, starting with Hyderabad.

Source: RACEnergy Website

Charge+Zone

Charge+Zone is a start-up based in Vadodara and founded in 2018. The company provides a hassle free and reliable charging services for all types of Electrical Vehicles (EVs). They are part of TecSo Global group which is a leader in Renewable Energy Solutions, Product Development and Software Engineering.

Table 74 Business overview of Charge Zone

Company – Charge+Zone	
Location / presence	• Vadodara, Gujarat
Present capacity (number of swapping stations)	• 31+
Swapping offerings	
Vehicle segments catered to	• 2 and 3-wheeeler EVs
Key strategic moves and partnerships	

Company – Charge+Zone	
India	• Charge zone has been a major player in EV charging business and has recently stepped into the battery swapping business. • 31 charging stations established by OLA Electric across 4 hubs in Delhi and Gurgaon have been acquired by Charge Zone.
Tie-ups and partnerships	• Charge Zone has raised funding of USD 3 million in a pre-series A round led by Venture Catalysts. It had also raised an undisclosed amount from Mumbai Angels previously.
Future Plans	• Aims to deliver battery swaps/ charging services to 1000+ e-rickshaws and e-autos in Delhi NCR across 25 micro hubs.

Source: Charge+Zone Website

Okaya

Okaya is a pioneer in the battery manufacturing industry. It is known for providing a wide range of batteries solutions like Tubular Battery- Inverter Battery and Solar Battery, SMF Battery, E-Rickshaw Battery, Lithium and EV charging solutions. It is providing smart battery swapping stations solutions other than solutions such as EV li-ion batteries, EV charging solutions, etc. The battery swapping solution is a charging cabinet which has 12 rechargeable cubicles.

Table 75 Business overview of Okaya Power

Company – Okaya Power	
Location / presence	New Delhi
Present capacity (number of swapping stations)	-
Swapping offerings	
Vehicle segments catered to	- Cargo vehicles, and 2 and 3-wheeeler EVs
Key strategic moves and partnerships	
India	• Okaya has entered into the Electric Mobility space by offering solutions from Electric Vehicles and Electric Vehicle Batteries to EV Charging and Battery Swapping solutions.
Tie-ups and partnerships	• Okaya Power has announced that is has become a core member of the Charging Interface Initiative (CharIN E.V.), an open coalition of world-class firms within the electric vehicle (EV) industry. The move is aimed at supporting the Combined Charging System (CCS) as a global standard for EV charging with aim to enhance charging experience and promote electric mobility in the country. • Okaya Power and Prakriti E-mobility plan to collaborate on EV Charging Stations. However, the collaboration doesn't include setting up battery swapping stations.
Future Plans	• Initial plan is to install more than 300 swapping stations in India.

Source: Okaya Website

Detailed business overview of Global battery swapping players

Some of the key global players in this business are highlighted below:

Gogoro

Gogoro is the largest scooter company in Taiwan. It allows users to buy scooters without a battery, making the initial purchase cheaper. Today, Gogoro is recognised as a global leader in lightweight electric vehicle battery swapping. The Gogoro Network is a sustainable smart city battery swapping ecosystem that provides vehicles makers, riders and cities with a cleaner, faster and superior electric refuelling solution.

Gogoro has differentiated itself from the competition through its early and compelling vision for light EV battery swapping. It offers an extensive product portfolio across the battery swapping supply chain, a strong track record on quality and performance in its product line, and an unmatched partner network highlighted by several of the world's largest two-wheeler OEMs.

Table 76 Business overview of Gogoro

Company – Gogoro	
Location / presence	• Taiwan
Present capacity (number of swapping stations)	• -2100+
Swapping offerings	
Vehicle segments catered to	• E-2-wheelers
Key strategic moves and partnerships	
Global	• Gogoro will go public on Nasdaq after a USD 2.35 billion SPAC deal[98] with Poema Global that is expected to close in the first quarter of 2022.[99]
India	• Gogoro has entered into a deal with Hero MotoCorp, the market leader for two-wheeled vehicles in India.
Tie-ups and partnerships	• Has a collaboration with China's two largest 2-wheeler makers- Dachangjiang Group and Yadea. • Gogoro is also known for its own range of high-end two-wheel scooters but has made deals with other manufacturers to produce vehicles that use its batteries and charging stations, including Yamaha, Suzuki and AeonMotor. • It has announced a partnership with Gojek to enter the Indonesian market.
Future Plans	• Plan to enter new market such as India and Israel.

Source: Gogoro Website

Ample

Ample is a San Francisco based start-up focused on electric vehicle battery swapping. Ample's mission is to accelerate the transition to electric mobility by offering an energy delivery solution that is as fast, as convenient, and as cheap as gas while being powered by 100% renewable energy. Ample operates automated swapping stations and claims that it can replace a depleted battery with a fully charged one in less than 10 minutes.

Table 77 Business overview of Ample

Company – Ample	
Location / presence	• San Francisco, USA
Present capacity (number of swapping stations)	• -
Swapping offerings	
Vehicle segments catered to	• E-4-wheelers
Key strategic moves and partnerships	
Global	• Ample's technology has two main components- (a) fully autonomous swapping station that removes depleted battery modules from the car and replaces them with fully charged ones. Ample's stations require

[98] SPAC deal: A deal which involves a special purpose acquisition company. SPAC is a company which has no commercial operations and is formed strictly for the purpose of acquiring or merging with an existing company or for raising capital through Initial Public Offering
[99] Source Reuters (click here)

Company – Ample	
	no construction and can be assembled wherever two parking spots are available. This makes them a convenient solution for a diversity of locations including grocery stores, gas stations and highway rest stops. (b) A modular battery architecture that allows for any EV to use Ample's stations. Its batteries are made out of lego-like modules that can accommodate any vehicle regardless of size or model. • Ample is currently being deployed regionally in the Bay Area, where they are actively working with a wide range of ridesharing, last-mile delivery, and municipal fleet partners.
Tie-ups and partnerships	• Ample has hit unicorn status with new funding of INR 3760.11 (EUR 44.6) million. • Ample also received a funding of INR 12032.4 (EUR 142.65) million round in August 2021. • Global energy companies such as Royal Dutch Shell, Repsol and Eneos and Banco Santander are the key investors in Ample. • Ample has partnered with ride services company Uber, offering battery swapping services initially to Uber drivers in California • Ample is also entering the Japanese market in partnership with Eneos.[100]
Future Plans	• Actively working with a number of the world's largest automakers to enable mass deployment in the US, Europe, and Asia. • Ample and Uber have agreed to extend their partnership to Europe, where Uber aims to electrify half the rides that are booked across seven European capitals viz. London, Amsterdam, Brussels, Berlin, Paris, Madrid and Lisbon by 2025.

Source: Ample Website

NIO

NIO is a Chinese multinational automobile manufacturer and specializes in designing and developing EVs. NIO Power is the subsidiary that operates the battery swapping stations. NIO Power provides mobile internet-based power solution with extensive networks for battery charging and battery swap facilities. Enhanced by Power Cloud, it offers a power service system with chargeable, swappable and upgradable batteries to provide users with power services catering to all scenarios.

Table 78: Business overview of NIO

Company – NIO	
Location / presence	• Shanghai, China
Present capacity (number of swapping stations)	• 301+
Swapping offerings	
Vehicle segments catered to	• E-4-wheelers
Key strategic moves and partnerships	
Global	• Nio's charging and swapping system and BaaS (Battery-as-a-Service) is being made fully available to the industry. • NIO's first station was opened in 2018. It took a few years to get into the first million swaps in October 2020, and the second million in March 2021, but now it accelerated and on September 29, 2021, NIO users have completed over 4,000,000 battery swaps.
Tie-ups and partnerships	• Nio Inc. has entered into a partnership with China Petroleum & Chemical Corporation or Sinopec, on setting up battery swap stations at Sinopec's gas filling stations.

[100] Source: Ample (click here)

Company – NIO	
Future Plans	• NIO plans further expand NIO Power's charging and swapping network. Company has raised its target of having over 700 battery swap stations installed by end 2021. • From 2022 to 2025, it will install 600 new battery swap stations in China. • By the end of 2025, the company will have more than 4,000 battery swap stations worldwide with around 1,000 outside of China. Meanwhile, NIO also plans to set up battery swapping station in Norway.

Source: NIO Website

5.8 Overview of battery swapping station in India

Battery Smart and Charge+Zone – Primary Survey

Visits were undertaken to battery swapping stations of **Battery Smart** and **Charge+Zone** in Gurgaon, Haryana. The objective of such visit was to understand the overall ground operation of swapping stations, charging methods, operational practices and high-level cost economics.

Following are the key findings from the visits:

Key findings from the primary visits - Battery Smart and Charge+Zone stations

- The swapping station has following payment models viz.
  - INR 200 (EUR 2.37) daily fee for a maximum of three swaps, or
  - Monthly subscription fee of INR 4500 (EUR 53.35) with option for maximum 3 swaps per day, or
  - Monthly subscription fee of INR 3500 (EUR 41.5) with option for maximum 2 swaps per day
  - Some outlets also have weekly and fortnightly subscription plans. In addition to the above, one-time security deposit fee of INR 5000 (EUR 59.27) is collected from each customer during onboarding out of which INR 3000 (EUR 35.57) is refundable and INR 2000 (EUR 23.71) is meant for maintenance of batteries and associated infrastructure.

- The swapping centers usually serves e-3W as well as a few e-2W. The customers drop off their discharged batteries and then collect the charged batteries from the exchange point in the center. In Battery smart swapping station, the Battery smart app would notify the EV driver when battery charge falls below (20%).

Battery Smart swapping station		
Overview	**Discharged batteries from customers**	**Batteries being charged**
		

  - In Battery Smart stations, customers were allowed to check the charge of individual batteries before swapping. Once verified, the operator in the battery swapping center enters the customer's credentials in the app and scan the QR codes present on the batteries. This helps the battery swapping center to track which batteries are collected by the customer.

Key findings from the primary visits - Battery Smart and Charge+Zone stations

- In Charge+Zone station, the customers could not manually verify the charge of batteries, but the charging status of each battery was visible in the bulk charger. Hence, the operators only gave those batteries which were completely charged.

- Batteries are also connected to an intelligent IOT enabled platform for the company to monitor the battery health, location, etc.
- The Battery smart swapping station has batteries of three companies in stock viz. Lohum, Greenfuel, and Liveguard. Similar such batteries were present in Charge+Zone stations.
- Following were the battery and charger specifications:
  - Battery
    - Voltage: 51.8 V
    - Capacity: 40 AH
    - Charge and discharge current: 0.5 C
  - Charger: 1 kW
- In Battery Smart station, the swapping station had the capacity to charge 50 batteries at once. They used a fast charger to charge the batteries, which took roughly 100-120 mins to completely charge the batteries. One fast charger was dedicated to charge one battery at a time.
- The input for charging was through the 415-volt distribution line of the power distribution utility. Charging racks were placed in parallel to each other for charging.

Charge+Zone Bulk charger

- Charge+Zone used the bulk chargers manufactured by Exicom. It had 6 such bulk chargers and each bulk charger was capable of charging twenty batteries at once. 3 out of 6 bulk chargers were operational at the time of the visit.
- A battery needs 1.5 units to be fully charged. The e3W uses two batteries at a time and its driving range was ~70-80 kms post which the driver needs to swap the batteries again. Hence, an e3W consumers ~3 units in for its full range ride.

High-level economics of Battery Smart swapping station

1

To understand high-level cost economics of the Battery Smart swapping station, we consider two cases:

- One where user **pays monthly subscription** fees of INR 4500 (EUR 53.35)
- Secondly, where the **user pays daily charge** of INR 200 (EUR 2.37) for 3 swaps per day.

(In each of the above, the user will get 6 batteries from the swap station every day)

2

On an average day, ~100 rickshaws arrive for swapping. Consider a rickshaw needs 3 swaps in a day, it works out to ~33 distinct EV users.

3

- In a case of **daily payment**, if everyone pays INR 200 (EUR 2.37) per day, the total revenue per day for the stations comes out to be ~ INR 6,600 (78.25).
  - **Total monthly revenue is ~ INR 2,00,000 (EUR 2371.15)**
- In a case of **monthly subscription**, the daily payment is INR 4500/30 = INR 150 (EUR 1.78) per day, the total revenue per day for the stations comes out to be ~ INR 4,850 (EUR 57.50).

– **Total monthly revenue is ~ INR 1,50,000 (EUR 1778.37)**

4

It takes 1.5 units to charge a battery. Each e3W needs two batteries and ~100 rickshaws arrive for swapping and hence, entire energy consumed by the station per day is ~ 300 units. At ~ INR 8 / kWh, the **energy cost** works out to be **~ INR 2,400 (EUR 28.45) for a day** and **INR 72,000 (EUR 853.62) per month**.

5

The swapping station has 2-3 employees for manual operations and salaries for them total to INR 40000 (EUR 474.23) (daily rate of INR 1300(EUR 15.41)). **Rental cost of the swapping stations is ~INR 30000 (EUR 355.67)**

6

Taking the above into account, following is the high-level economics of the swapping station considering only the day-to-day operational expenses. Detailed financial analysis for swapping business will be carried out in WP 2:

Unit: INR	Case 1: Daily fee payment	Case 2: Monthly subscription
No of battery swaps per day (a)	~100	~100
Swaps per vehicle (b)	3	3
No of vehicles (c)=(a)/(b)	~33	~33
Revenue per vehicle (Rs) (d)	200	150
Total revenue per month (Rs) (e)=(c) *(d)*30	**~ 2,00,000**	**~ 1,50,000**
Energy consumed by a vehicle in one trip (kWh) (f)	3	3
Energy consumed by station per day (kWh) (g) =(f)*(a)	300	300
Energy cost (Rs / kWh) (h)	8	8
Total energy cost per month (Rs) (i) = (g)*(h)*30	72,000	72,000
Manpower cost per month (Rs) (j)	40,000	40,000
Rental cost per month (Rs) (k)	30,000	30,000
Total costs per month (Rs) (l) = (i) +(j)+(k)	**1,42,000**	**1,42,000**
Approx. Margin per month (Rs) (m) = (e)-(l)	**~58,000**	**~8000**

7

It is important to note here that:

- All drivers would not resort to daily fees or monthly subscription plan. The station sees a mix of daily, weekly, fortnightly and monthly plans
- Not all drivers will use full 3 swaps per day. A driver may use only 2 swaps per day even though he is subjected to daily fee of INR 200 (EUR 2.37) (which entitles him for 3 swaps) or subscription-based fee of INR 150 (EUR 1.77) per day (which entitles him for 3 swaps). In such a case, the number of battery swaps remain constant but number of vehicles visiting the station and revenue per day increases

8

It is hence understood that the net margin per month will vary between INR 8,000 – 58,000

5.9 Licensing or registration requirements for operating batteries swapping infrastructure

Based on interaction with industry players, there is no special permission or licensing/registration requirement for battery swapping stations in India. Ministry of Power vide its notification (No. 23/08/2018-R&R) dated 13th April 2018 has provided clarification on charging infrastructure for electric vehicles. The notification stipulates that charging of battery of an electric vehicle by a charging station will not be considered as sale of electricity but a service where charging station consumes electricity and earns revenue from the owners of electric vehicles. Therefore, charging of batteries through charging stations does not require license under the provisions of the Electricity Act, 2003.

However, the battery swapping player has to evaluate and adhere to following requirements for setting up of battery swapping stations:

a. Requirements related to grid connectivity

The BSS operator needs to apply for connectivity/ new connection with the concerned state power distribution licensee/ company. He is required to download the “request for new connection LT/HT” form from the Discom’s website or collect it physically from the Discom office. The documents required consist of identity proof of applicant (with authorization letter in case of firm/company) and proof of ownership/ occupancy of the premise as per the layout plan. Discom will conduct technical feasibility study for providing the connection.

The cost of extension of distribution mains and extension/upgradation of the system up to the point of supply for meeting demand will be paid by the BSS operator. In case the connected / contracted load of any new connection is projected such that, it requires a separate transformer then the BSS operator will bear the cost of transformer. Moreover, land/room required for housing the transformer substation, switch gears, meters and panels shall be provided by the Discom, for which rent, or premium is to be paid by the BSS operator himself. Finally, an agreement, in the standard format, is executed between the applicant and Discom.

b. Requirements related to land acquisition

If the EV charging/ swapping station is being set up on a leased land from an individual or a private entity, an NOC from the landowner may be required by applying for connectivity to the Discom for installing EV tariff meter.

In case the land is owned by municipal body/ corporation, a permission certificate/NOC from the commissioner or any other competent authority for installation & operation of battery swapping stations may be required.

c. Requirement of communication network

The swapping station providers are required tie up with at least one online Network Service Provider to enable advance remote/online booking of charging slots by EV owners. Such online information to EV owners should also include information regarding location, types, and numbers of bulk chargers available, service charges for battery swapping etc. They are also required to share charging station data with the appropriate DISCOM and adhere to protocols as prescribed by CEA for this purpose.

d. Provision related to Open Access

Through open access, a consumer can purchase power directly from a generating company through the intra-state transmission system or distribution system. Each state has its separate procedure for granting open access to entities, however broadly a consumer has to adopt the following procedure for transacting power through open access:

1. Customer who wants to avail open access have to first register themselves with concerned SLDCs.
2. Open access customer needs to sign up a power purchase agreement with their counterpart entities.

3. Open access customer shall seek concurrence of STU and/or transmission licensee and/or distribution licensee involved in the transaction on the prescribed format. STU and/or transmission licensee and/or distribution licensee will give concurrence considering available power transfer capability and technical feasibility of such transaction.
4. An Application for scheduling of Bilateral Transaction through Short-Term Open Access in the intra-State transmission/distribution system shall be made by Open access customer to the State Load Despatch Centre. The application should contain details regarding days, time slots and quantum of power to be transacted.
5. SLDC shall either give acceptance or reject the application made by the Open access customer.
6. Post acceptance, requisite charges for open access needs to be paid by the open access customer

The draft Electricity (Promoting renewable energy through Green Energy Open Access) Rules, 2021 issued by MoP has allowed consumers with a load of 100 kW or more to be eligible for buying renewable power through open access without any other surcharges added to their bills. Presently, most states in India have the minimum eligibility criteria for sanctioned load set at 1 MW or above. By reducing the load requirement 100 kW has opened doors for consumers such as battery swapping stations to procure green power through open access.

5.10 Financial and economic analysis of battery swapping stations

The model for the battery swapping stations was developed to carry out the financial and economic analysis basis on ground parameters and realities. Multiple stakeholders and experts were referred and interviewed to understand the multiple business models and revenue streams. Key operational parameters, capital expenditures, and emission savings from battery swapping were considered into the model to provide a holistic view of the business.

As a result of the assumptions considered, results in the form of NPV (Net Present Value), IRR (Internal Rate of Return), and emission savings were obtained. The impact of multiple factors on the NPV were captured through a sensitivity analysis as well.

In the sections that follow, all the assumptions, and financial analysis conducted are detailed out for battery swapping stations.

Assumptions used for the model

The model requires multiple assumptions on operational and capital expenditure levels to provide a lucid picture of the battery swapping stations. One of the key considerations for the model is the battery sizing and the target vehicle segment. Modularity of the batteries helps the battery swapping station to cater to multiple vehicle segments through a single size battery which can be stacked as per the user requirements.

In the section that follows, every assumption of the model is described in detail.

Operational period assumptions

Based on the discussion with multiple stakeholders in the industry, the following project timelines were used to construct the model:

Table 79: Assumptions for operation period

Sl.	Particular	Description
1.	Construction Start Date	1st April 2022
2.	Construction Period	2 months
3.	Date of Commissioning	31st May 2022
4.	Station life	10 years

Even though the field of battery swapping is gaining significant traction, the utilization of the battery swapping stations would be dependent on the number of swaps that the vehicles go through. Unlike the capacity utilization of plants or manufacturing units which is usually a percentage figure, for a battery swapping station it has been considered to be the number of swaps per day. In light of the burgeoning market, the number of swaps has been increased throughout the project life to ensure increasing utilization of the stations.

Table 80: Assumptions for Capacity Utilization for operational period (cycles per day)

Year	1	2	3	4	5	6	7	8	9	10-11
Capacity Utilization (cycles per day)	4.0	5.0	6.5	8.0	9.0	9.5	10.0	10.5	11.0	11.5

Therefore, the project has been conceived for a period of 10 years and the capacity utilization in the first year is assumed to be 4 cycles per day with increment to 11.5 cycles per day in year 10 until the end of operation for the stations. Cycles per day can be maximized based on the charging time of the battery assumed.

Some civil works are also associated with setting up of battery swapping stations and pertaining to that, the construction period has been taken as 2 months.

Capital expenditure assumptions

Setting up battery swapping stations requires capital expenditure into batteries and charging station. The assumptions taken for batteries is tabulated below:

Table 81: Assumptions for Capital Expenditure

Sl.	Particular	Unit	Value
1	**Batteries**		
1.1	Number of stations	Nos.	20
1.2	Number of batteries per station	Nos.	15
1.3	Maximum number of batteries charged simultaneously (1.1 x 1.2)	Nos.	300
1.4	Batteries per user	Nos.	1.5
1.5	Total number of batteries (1.3 x 1.4)	Nos.	450
1.6	Cost per battery (1.5 kWh* capacity)	INR	35,000
2	**Station**		
2.1	Investment per station	INR Cr	0.09
3	**Others**		
3.1	Miscellaneous Expenses (as a percentage of station and battery capex)	%	10%
3.2	Contingency (% of total capital Cost)	%	5%

*Battery capacity considered based on industry stakeholder interactions

The cost of land has not been considered in the assumptions owing to the fact that the battery swapping spaces are rented from fueling stations or mall compounds or other high traffic areas. The cost of the rent has been considered in the operational parameters of the model.

The phasing of capex is shown below:

Table 82: Capital Cost Drawdown

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Battery Swapping Station	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Battery Capex	50%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%
Misc. Expenses	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Contingency	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

The capital cost drawdown is based on the useful life of the battery. The useful life of the battery is calculated as follows:

Table 83: Battery specific assumptions for operational aspects

Sl.	Particular	Unit	Value	Remarks
1.	Battery Capacity	kWh	1.5	As per industry discussions
2.	Cycle Life	Nos.	1600	Secondary Research and Industry discussions
3.	Charging time	Hours	1,.5	General battery specifications
4.	Depth of Discharge	%	80%	EV performance specifications
5.	End of Life	%	80%	
6.	Battery Life	Years	5.00	Calculated basis the cycle life and cycles per day
7.	Usable Battery Capacity	kWh	1.08	Calculated based on Capacity, depth of discharge, and end of life assumptions
8.	Maximum Cycles per day	Nos.	16	Calculated based on the charging time

The battery life is calculated as follows:

$$Battery\ Life = \left(\frac{Cycle\ life}{365 \times Cycles\ per\ day}\right)$$

The value obtained from the battery life is rounded off to the next larger whole number taking into consideration the battery management done by the swapping station operators.

The usable battery capacity is calculated as follows:

$$Usable\ battery\ capacity = Battery\ Capacity\ \times Depth\ of\ Discharge\ \times \frac{(1 + End\ of\ Life)}{2}$$

Financing assumptions

The financing of the project has been distributed into three categories viz. Grant, Debt, and Equity. The following table captures the assumptions for the same.

Table 84: Assumptions for financing

Sl.	Particular	Value	Remarks
1.	Grant	0%	as a percentage of total capital cost
2.	Debt	70%	as a percentage of capital cost after deducting grant

Sl.	Particular	Value	Remarks
3.	Equity	30%	
4.	Interest rate on Long-term loan	12%	Based on discussion with industry players
5.	Interest rate on Working capital	12%	
6.	Loan Repayment Period	5 years	Based on discussion with industry players

The loan repayment period has been constricted to 5 years due to the fact that batteries are a major component of the capital expenditure of the business and require to be replaced upon reaching a state of health of 80% beyond which they cannot be utilized in EV applications.

Operating expenditure assumptions

The prime operational assumption of a swapping station is related to the number of cycles that the batteries go through that has been highlighted with the capacity utilization as shown in

Table 85: Assumptions for Operating Expenditure for battery swapping stations

Sl.		Particular	Unit	Value
1		**Manpower**		
	1.1	Manpower per station	Nos.	2
	1.2	Salary of Station manpower	INR/month	15,000
	1.3	Yearly salary escalation	%	3%
2		**Electricity**		
	2.1	Cost of Electricity	INR/kWh	7.75
	2.2	Electricity cost escalation	%	5%
3		**Area Lease Rental**		
	3.1	Area required per station	sq. feet	150
	3.2	Rental for area	INR/sq. feet/month	250
	3.3	Rental escalation	%	5%
4		**O&M**		
	4.1	O&M expense per station	INR/year	50,000
	4.2	Escalation	%	5%

Revenue assumptions

The revenue for the battery swapping stations is dependent on the preference of the end users of the battery. There is a fixed stream of revenue through a lease rental collected from the users on a monthly basis. When it comes to usage, the users can opt to either pay for the quantum of energy used from the battery or to pay a fixed charge for every swap. The usage basis option suits personal usage whereas commercial users would prefer the fixed swapping charge.

The assumptions related to revenue are summarized below:

Table 86: Revenue assumptions for battery swapping stations

Sl.	Particular	Unit	Value
1.	Swapping cost (usage basis)	INR/kWh	35
2.	Swapping cost escalation annual (usage basis)	%	5%

Sl.	Particular	Unit	Value
3.	Swapping cost (fixed swapping rate)	INR/swap	50
4.	Swapping cost escalation annual (fixed swapping rate)	%	5%
5.	Lease rental monthly charge per battery	INR	900
6.	Customers opting for fixed swapping rate	%	30%
7.	Customers opting for usage based swapping rate	%	70%

Other than the revenue from regular operations, the battery swapping operator would have a revenue stream from the selling of end-of-life batteries for reuse applications. The assumptions for the reuse based revenue are shown below.

Sl.	Particular	Unit	Value
1.	Price realized for reuse	INR/kWh	3000
2.	Capacity left in batteries	kWh	1.2
3.	Price realized per battery	INR	3600

Other assumptions

1 Depreciation

The following table highlights the assumptions used for depreciation:

Table 87: Assumptions for computation of depreciation

Sl.	Particular	Unit	Value	Remarks
1.	Maximum Permissible Depreciation	%	100%	-
2.	Salvage Value (Station)	%	0	Owing to the rapidly evolving battery chemistries
3.	Station (SLM)	%	10%	Based on salvage value and useful lifetime
4.	Battery (SLM)	%	20%	
5.	Station (WDV)	%	15%	As per IT Act
6.	Battery (WDV)	%	15%	

2 Tax

The following table highlights the assumptions used for tax rates.

Table 88: Expected tax rates for financial model

Sl.	Particular	Unit	Value	Remarks
1.	Tax rate	%	25.17%	Corporate tax rate
2.	MAT Rate	%	0.0%	As per prevailing MAT structure

3 Working capital assumptions

The working capital assumptions are captured below:

Table 89: Working capital assumptions

Sl.	Particular	Unit	Value
1.	Debtor	Number of Days	30
2.	Creditors	Number of Days	30
3.	Salary months	Months	1
4.	O&M months	Months	1

4 Emission assumptions

The emission savings from swapping is computed by analyzing the emissions which would have occurred by using conventional fuel based vehicles in place of swapping.

Table 90: Emission savings assumptions

Sl.	Particular	Unit	Value
1.	Number of batteries used in each E-2W	Nos.	1
2.	Number of batteries used in each E-3W	Nos.	2
3.	**2 Wheeler**		
3.1.	CO Emissions	g/km	1.000
3.2.	NOx Emissions	g/km	0.100
3.3.	PM Emissions	g/km	0.005
3.4.	Distance Travelled	km/kWh	60
3.5.	Batteries Allotted	%	55%
4.	**3 Wheeler**		
4.1.	CO Emissions	g/km	0.220
4.2.	NOx Emissions	g/km	0.160
4.3.	PM Emissions	g/km	0.025
4.4.	Distance Travelled	km/kWh	20
4.5.	Batteries Allotted	%	45%

Results

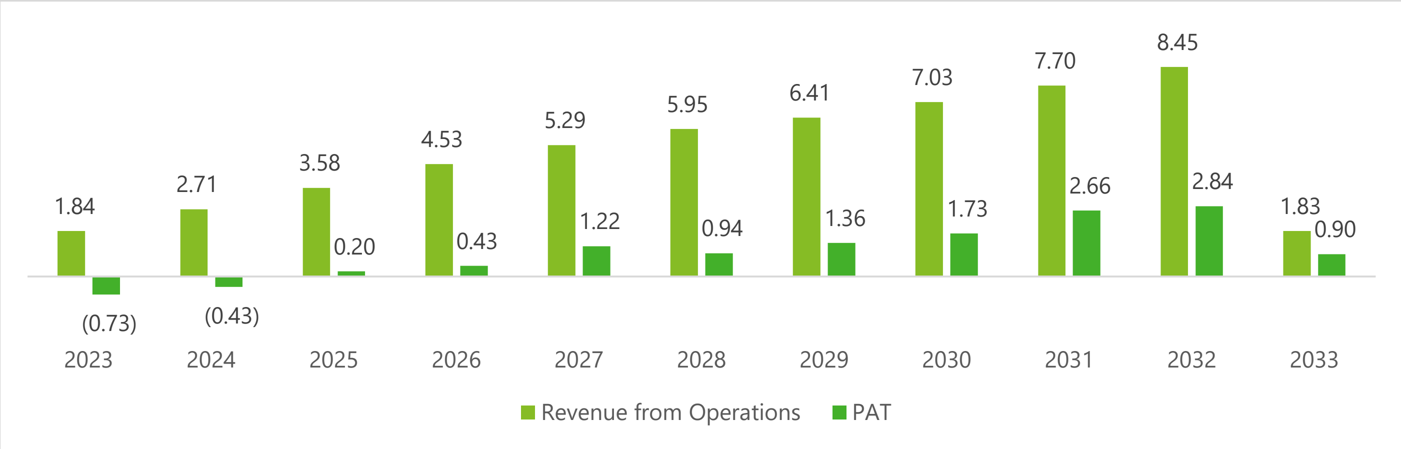
Key results

The results of the model are based on certain assumptions as follows:

- Number of stations: 20
- Number of batteries per swapping station: 15
- Project life: 10 years
- Capacity Utilization: As shown in Table 80
- Grant: 0%
- Debt: 70% (12% interest rate)

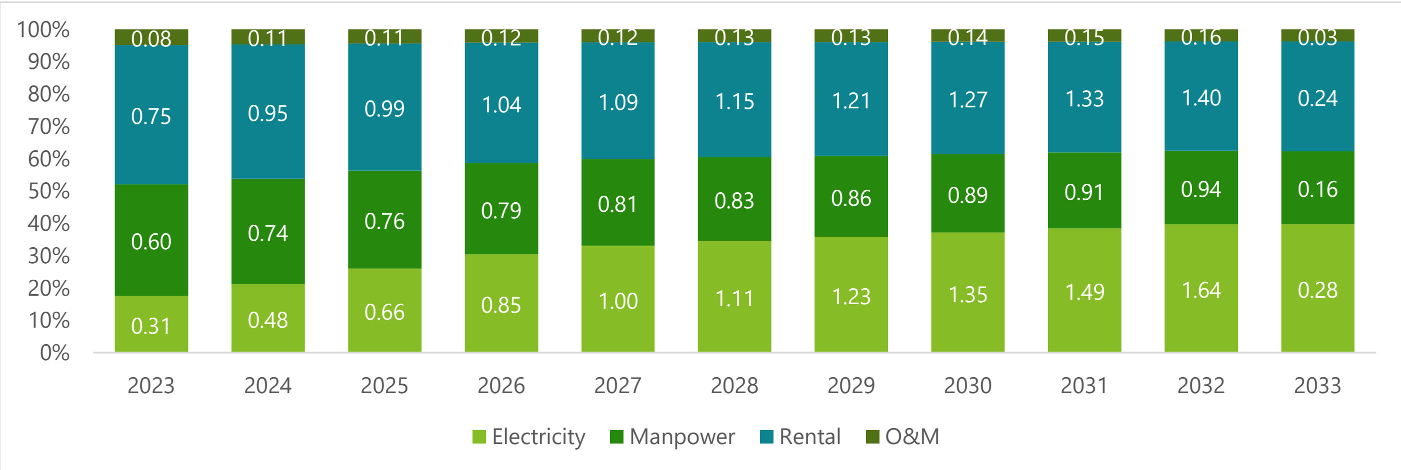
All other assumptions as stated in the previous section remain the same unless stated otherwise.

Figure 82: Revenue from Operations and PAT for battery swapping stations



It can be observed that the revenue from operations is on a rise with the rising utilization of the stations and from FY25, the business produces profits.

Figure 83: Cost Breakdown of battery swapping stations



Lease rental and electricity are the largest contributors to the cost of operating battery swapping stations followed by manpower and O&M expenses. It is quite understandable owing to the presence of such stations in high footfall and high traffic regions which have a higher rental costs for operating in them. With the increasing battery cycles, the electricity cost component also rises throughout the station lifetime. Owing to the requirement of the stations to be available 24x7, two personnel would be allocated to each of the swapping stations.

5 Financial ratios

To assess the financial position of the plant, multiple financial ratios have been assessed. The table below summarizes the average values obtained for some of the key financial parameters of the plant.

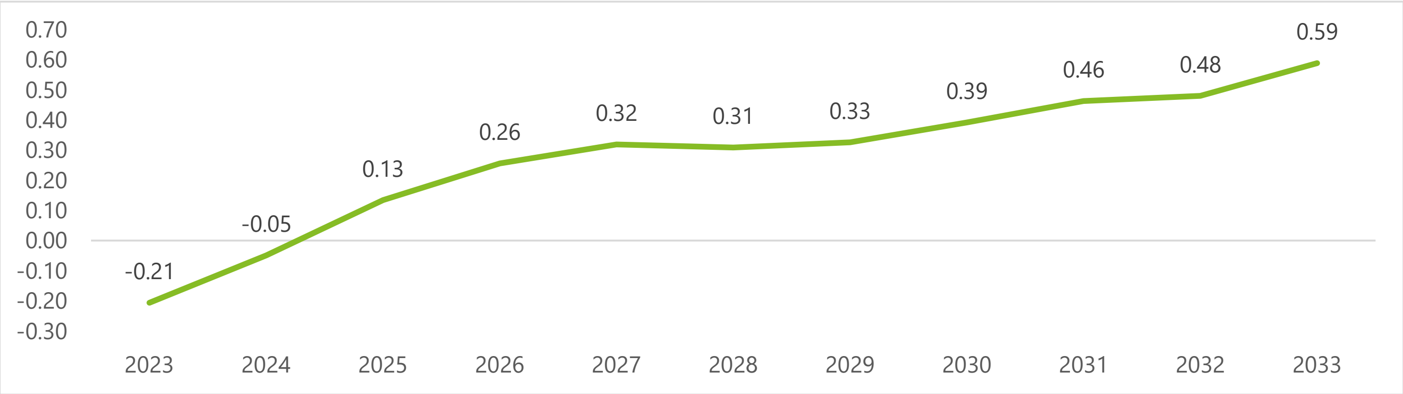
Table 91: Key financial ratios for battery swapping stations

Sl.	Particular	Average Value
1.	Operating Margin	27%
2.	Profit Margin	15%
3.	DSCR	18.39

Sl.	Particular	Average Value
4.	Interest Coverage	33.81

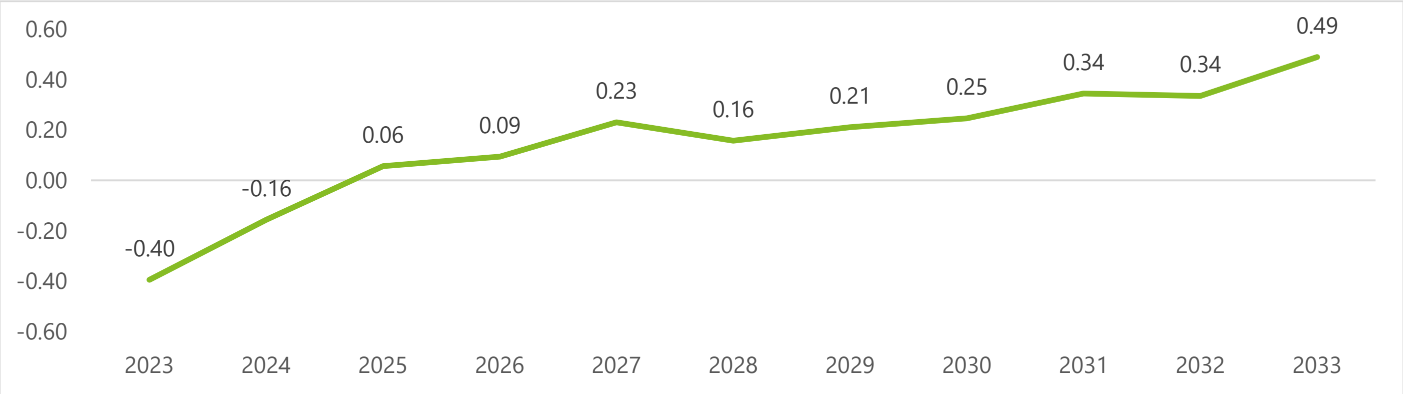
The **operating margin** of the plant varies between -21% to 59% for the operating period with an average of 27%. The margins are negative for first 2 years of operation and continue the increasing trend till the end of project life. The rate of increase flattens in FY 28 owing to the fact that new batteries are procured for the business.

Figure 84: Operating Margin for battery swapping stations



The **profit margin** of the swapping stations experiences larger variations compared to operating margins as it ranges from -40% to ~50% for the operating period with an average of 15%. The plant starts to be profitable from FY30 and continues the trend until FY34 post which it hovers around 25-23%.

Figure 85: Profit margin for battery swapping stations



The **DSCR and the interest coverage** of the plant point towards its ability to generate sufficient operating income to cover its annual debt and interest payment.

Figure 86: DSCR of battery swapping stations

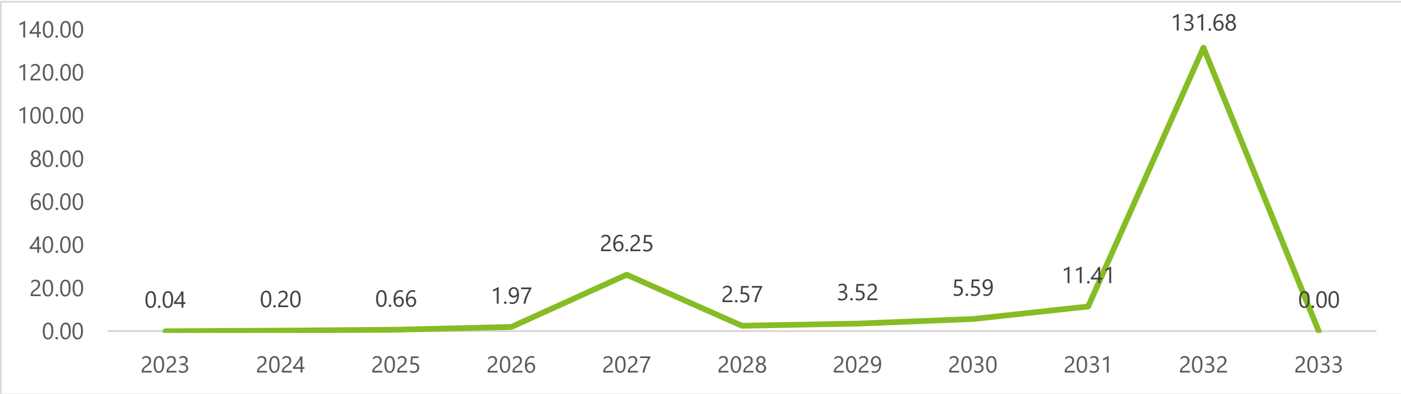
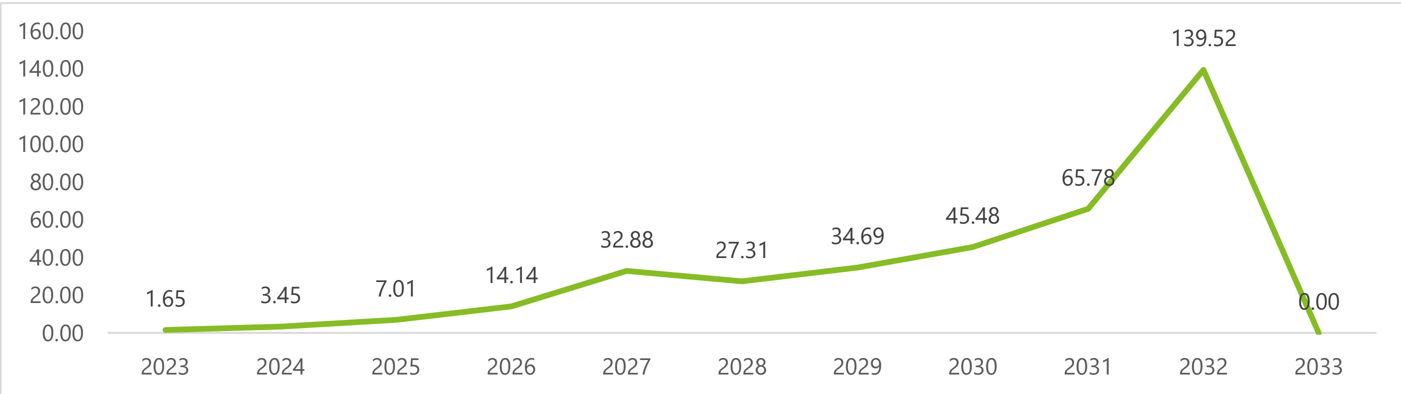


Figure 87: Interest Coverage for swapping stations



Sensitivity analysis

Basis the view of major cost contributors and the revenue model of battery swapping stations, the sensitivity analysis was carried out for the two payment options with users (usage based vis-à-vis fixed swapping charge) and the lease rental paid by the stations vis-à-vis the grant sanctioned by the supporting development bank. A negative NPV and IRR below the WACC have been highlighted in red to show the unviability of the business with the parameters.

Swapping Cost Scenarios

Table 92: Sensitivity analysis (NPV) based on swapping payment models for swapping stations

NPV (INR Cr)		Usage Basis (INR/kWh)									
		20	22.5	25	27.5	30	32.5	35	40	45	50
Fixed Rate (INR/swap)	30.0	-3.6	-2.6	-1.7	-0.8	0.2	1.1	2.0	3.8	5.6	7.4
	32.5	-3.2	-2.3	-1.3	-0.4	0.6	1.4	2.3	4.2	6.0	7.8
	35.0	-2.8	-1.9	-1.0	0.0	0.9	1.8	2.7	4.5	6.3	8.1
	37.5	-2.5	-1.5	-0.6	0.4	1.3	2.2	3.1	4.9	6.7	8.5
	40.0	-2.1	-1.2	-0.2	0.7	1.6	2.5	3.4	5.3	7.1	8.8
	42.5	-1.7	-0.8	0.2	1.1	2.0	2.9	3.8	5.6	7.4	9.2
	45.0	-1.3	-0.4	0.5	1.4	2.3	3.2	4.2	6.0	7.8	9.5
	47.5	-1.0	0.0	0.9	1.8	2.7	3.6	4.5	6.3	8.1	9.9
	50.0	-0.6	0.4	1.2	2.1	3.1	4.0	4.9	6.7	8.5	10.3

NPV (INR Cr)	Usage Basis (INR/kWh)									
	20	22.5	25	27.5	30	32.5	35	40	45	50
55.0	0.2	1.1	2.0	2.9	3.8	4.7	5.6	7.4	9.2	11.0

Table 93: Sensitivity analysis (IRR) based on swapping payment models for swapping stations

IRR (%)		Usage Basis (INR/kWh)									
		20	22.5	25	27.5	30	32.5	35	40	45	50
Fixed Rate (INR/swap)	30.0	-10%	-4%	2%	7%	12%	16%	20%	28%	35%	42%
	32.5	-7%	-1%	4%	9%	13%	18%	21%	29%	37%	44%
	35.0	-5%	1%	6%	11%	15%	19%	23%	31%	38%	45%
	37.5	-3%	3%	8%	13%	17%	21%	25%	32%	39%	46%
	40.0	0%	5%	10%	14%	18%	22%	26%	34%	41%	48%
	42.5	2%	7%	12%	16%	20%	24%	28%	35%	42%	49%
	45.0	4%	9%	13%	17%	21%	25%	29%	37%	44%	51%
	47.5	6%	11%	15%	19%	23%	27%	31%	38%	45%	52%
	50.0	8%	13%	17%	21%	25%	28%	32%	39%	46%	53%
	55.0	12%	16%	20%	24%	28%	31%	35%	42%	49%	56%

As per the industry inputs, fixed swapping rate is highly adopted in comparison to usage basis rate. The ease of payment and the higher usage of battery swapping by commercial operators are key drivers for such a trend. It can be observed that the beyond a fixed swapping rate of INR 55/swap, the busines is feasible for operation.

Fixed Swapping rate vis-à-vis Monthly rental payments

Rental payments are one of the largest cost contributors for the swapping business. It is pertinent to understand it its effect on the viability of business against the major revenue driver i.e. swapping rate. To maintain parity in revenues, the usage based swapping rates have been fixed at 70% of the fixed swap rate. For example, if the fixed swap rate is taken as INR 50/swap, then the corresponding usage based rate is INR 35/kWh.

Table 94: Sensitivity analysis (NPV) based on Fixed Swapping rate and monthly rental payments

NPV (INR Cr)		Monthly Rental (INR/sq.ft.)									
		250	300	350	400	450	500	550	600	650	750
Fixed Rate (INR/swap)	30	-3.21	-4.27	-5.52	-6.78	-8.04	-9.30	-10.56	-11.82	-13.09	-15.61
	33	-2.15	-3.19	-4.24	-5.46	-6.73	-7.99	-9.25	-10.51	-11.77	-14.30
	35	-1.14	-2.13	-3.16	-4.21	-5.41	-6.68	-7.94	-9.20	-10.46	-12.99
	38	-0.10	-1.11	-2.11	-3.13	-4.18	-5.36	-6.63	-7.89	-9.15	-11.67
	40	0.91	-0.10	-1.08	-2.08	-3.11	-4.15	-5.31	-6.57	-7.84	-10.36
	43	1.88	0.95	-0.09	-1.05	-2.05	-3.08	-4.12	-5.26	-6.52	-9.05
	45	2.88	1.92	0.98	-0.05	-1.03	-2.03	-3.06	-4.10	-5.21	-7.74
	48	3.89	2.90	1.96	0.98	-0.02	-1.00	-2.00	-3.03	-4.07	-6.42
	50	4.90	3.90	2.92	2.00	0.98	0.01	-0.98	-1.98	-3.01	-5.11

NPV (INR Cr)	Monthly Rental (INR/sq.ft.)									
	250	300	350	400	450	500	550	600	650	750
55	6.86	5.92	4.91	3.93	3.01	2.06	1.03	0.05	-0.93	-2.96

Table 95: Sensitivity analysis (IRR) based on Fixed Swapping rate and monthly rental payments

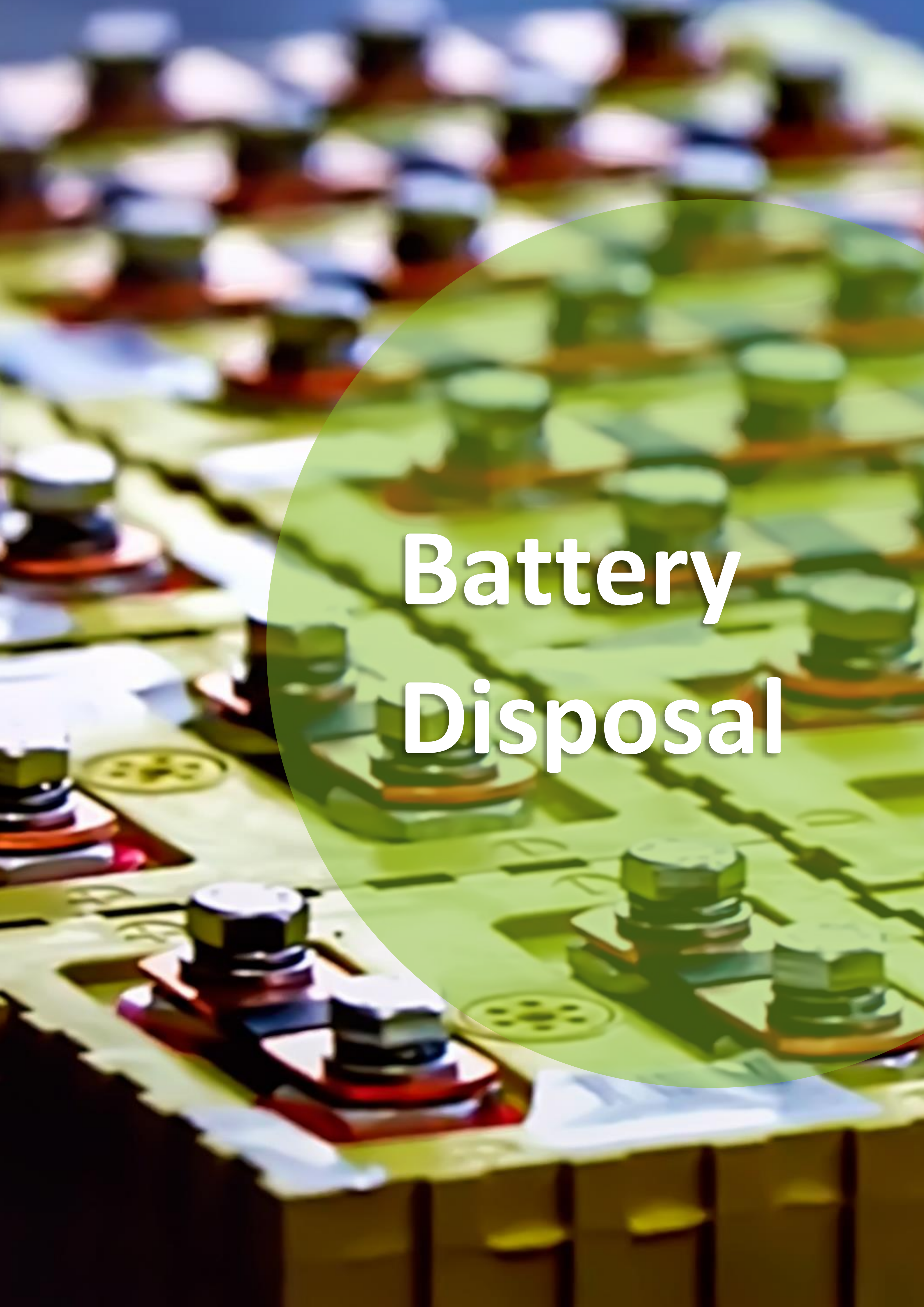
IRR (%)		Monthly Rental (INR/sq.ft.)									
		250	300	350	400	450	500	550	600	650	750
Fixed Rate (INR/swap)	30	-7%	-13%	-22%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	33	-1%	-6%	-12%	-19%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	35	5%	0%	-5%	-10%	-17%	-26%	n.a.	n.a.	n.a.	n.a.
	38	10%	5%	1%	-4%	-9%	-15%	-23%	n.a.	n.a.	n.a.
	40	15%	10%	6%	1%	-4%	-8%	-13%	-21%	n.a.	n.a.
	43	19%	15%	10%	6%	2%	-3%	-7%	-12%	-19%	n.a.
	45	24%	19%	15%	11%	6%	2%	-2%	-6%	-11%	-24%
	48	28%	23%	19%	15%	11%	7%	3%	-2%	-5%	-15%
	50	32%	28%	23%	19%	15%	11%	7%	3%	-1%	-8%
	55	40%	36%	31%	27%	23%	19%	15%	11%	7%	0%

It is evident from the sensitivity analysis that the rental values against any swapping rates can be increased to a certain level only beyond which the business becomes unviable.

To conclude, the battery swapping business has certain components in the revenue and cost aspects which are key determinants of the feasibility of the business. The battery sizing decided at the beginning of the business and the optimal balance between the customers opting for fixed swapping rate against the customers paying on usage basis are two of the major factors to be kept in mind while operating the stations.

From the cost aspect of the business, any battery swapping station having lower rental lease payments would have an added advantage over other players. The lower cost provides the operator with attractive revenue models based on competitive pricing for any payment model chosen by the users.

Battery Disposal



Chapter 6. Overview of battery disposal

As per the e-Waste Management Rules of 2016, disposal means any operation which does not lead to recycling, recovery or reuse and includes physio-chemical or biological treatment, incineration, and deposition in secured landfill. The act of disposal ensures that hazardous wastes such as batteries are directly not put into landfills and they go through suitable treatment before being discarded.

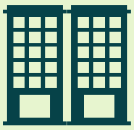
Disposal also encompasses the handover of the battery after usage to designated collection centers which channelizes the used batteries to dismantlers and recyclers. The utilization of the battery recycling capacity of the country is highly dependent on proper disposal of batteries. Adequate disposal ensures a healthy feed to the recycling plants and thus helps in development of an efficient circular economy.

6.1 Channels for collection of batteries for disposal

Since batteries are hazardous, they require safe disposal so as to prevent environmental contamination. The collection routes for battery disposal are similar to that of battery recycling. EPR (Extended Producer Responsibility) is a driving factor for the implementation of proper channels for collection of batteries. OEMs and companies, who have EPR practices, have the responsibility for ensuring collection of batteries from consumers.

India has EPR for lead acid batteries since 2001 since the enactment of the Battery Waste Management Rules. This has led to the development of proper channels of collecting lead acid batteries through retailers of the battery manufacturers. Apart from the EPR route, there are informal channels such as itinerant collectors (kabadiwaalas) who collect scrap (including batteries) from the end users.

Primarily there are three routes for collection of batteries for disposal shown below:



Battery Manufacturers, automobile OEMs having EPR	Waste Collection Centers	Scrap Dealers

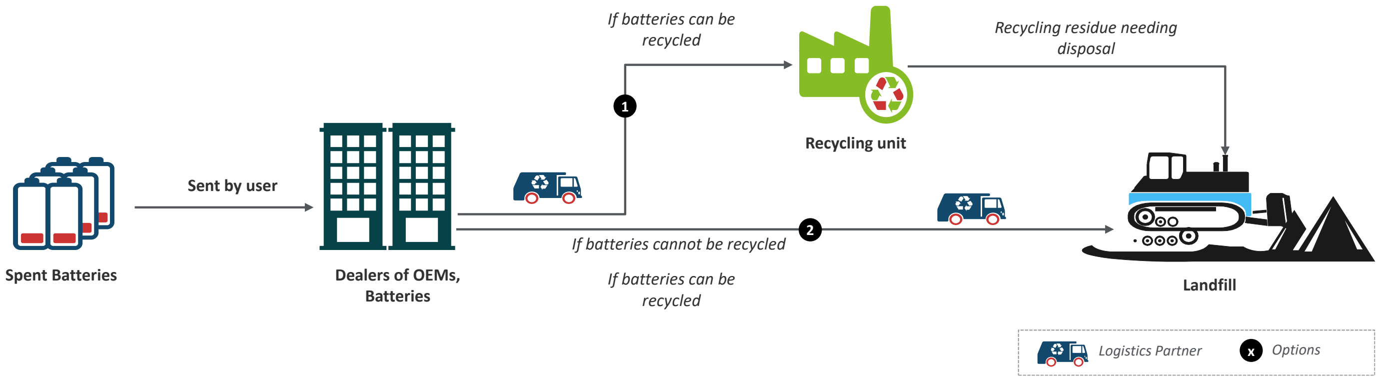
Organized sector for battery disposal

Battery manufacturers usually collect batteries back from the premises of the retailers / waste collection centres. Such practices have provided higher reclamation of spent lead acid batteries in the country. Waste Collection centers act as aggregators. Batteries form a large part of the waste material collected by them and based on the agreements inked by them, they further transport the battery to the recyclers, or send them for disposal.

For instance, Exide batteries in India fulfills 40% of its lead and lead alloy requirements from recycled lead. The company buys back old batteries through its extensive dealer network. The buyback arrangement here establishes a channel for collection of batteries which are then recycled at smelters at various parts of the country. Exide utilizes two of its hi-tech smelters in Pune and Bangalore along with third party smelters (in country's other parts).

The dealers of batteries have adequate arrangements in place to ensure that the batteries are stored safely and that they are channelized to recycling centers or disposal facilities as per requirement. Organizations having Producer responsibility also carry out the function of ensuring that the batteries are collected at registered collection centers and channeled adequately.

Figure 88: Modes of Battery Disposal – Organized route



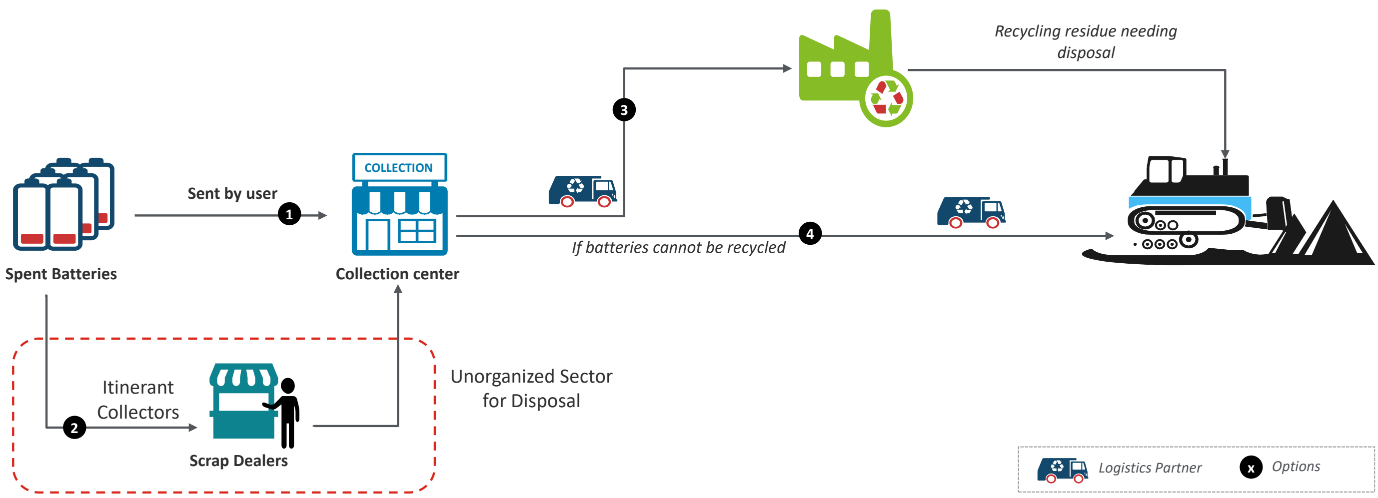
The EV traction batteries cannot be directly disposed into landfills. Chemistries such as lead acid, nickel metal hydride, and lithium-ion can be recycled and direct disposal of these batteries into landfills without processing is not permitted as per the Battery Waste Management Rules (BWMR) and E-Waste Management Rules (EWMR). The disposal of batteries is done at secured landfills by registered disposal firms. In case the batteries collected are not recyclable due to damage or leakage, the batteries are directly sent to the disposal agencies.

At present, there is an absence of monitoring system for battery disposal in India. Although the manufacturers are required to maintain records of the waste generated, handled and disposed and share the same to the State Pollution Control Board (SPCB), they can only account for the batteries that reach their collection centers or dealers. The battery manufacturers / bulk consumers also have to file returns of the sale of new batteries and collection of used batteries every year. The BWMR of 2001 set out battery collection targets of 90% of new batteries sold from the second year of the rule implementation but the dominance of the informal sector till date points towards requirement of stronger enforcement measures.

Unorganized sector of battery disposal

The large network of unorganized scrap dealers, who collect the waste items from itinerant collectors (kabadiwaalas), form a substantial part of the battery collection efforts for disposal. They act as aggregators for itinerant collectors and bring scale to the collection business. Scrap dealers provide batteries to the collection centers, who accordingly transport the batteries for disposal as required.

Figure 89: Modes of Battery Disposal – Organized and unorganized route



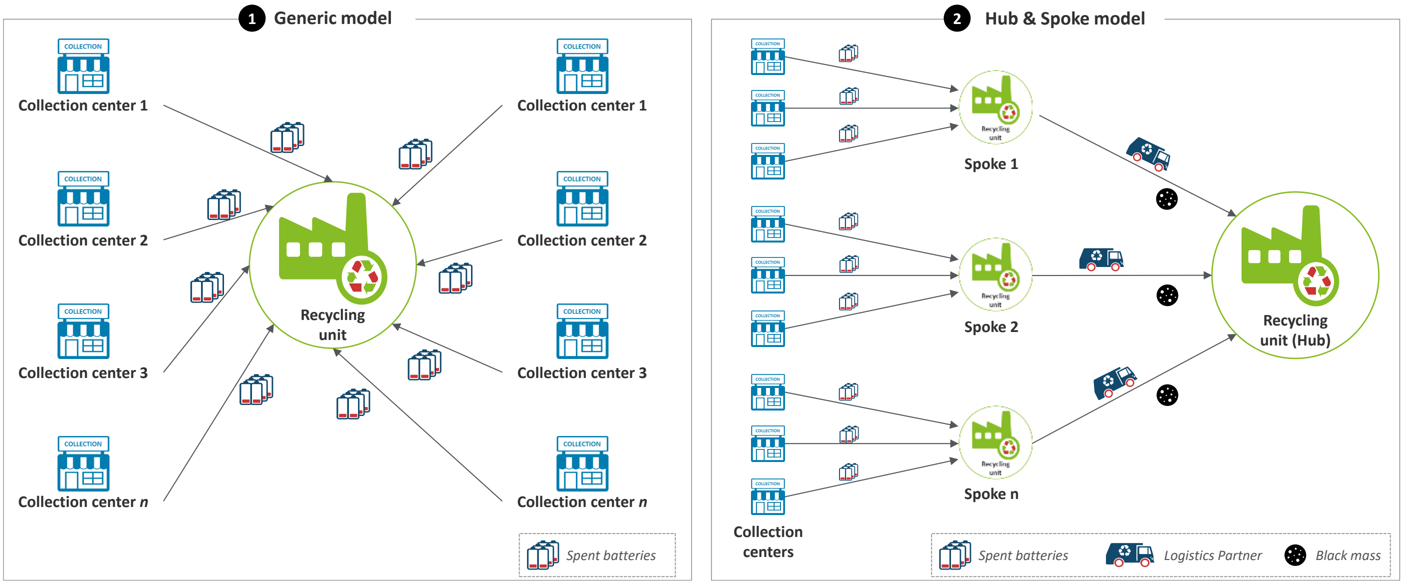
The dominance of the unorganized sector lies in the fact that they provide the ease of disposal to end users. Itinerant collectors travel to every nook and corner of cities to collect waste generated which is diverted to scrap dealers who send the batteries to the collection centers. Unlike the collection centers, the scrap dealers and itinerant collectors don't house proper storage facilities and hence, the risk of contamination and fires are high.

6.2 Logistics of battery collection

Setting up of battery recycling units is capital intensive. For lithium-ion batteries, the value of the battery resides in the black mass (cathode material) which upon recycling provides the desired metals and minerals in them. In general, nearly one third of the battery weight lies in the black mass and transporting the black mass in place of the entire battery is cost effective.

Batteries can reach the recycling facility through two methods viz. the hub & spoke model and the generic collection center to recycling unit model.

Figure 90: Possible battery receiving models for recycling



Source: Industry insights

As it can be seen above, the spokes are desired to extract the black mass from the batteries and send it to the hubs where the extraction of the desired material occurs. Spokes employ mechanical separation and shredding to separate the copper and aluminum in the batteries along with the plastics. Once shredded, there is a significant size reduction in the components to be transferred to the recycling units. The black mass upon reaching the recycling unit is processed further as required.

The hub and spoke model is applicable to only hydrometallurgy and direct recycling technologies which operate on the black mass of the batteries. The generic model is applicable to all recycling technologies viz. hydrometallurgy, pyrometallurgy, and direct recycling. The generic model concentrates all the battery recycling related steps in the recycling unit which includes battery discharging, shredding, and the concerned technology application.

The cost of collection for battery recyclers is the battery purchase cost from both the formal and informal sectors. The cost of collection is in the range of INR 100 – 135 per kg of spent battery. Cost of transportation i.e. ensuring the batteries reach the recycling facility, is in the range of INR 25-35 per kg of spent battery.

For instance, Li-Cycle utilizes a hub and spoke model. The generic model for logistics is being used by Umicore in Belgium as well as by multiple other players in India. New and emerging players of the world are adopting the hub and spoke model whereas the older players have been using the generic model. One key reason for such model adoption is the evolution of battery chemistries. Previously, lead acid batteries were dominant, which are usually recycled using smelters. However, with the advent of lithium-ion batteries and hydrometallurgical recycling methods, the hub and spoke model has seen larger adoption.

6.3 Dismantling

Once spent batteries are collected, they are sent to dismantling facilities. Dismantling/disassembly of EV batteries involve breaking down of the battery to cell or module level post which such cells and modules are sent to recycling facilities. The disassembly of lithium-ion battery systems from automotive applications is complex and therefore time and cost consuming due to a wide variety of the battery designs, flexible components like cables, and potential dangers caused by high voltage and the chemicals contained in the battery cells. All these factors have to be considered when planning the disassembly process(es) and appropriate workstations.

Steps of disassembly

Disassembly should always be done by specially trained personnel as the entire process is carried out at a connection voltage of 60 V DC. In order to ensure safety of workers, all the tools must be insulated, and electrostatic discharge workstations must be used to remove the static charge from workers to avoid the risk of electrocution.

Opening the battery housing

The disassembly process begins with discharging the battery pack. The power is fed back to the grid or is temporarily stored. Once discharged, the battery housing is opened by loosening the screws along the edge of the cover and thereby removing the cover. Based on the battery type, the sealing rings between the battery cover and the housing will differ. Hence, high forces may have to be exerted to ensure that the cover is removed. The seal may be damaged during removal depending on the material of the sealing ring. Depending on the size of the battery, the lid may be removed by two workers or a crane.

Disassembly of the battery pack

After removing the housing cover, the battery components can then be disassembled form the battery pack. In order to do this, the wirings, cooling system, high voltage modules and battery modules are removed. First, the cabling of the BMS master along with the cooling system, the module slave board, and the high voltage modules are removed. The coolant is first removed from the battery pack by using an extraction system (in liquid-cooled battery packs). This is done to prevent leakage of the coolant which could cause potential short circuits. The cooling system is then separated from the cooling elements of the packing case. The metallic cold plates and the cooling system components are then removed. These metallic plates and cooling system components can also be recycled owing to their composition. The HC and LV harnesses which connect the modules to peripherals are removed next. Post this, an insulated screwdriving tool is used to remove the complex, screwed high-voltage module. The battery modules are usually attached to the battery packs through screw connection and additional fixation (such as adhesives, foams, or waxes) which are difficult to remove. The screws and adhesives are then removed in order to access the battery modules. Usually ten to forty eight modules are present in a battery pack.

Disassemble of battery modules

The battery modules must be disassembled/opened to remove the battery cells. The battery module cover is usually either pressed or screwed and is removed with the help of insulated screwdrivers or inserting force/pressure. After removing the module cover, the module housing must be removed. The wiring harness is removed next to open the module. The cell contacts are then separated to remove the cells. The cell contacts should be covered or taped with insulating material for safety reasons. In most cases, the cells are glued together for thermal and electrical insulation and cannot be removed without damaging them.

Challenges

There are certain challenges associated with the disassembly of traction batteries.

- **Variety of battery packs:** A wide variety of battery pack designs and interconnect technologies make the disassembly process complex, time-consuming, and cost – intensive
- **Flexibility:** Owing to significant differences in the design of battery packs, the disassembly process warrants the use of different tools and require a high degree of flexibility
- The requirements of battery cell producers differ from those of the remanufacturers or recyclers, thereby putting more pressure on disassemblers.
- **Safety risks:** High voltage and battery electrolyte and chemicals pose a safety risk to the workers while dismantling batteries

6.4 Battery recycling in India

India is on the path of adding a greater number of electric vehicles in the coming decade on the back of growing concerns of emissions and policy push for adopting EVs. The adoption of electric vehicles has been slow but the cumulative market size of batteries by 2030 is expected to be between 268 GWh to 498 GWh. The recycling industry is in the nascent stages, as many companies have started developing capabilities.

For lead acid batteries, the Battery Waste Management Rules (BWMR) were announced in 2001. The rules outlined responsibilities of manufacturers, importers, re-conditioners, and assemblers to ensure that used batteries are collected and sent to registered recyclers. The implementation of these rules has been a challenge, as recycling by informal sector persists.

Strengths and weaknesses of the Indian recycling system for batteries:

PROS

- A **large network of itinerant collectors** (kabadiwaalas) has larger reach for waste collection and serve both the organized and unorganized recycling sectors
- **Experience with recycling of lead-acid batteries can be leveraged** to develop new rules covering lithium-ion and advanced battery chemistries

CONS

- **Unavailability of a comprehensive battery waste management rules/ guidelines** covering EV traction batteries such as Lithium-ion, Nickel metal hydride
- **High share of informal smelters** in recycling of chemistries such as lead acid drives end-of-life batteries away from the organized recyclers due to which they are unable to operate at scale and improve profitability
- Battery chemistries other than lead acid are governed by **e-Waste Management Rules** having gaps in terms of safe disposal and recycling of batteries leaving room **for improper practices**

Lithium-ion battery recycling in India

The lithium-ion battery recyclers in India are mostly e-waste recyclers as these batteries fall under the purview of e-Waste Management Rules, 2016. Recyclers collect batteries through various channels viz. battery manufacturers, collection centers (third party run or by the recycler), and also through the informal sector which provides the recyclable batteries at the collection center. Collection centers in India are widely aggregators of e-waste and don't house the capability of disassembling batteries themselves.

Once the batteries have been collected, they are sent to the recycling facilities, where pre-treatment is carried out. During pre-treatment, the batteries are dismantled either manually or automatically based on the process automation levels of the recyclers. The batteries are first disassembled and shredded to the required levels as per the method applied by the recyclers. Since in India, none of the recyclers have adopted pyrometallurgy for recycling of lithium-ion batteries, the pre-treatment is a necessary step. After pre-treatment, the black mass i.e. the cathode material is further treated for refining and recovery of the desired materials.

Many of the players in the Indian lithium-ion battery recycling business are suppliers of black mass as compared to an end to end recycling and refining process player. This is mostly constrained by the technology, lack of demand from organized sector, unfavorable policies and lack of incentives for investments in the sector. Further, there is a strong demand of the black mass from other industries, other than battery manufacturing. Many recyclers such as TES-AMM use their Indian facilities for pre-treatment only and send the black mass to their factory in Singapore. The table below captures the various recyclers, with capabilities to recycle Lithium-ion batteries.

Table 96: Lithium-ion battery recyclers in India (non-exhaustive)

Recycler	Technology	Location in India
Attero Recycling	Hydrometallurgy	Uttarakhand
Tata Chemicals	Hydrometallurgy	Maharashtra

Recycler	Technology	Location in India
TES-AMM	Mechanical and Hydrometallurgy	Chennai
Exigo Recycling	Hydrometallurgy	Haryana
Sungeel	Hydrometallurgy	Andhra Pradesh
E-Parisaraa	Mechanical	Karnataka
Ecoreco	Mechanical	Maharashtra
Surbine Recycling	Hydrometallurgy	Gujarat
BatX Energies	Hydrometallurgy	Haryana

Source: Company Websites, Secondary Research; Note: Mechanical process adopters generate black mass only and don't recover materials.

The institutions, who have deployed the mechanical process as the preferred technology, are involved only in the dismantling and extraction of black mass from the lithium-ion batteries. The entry of established players such as Tata Chemicals is an encouraging sign for the industry as they would possibly bring scale and try and transform the sector into an organized play. The other encouraging step which some of these players have taken is the use of hydrometallurgy for recycling which is the most environmentally friendly process for recycling lithium-ion batteries presently.

6.5 Battery disposal globally

For battery disposal, European countries follow the Batteries Directive which was brought out in 2006. The Batteries directive was substantially amended in 2020. The directive covers all the aspects of collection and recycling of portable and industrial batteries. Industrial batteries cover the batteries used in electric vehicles and have specific collection requirements as per the directive.

Germany has come out with effective collection schemes. The country has brought out legal obligations for battery producers to collect the waste batteries from customers and have them deposited in containers managed by various collection schemes. There schemes active in Germany as of now namely CCR REBAT Germany, European Recycling Platform, and Ocorecell, etc.

The battery manufacturers are free to employ the services of any number of collection schemes in Germany. The collection schemes encompass the public waste disposal authority to leverage their wide reach and door to door collection ability.

CCR Rebat for instance, collected 10,129.3 tonnes of primary and secondary batteries in 2020. They received 56% of their batteries from distributors, 32% from voluntary collection centers, and the balance through public waste disposal systems and treatment facilities. CCR Rebat has contracts with more than 300 battery producers and retailers and serves 16000 collection points. CCR Rebat provides collection containers, free pickup of collected batteries, recycling, reporting and finally the official documentation of the services.

The BattG (German Battery Act) is the empowering act behind the collection schemes. BattG provides the necessary legal framework for manufacturers to ensure that they undertake collection of waste batteries. As per the latest amendments of BattG, direct collection of battery waste can only be done by privately operated collection schemes such as CCR Rebat. The move is intended to generate competition amongst the players which would eventually result in healthy battery collection and disposal environment.

The German Battery Act which is based on European Batteries Directive provides an impetus for battery manufacturers, OEMs to ensure that adequate channels for battery collection are utilized. Competitiveness amongst the private collection schemes ensures that collection rates are high and the necessary feed for battery recycling and refurbishing units is always present.

6.6 Licensing or registration requirements for disposal of batteries in India

The disposal of batteries takes place through the collection centers and the disposal facilities. The disposal facilities are also known as TSDFs (Treatment, Storage, and Disposal Facilities). The collection centers for batteries have to comply with e-waste Management rules 2016 (covering all battery chemistries except lead acid). The Battery Waste Management Rules, 2001 define the procedures for dealers and their responsibilities for managing the disposal of batteries from customers.

Collection centers

Collection centers in India have to adhere to the e-waste Management rules (EWMR) 2016[101] (covering all battery chemistries except lead acid). Collection centers may be operated by the following:

- a producer, or
- a joint association of producers, or
- dismantlers, or
- refurbishers, or
- recyclers.

The Battery Waste Management Rules of 2001 does not have provisions which elaborate on the licensing and registration requirements of collection centers. But, lithium-ion cells and other cell chemistries which are till date predominantly used in electronics find place in e-waste Management Rules of 2016. The Draft Battery Waste Management Rules of 2020 have addressed the requirements for collection centers.

The registration, compliance, and clearances necessary for collection centers as per E-waste management rules are mentioned below.

Registration

- Collection centers run by producers or an association of producers are required to be operated as per the authorization of extended producer responsibility. The authorization is according to the guidelines of CPCB (Central Pollution Control Board).
- The collection centers by dismantlers or refurbishers or recyclers need to have permit from the State Pollution Control Board where the facility exists.

Compliance

- Collection centers must ensure that the facilities are in accordance with the standards or guidelines issued by Central Pollution Control Board from time to time related to weighing equipment, maintenance of records, necessary fire-fighting arrangements, escape routes for emergency exit, shed/ spaces for storage of the waste, etc.
- Collection centers must ensure that the e-waste collected by them is stored in a secured manner till it is sent to authorized dismantler or recycler. Other requirements to be maintained are as highlighted below:
    - Collection center also must have proportionate volume of storage which ranges between 1.0 m3/tonne to 10.0 m3 / tonne based on the waste category
    - Categorization of waste is a necessary step to ensure proper dispatch to dismantlers and recyclers
- Collection centers must ensure that no damage is caused to the environment during storage and transportation of e-waste
- Collection centers must maintain records of the e-waste handled as per the guidelines of Central Pollution Control Board and make such records available for scrutiny by the Central Pollution Control Board or the concerned State Pollution Control Board

Disposal facility

Disposal facilities undertake storage, treatment and disposal of waste batteries. These facilities have to comply with the Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2015[102] prepared by CPCB. Following are some of the requirements as per the rules:

Registration

- A facility willing to undertake disposal operations should apply to the State Pollution Control Board

Clearance

[101] CPCB E-waste Management rules 2016, Technical guidelines (access here)

[102] CPCB Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2015 (access here)

- Consent to establish a facility has to be granted by the State Pollution Control Board under the Water (Prevention and Control of Pollution) Act, 1974 (25 of 1974) and the Air (Prevention and Control of Pollution) Act, 1981 (21 of 1981)
- Suitable environmental clearance also needs to be obtained

Compliance

- Disposal facility has to comply with the following:
- Provisions of the Environment (Protection) Act, 1986, and the rules made there under.
- Provisions outlined in the Central Pollution Control Board guidelines on "Implementing Liabilities for Environmental Damages due to Handling and Disposal of Hazardous Waste and Penalty"
- Any other conditions for compliance as per the Guidelines issued by the Ministry of Environment, Forest and Climate Change or Central Pollution Control Board from time to time.

6.7 Case studies on battery disposal

WeRecycleBatteries.com

WeRecycleBatteries.com is one of the battery aggregators that provides battery disposal services in the USA and Canada. The company was founded in 2009 and provides an array of services which includes disposal of batteries.

WeRecycleBattries.com works with companies to help them reach their recycling objectives. The company connects the suppliers of batteries to their preferred choice of recyclers. WeRecycleBattries.com trains the staff of the EOL (End of Life) battery supplying organization to proper packaging and shipping documentation requirements. Once the packaging is done, WeRecycleBattries.com picks up the batteries from the supplier and sends them to the designated recyclers or processors.

WeRecycleBatteries.com uses its wide array of collection points and organizations with battery stewardship to ensure a healthy feed of batteries for the recycling firms. At the same time, it helps the battery suppliers to ensure that their batteries are professionally managed for disposal as per the regulations. The expenses of WeRecycleBatteries.com lies in setting up the collection network, procuring hazardous waste capable containers, training of supplying organization staff and most importantly logistics of transporting the batteries from collection centers to recyclers.

Bizlog Value Chain

Bizlog is a company based out of Bengaluru, India and provides services in the field of circular economy, reverse logistics, and returns management (process of overseeing materials that are returned to an organization). It enables disposal of e-waste (including batteries) through the help of its technological platforms that connects customers to its collection centers spread in 35 cities across India. Under its solid waste management services, Bizlog enables end to end logistics. End to end logistics include individual consumer pickup, corporate pickups, aggregator pickups as per the CPCB (Central Pollution Control Board) norms including the consolidation of waste. Bizlog collects e-waste from customers as well as from bulk consumers which makes it an ideal fit for battery waste collection. Bizlog ensures that the batteries collected by them through multiple routes are sent to appropriate recyclers or disposal centers.

Bizlog incurs much of its costs in setting up the supply chain connecting the waste batteries from collection centers to recycling units and transportation. Bizlog generates the revenue as per agreements inked with recyclers or producer responsibility organizations. The technology platform of the company is a critical enabler for the entire business model and helps it in day-to-day operations.

Maharashtra Enviro Power Limited (MEPL)

Promoted by SMS Infrastructure Limited, MEPL deals with hazardous waste treatment and disposal facilities. It has built its own facilities and operates the same by itself. MEPL provides three services viz. direct land filling, land filling after treatment, and incineration by PVGR (plasma volume gasification replacement) for handling hazardous wastes.

MEPL deals with e-waste which includes the batteries generated from mobiles and electric vehicles. MEPL has a secured landfill which meets criteria for hazardous waste landfill as per the CPCB (Central Pollution Control Board).

Few hazardous wastes have characteristics which lead to leaching of toxic contents like metals (e.g. batteries). Specific chemicals and binders are used for such wastes to neutralize these undesired effects. MEPL designed and installed an automatic and mechanically operated system for stabilization process, whereby toxic materials are immobilized by binding with cement, fly ash, bentonite, hydrated lime and other specialized chemicals before they can be landfilled. Post stabilization analysis of the wastes is carried out before the final disposal.

Apart from handling of battery waste, MEPL also provides transportation services for waste generator for case of batteries the dealers. The logistics department provides hazardous waste packaging, labelling, and transportation guidelines provided by Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2015.

MEPL collects disposal fees from recyclers and dismantlers for its landfilling services and hazardous material neutralization services. Other than the core functions of disposal, MEPL also provides transportation services for hazardous wastes and in turn charges additional fees for such service.

6.8 Key recommendations

It is necessary to have a robust recycling and disposal ecosystem for batteries in India. As the electric vehicles start gaining traction, necessary channels for utilizing end of life batteries would be important to ensure a healthy and steady flow of battery raw materials and avoid shortage during manufacturing.

To develop a thriving battery collection system, following steps are being recommended:

National level battery collection scheme

A national level not for profit battery collection scheme should be introduced. For instance, Germany introduced GRS Batterien Foundation, a collaborative effort between battery manufacturers, which paved the way for higher collection rates through private participation. The manufacturers of batteries and OEMs can be mandated to spearhead the collection scheme and later on, private participation may be introduced.

Responsibility attribution to manufacturers and vehicle OEMs

Since electric vehicles have complicated battery structures, it is important to include the vehicle OEMs in the battery collection mechanism. The network of service centers of OEMs can act as collection centers for traction batteries. A registry of such collection at an OEM level can ensure higher collection rates. For instance, European Batteries Directive of 2020, acknowledges electric vehicle manufacturers as producers as well which also enables the directives to roll out extended producer responsibility through them.

Repository for battery end of life configuration

Battery manufacturers must provide the construction configuration of their batteries at the end of life in a designated portal which may be governed by the CPCB with access to manufacturers, collection centers, and recycling centers to help in proper channelization and recycling. Collection centers having information on end-of-life and battery configuration can better channelize the batteries to relevant recycling facilities and ensure higher recovery in the process. The EU Batteries Directive of 2020 advocates for the development of an electronic system with access to only accredited battery manufacturers, second-life operators, and recyclers. The electronic system is intended to provide exploded diagrams of battery system/ packs, disassembly sequences, type and number of fastening techniques, tools required, number of cells, and necessary warnings, etc. Such information can help in ensuring healthy recovery of materials and safety of end-of-life and waste battery handlers.

Including Municipalities in collection process

Just like the unorganized sector, municipalities have door-to-door waste collection process. The collection of battery waste at consumer door-step and their channelization through designated collection centers to recycling plants would boost consumer awareness and the circular economy as a whole. For instance, GRS Batterien Foundation of Germany which was operational up to 2020 collected nearly 40% of the total batteries (9,557 tonne) from Municipalities. Similarly, CCR Rebat in Germany, in its largest collection scheme, utilizes the public waste disposal system to ensure maximum take back of batteries.

Battery Recycling

Chapter 7. Overview of battery recycling

The growth of electric vehicles is expected to create a substantial demand for traction batteries. The coming decade is expected to be dominated by Lithium-ion batteries owing to the rapid technological development of the chemistry and falling prices. However, with growing supply chain concerns and need for raw materials, it becomes important to have a robust recycling ecosystem to ensure that useable minerals from batteries can be extracted to manufacture new batteries.

The need of recycling is further justified by the increasing impetus towards circular economy. The concept of circular economy provides new ways of creating value, and ultimately prosperity, through extending product lifespan and relocating waste from the end to the start of the supply chain[103]. Greater impetus should hence be given to reuse, remanufacturing and, as a last resort, recycling for providing raw materials.

Policies significantly drive the recycling practices across the globe. China for instance, has NEV recycling regulations[104] which sets recovery rates for battery minerals. European Union Directives of 2006 provides recycling targets (as a percentage of average weight) for different battery chemistries. Chinese battery recyclers have adopted hydrometallurgy largely and are adhering to the NEV regulations whereas European battery recyclers have extended their existing pyrometallurgical processes and incorporated hydrometallurgy to refine their products.

The reserves of battery metals are limited in nature and there is a dire need to have recycling infrastructure and technology in place to fulfil the demand of battery manufacturers. It is important to note that recycling is crucial not only for securing the supply of key raw materials for the future but also for reducing the need for new mineral extraction, thereby lowering the environmental footprint.

7.1 Technologies for battery recycling

It is worthwhile to mention that the primary end of life (EOL) options for batteries are 1) landfill disposal, 2) re-purposing/reuse and 3) recycling. It is believed that recycling is the safest, most practical and most efficient alternative. Globally, policy actions are being targeted to provide the necessary framework to achieve greater reuse and recycling of battery materials.

Primarily, there are three recycling methodologies:

1 Pyrometallurgy	2 Hydrometallurgy	3 Direct recycling

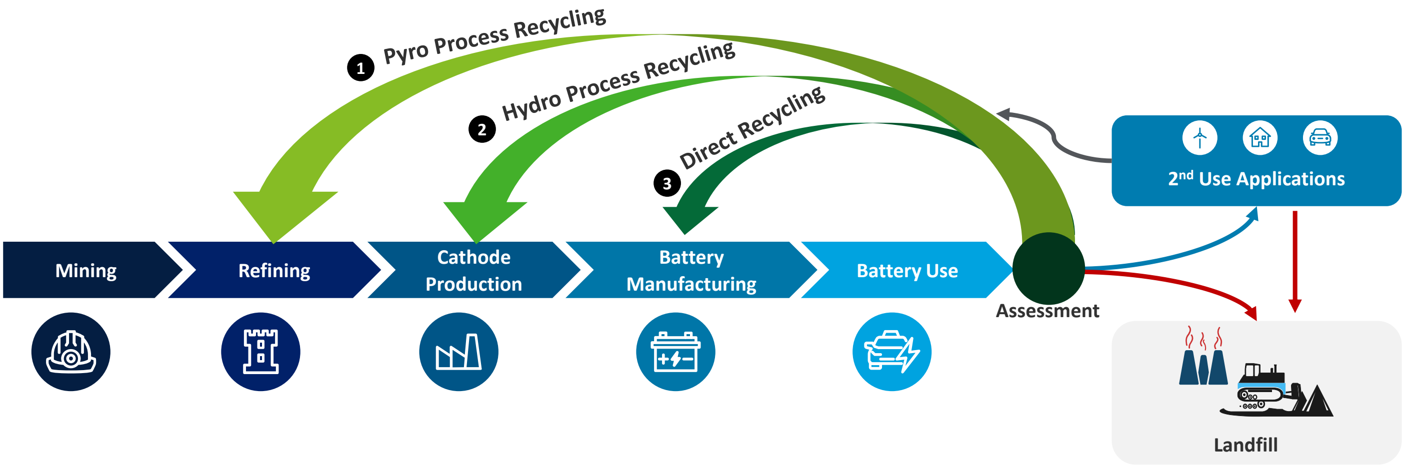
- ***Pyrometallurgy*** is the technology which has been used for lead acid and Nickel metal hydride batteries in the past and the process has been adequately modified by recyclers to accommodate Lithium-ion chemistries. In this technology, the batteries are put into a high temperature smelter to reduce the component metal oxides into alloys. The alloys so obtained are put through chemical processes to obtain the desired materials out of them.
- ***Hydrometallurgy*** employs chemical processes to obtain the desired materials in batteries rather than using high temperatures as done in pyrometallurgy. This route requires certain mechanical and/or thermal pre-treatment to separate the cathode and organic materials in the batteries which can be put through chemical processes such as leaching, precipitation, solvent extraction, etc. The hydrometallurgical route has significant lower carbon emissions and energy usage in comparison to pyrometallurgy[105].
- ***Direct recycling*** includes the extraction of anode and cathode material from the batteries and reconditioning of those materials based on the analysis of lost vital anode and cathode components. In principle, the mixed metal oxide cathode materials can

[103] UNIDO – Circular economy (access here)
[104] NEV (New Energy Vehicles) recycling regulations in China have set recovery rates for cobalt, nickel, and manganese to be at least 98%, 85% for lithium and 97% for rare earths used in batteries.
[105] Argonne National Laboratory, EverBatt (assumptions based on recycling plant of 10,000 TPA capacity)

be reincorporated into a new cathode electrode with minimal changes to the crystal morphology of the active material. These materials can be then reused as fresh cathode material in new battery manufacturing.

Keeping in mind that Lithium-ion chemistry is expected to remain the mainstay in future coupled with the environmental impacts of various recycling technologies, hydrometallurgy is considered as an ideal choice for recovering materials from batteries.

Figure 91: Lithium-ion Battery Recycling Overview



Source: Argonne National Laboratory

The figure shown above shows the entry point of the outputs from various recycling processes into the battery value chain for the lithium-ion chemistry. As the processes become more technology intensive and advanced, their entry point into the battery value chain is closer to the end product. One the one hand, Pyrometallurgy is a very matured process but requires further refining for its outputs to enter into the battery value chain. On the other hand, direct recycling is a very newer technology, but its outputs enter into the battery manufacturing step directly.

The table shown below captures the various technologies being used to recycle EV traction batteries across the world and gives a brief overview of the processes.

Table 97: Multiple battery recycling technologies and their uses for various chemistries

	Pyrometallurgy	Hydrometallurgy	Direct Recycling
Lithium-ion	• Matured technology for recovering metal alloys • Further refinement is required to get the desired metal • Requires high capital investment, energy usage, and results in more emissions. • Does not recover Lithium, aluminum or inorganics • 95-99% of cobalt, nickel and copper can be recovered.	• Has a high raw material recovery rates and yield • Product purity suitable for cathode manufacturing • Can accommodate multiple batteries and cathodes • Matured technology with low basic investments and emissions • Requires prior dismantling/ discharging/ crushing • Recovery rate is generally between 85-90%.	• Avoids lengthy and expensive purification steps reducing costs. • Advantageous for low value cathodes such as LMO, LFP – technology/cathode agnostic • Most energy efficient compared to other recycling processes. • Can recover anode as well. • Complex process with the risk of obsolescence of technology when returned to market. • Almost 100% of cathode and anode material recovered.
Nickel Metal Hydride	• The process doesn't require prior discharging, conditioning. • Pure metal alloys are generated. • Matured technology	• Lower capital investment with options for recovery optimization. • Recovers rare earth elements with cathode metals (>95%) and metals	• Not employed for Nickel Metal Hydride batteries.

	Pyrometallurgy	Hydrometallurgy	Direct Recycling
	• The process is capital intensive • Energy intensive with higher emissions • Some companies have efficiency ~100% for Iron, nickel and cobalt.	with efficiency >90% with electrowinning. • Efficiency is highly driven by environmental conditions.	
Lead Acid	• Mainstay of both organized and unorganized Lead acid battery recycling. • The lead alloy generated is of high purity and the process is highly matured with nearly 100% recycling efficiency.	• Not generally used for lead acid batteries as pyrometallurgy provides nearly all the lead content of batteries in cost effective manner.	• Not used for lead acid batteries.

7.2 Recycling lithium-ion traction batteries

With the EV market growing rapidly, and possibly faster than some earlier expectations, the recovery of key raw materials nickel, cobalt, manganese and lithium from within the LIBs (lithium-ion batteries) is becoming increasingly important. Recycled LIBs can be a valuable secondary source for these critical materials, ensuring a stable supply chain.

Lithium-ion batteries can be classified into LFP (Lithium Iron Phosphate), NMC (Lithium Nickel Manganese Cobalt Oxide), LCO (Lithium Cobalt Oxide), NCA (Lithium Nickel Cobalt Aluminum Oxide), LMO (Lithium Manganese Oxide), LTO (Lithium Titanate) and Lithium Nickel Manganese Spinel (LNMO). All chemistries have distinct cathode compositions and all the chemistries except LTO have graphite as anode material. Based on the cathode composition, the lithium-ion batteries vary in terms of the elements that they constitute.

There are various metallurgical refining processes used to recycle LIBs. However, we will mainly focus on those already commercialized or with the most potential to be commercialized (i.e., pyrometallurgy, hydrometallurgy and direct-cathode recycling). Prior to the raw material extraction process, all methods require LIB waste feedstock to undergo some degree of pre-processing (mechanical and/or thermal). This depends on the input complexity (i.e. full battery packs, cells, or black mass intermediates) and can vary a lot but broadly involves some combination of sorting, disassembly, shredding, crushing or thermal calcination.

There are three technologies utilized to recycle Lithium-ion chemistry batteries:

Technology	Brief
Hydrometallurgy	• Includes mechanical pre-treatment and metal recovery from black mass by means of leaching, precipitation, solvent extraction, ion-exchange resins, and bioleaching.
Pyrometallurgy	• Includes processing of spent lithium-ion cells at high temperature without any mechanical pre-treatment and loading batteries directly into the furnace.
Direct Recycling	• Includes crushing and physical separation of components and recovery of black mass and reinstating lost lithium to put the ensure the health of the anode and cathode are restored to be used in new batteries.

7.3 Limitations and challenges faced in the recycling of Li–ion traction batteries

Recycling lithium-ion batteries is not a straightforward task; there are several considerations that are linked with recycling of lithium-ion batteries. Some of these challenges *(such as economic feasibility)* can be tackled by intervention from the government, whereas for others *(such as carbon footprint)*, the industry has to make concerted effort.

Key limitations and challenges faced by the industry in recycling lithium-ion batteries:

Economic feasibility

Battery recycling is a complex process and requires substantial capital investment. The recycled materials may also be more expensive than newly extracted materials. This poses a threat to its overall acceptability and hence will therefore require government incentives (policies, guidelines, etc.) to promote the circular economy.

Evolving design and technology

Batteries are subject to constant R&D to enhance their chemical composition. As a result, there is a question on the feasibility of using the materials recovered from 10-12 year old batteries to meet the needs of new generation batteries.

Traceability of recycled materials

LIBs can be used in less demanding applications once they are taken off from their first-life applications. The secondary usage may appear to be more feasible than recycling (due to the high cost of the latter) and thus batteries may ultimately end up in a landfill after their capacities gradually wear off. Thus, a monitoring or reporting system should be in place to enable traceability of recycled battery materials, which is challenging to implement.

Carbon footprint

One of the biggest supporting arguments for promoting battery recycling is that it helps in reducing an EV’s carbon footprint. However, the recycling process itself involves a number of carbon-emitting activities, starting with the emissions resulting from collecting and transporting batteries to the recycling process, which itself requires a considerable amount of electricity and thermal energy. Therefore, recycling batteries is only effective from a carbon footprint reduction perspective when the entire closed loop of battery recycling has a lower carbon footprint.

Quality of recycling

Materials from improper or substandard recycling could lead to battery explosion causing threat to life and property. Therefore, battery recyclers need to adhere to the highest quality standards to ensure the purity of the material recycled.

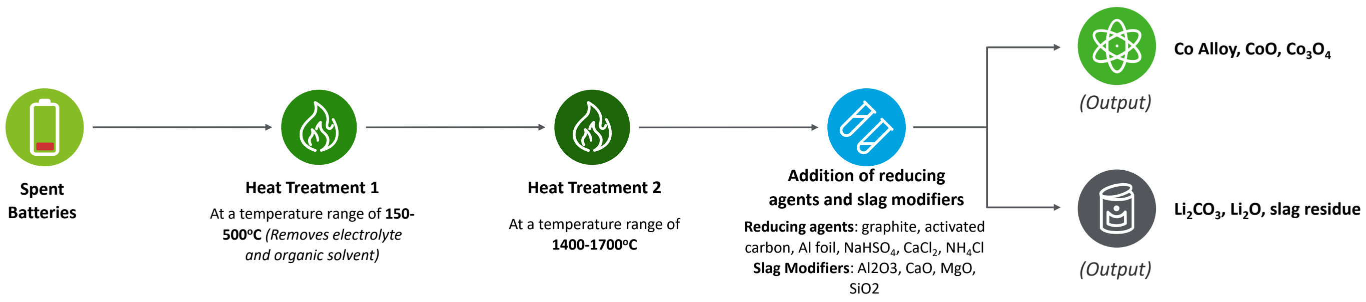
7.4 Lithium-ion battery recycling technologies

Pyrometallurgy

This process uses high temperature furnace for reduction of component metal oxides to an alloy of cobalt, copper, iron and nickel. In general, NiMH and Lead acid batteries are smelted in furnaces to obtain alloys of their underlying metals. Thus, pyrometallurgical recycling of lithium-ion batteries which also uses high temperature smelting is a natural progression from those used for other types of batteries making it very well established commercially.

The process is illustrated below:

Figure 92: Generic process flow of Pyrometallurgical Recycling of LiB



Source: M. Assefi, et al., Pyrometallurgical recycling of Li-ion, Ni-Cd and Ni-MH batteries: A mini-review, Current Opinion in Green and Sustainable Chemistry

The products of the pyrometallurgical process are metallic alloy fractions, slag and gases. As illustrated above, it uses a high temperature smelting process to reduce the battery components and embedded metal oxides to select alloys including cobalt, nickel, copper and iron. Other raw materials (lithium and aluminum) are largely rendered as uneconomic slag, while all the organic material including the anode, electrolyte solvent and plastic separator are oxidized into gaseous emissions and lost.

Pyrometallurgy is typically used for pre-processing methods to reach intermediate black mass and/or metal alloy products and then a hydrometallurgical process is used thereafter to recover raw materials. The slag from the process usually contains metals such as aluminum, manganese and lithium, which can be reclaimed by further hydrometallurgical processing, but can alternatively be used in other industries, such as the cement industry.

Some of the established companies employing pyrometallurgy for recycling EOL (end of life) lithium-ion batteries are Umicore, Accurec, Glencore, and BASF. Most of these players have modified their pre-existing recycling processes to accommodate lithium-ion battery recycling. The metallic alloy formed by pyrometallurgy is further put through hydrometallurgical process for metal extraction.

The advantages and disadvantages of pyrometallurgical recycling are stated below.

PROS

- A pure metal alloy is generated immediately in the pyrometallurgical step which can be easily treated
- There is no need for prior discharging of the EOL (end of life) cells or modules which is a slow and lengthy process
- Though energy intensive at the start, the process becomes very energy efficient once production is up and running
- This is a robust technology which can cater to a mix of different Lithium-ion chemistries without strict sorting requirements
- This produces minimal wastes (<2% in the form of Calcium Fluoride)

CONS

- Requires high initial investment cost
- Process cannot be used to recycle lithium, aluminum, or organics
- This is an ultra-high temperature process, involving safety risks such as explosions.
- Higher green-house gas emissions (including Hydrogen Fluoride gas)
- This process needs to be augmented with further metal refinement (often with hydrometallurgy)

In general, 95-99% of Cobalt, Nickel and Copper is available for further processing and possible reuse in Lithium-battery materials. Lithium recovery out of the slag fraction is up till 70%[106]. Compared to mining virgin raw materials for the batteries, the pyrometallurgical route consumes 26% lower energy and reduces GHG emissions by 10%[107].

Hydrometallurgy

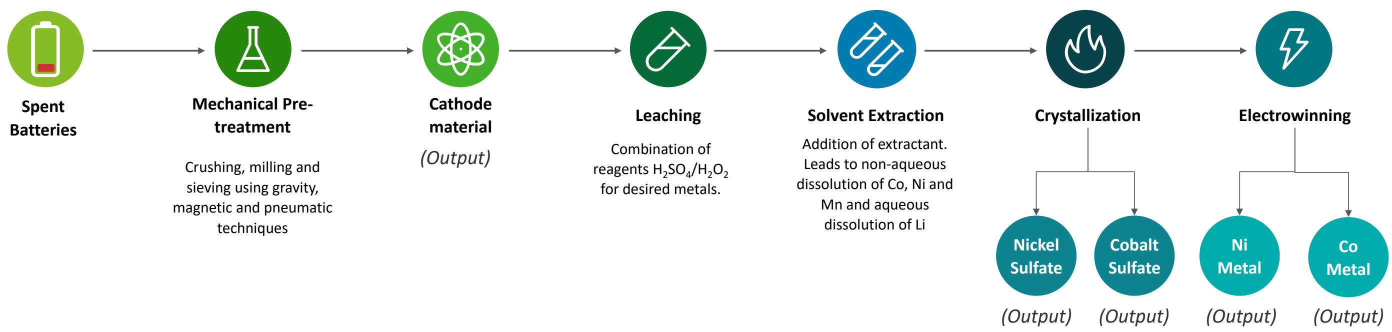
Hydrometallurgical recycling involves leaching active material from the cathode, electrolyte and anode materials (i.e. black mass) in aqueous solution (e.g. acid/alkali) using chemical reagents followed by a series of filtration, solvent extraction, precipitation and crystallization processes. This process leads to recovery of desired LIB raw materials including nickel sulphate, cobalt sulphate and lithium carbonate, manganese carbonate and graphite. The resulting recycled raw materials can then be directly used in cathode production depending on quality.

Generally, a combination of H_2SO_4/H_2O_2 is used as reagent in the recycling process. Based on various studies, it was found that leaching efficiency improved with the addition of H_2O_2.

After leaching, the second step is purification which separates the metals via selective chemical reactions. This includes solid–liquid reactions (e.g., ion exchange, precipitation) and liquid–liquid reactions (e.g., solvent extraction). In the last step, the metal of interest needs to be recovered from the solution as a solid product, i.e. a metal, a metal salt or a compound by crystallization, ionic precipitation, reduction with gas, electrochemical reduction, or electrolytic reduction.

A very important step in the hydrometallurgical process is the extraction of black mass from the batteries. Black mass in general refers to the cathode material extracted from the battery mechanically. The batteries are generally shredded after discharging. Discharging is usually done through saltwater dipping or via a discharge bank for larger batteries. The shredded material is subsequently sieved to separate different fractions and a magnetic separation is applied to remove iron particles. The fractions remaining will be mainly copper, plastics, aluminum, black mass (graphite, cobalt, nickel, manganese, lithium). The process flow for this is illustrated below:

Figure 93: Generic process flow of Hydrometallurgical Recycling of LiB



Source: UBS Analyst Report, Secondary Research

The advantages and disadvantages of hydrometallurgical recycling are stated below:

PROS	CONS
• Involves high raw material recovery rates and yield	• Mechanical dismantling/ discharging/ crushing processes are required unlike pyrometallurgy

[106] UBS Chemical Sector Analyst Report
[107] Gaines et. al, Direct Recycling R&D at ReCell Center

PROS

- Involves high product purity suitable for cathode manufacturing
- Mechanism is battery/ cathode agnostic
- Needs low capital investment costs
- Technology is relatively matured
- Process is carried out in low temperature (less than 120 °C, typically 60-80 °C)

CONS

- Limited effect of scale of product on overall cost
- Leaching process is sensitive to variation of feed and requires continuous operational adjustments according to pH, temperature, feed mix, etc.
- Use of acids with possibility of evaporation leads to safety risks

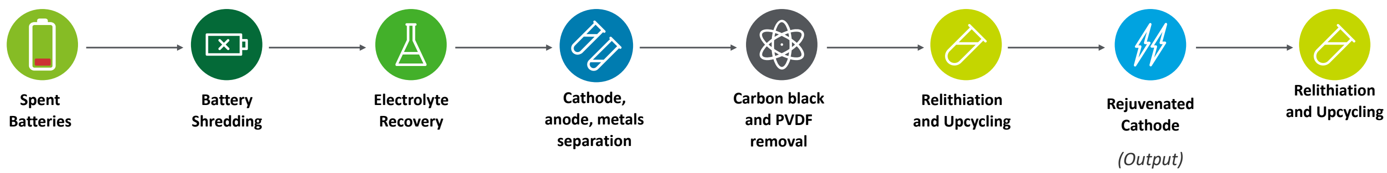
Hydrometallurgical unit operations often occur as refining steps at the end of a process chain because of their ability to produce high quality products. The recovery rate is generally between 85-90%. The recovered material can be applied for further processing and can be reused as Lithium-ion battery materials. Hydrometallurgical recycling in comparison to virgin raw material mining consumes 19% lower energy and emits 18% lower GHG gases[107]. The energy consumption is slightly higher than pyrometallurgical process but the GHG emissions are nearly twice as lower.

Direct recycling

Direct recycling is defined as the recovery, regeneration, and reuse of battery components directly without breaking down the chemical structure. In simple terms, the removal of cathode or anode material from the electrode for reconditioning and re-use in a remanufactured lithium-ion battery is known as direct recycling. In principle, mixed metal-oxide cathode materials can be reincorporated into a new cathode electrode with minimal changes to the crystal morphology of the active material.

In general, this will require the lithium content to be replenished to compensate for losses due to degradation of the material during battery use and because materials may not be recovered from batteries in the fully discharged state with the cathodes fully lithiated.

Figure 94: Direct recycling of LiB



Source: Gaines, et al, Direct Recycling R&D at the ReCell Center

In this process, the batteries are first disassembled, and they are put through a shredder to reduce the size as per the requirement of the direct recycling process. After shredding, a feedstock of anode and cathode on their current collectors is obtained. This feedstock is the most valuable component of lithium-ion cells, including the black mass, electrolyte, aluminum foils and copper coils. The electrolyte is then separated from the electrode material to enable the downstream processing. The separation can be done using supercritical CO2 extraction (only for LFP), thermal drying, water washing, or solvent extraction.

After battery shredding, electrolyte recovery, separation of components such as plastics, cell casing, magnetic ferrous-based metals, the electrode fragments that include anode on copper foil and cathode on aluminum foil are left behind. Using an ethylene-glycol based process, electrode materials are efficiently delaminated from the current collectors. Using thermal pyrolysis, the carbon black and PVDF (poly vinyl difluoride) are removed from the cathode composition.

As the lithium content in end-of-life batteries is generally 15-20% lesser compared to new batteries, there is a need to replenish the same to make the cathode material suitable for re-use in new batteries. This process of replenishing the lithium into the cathodes is called relithiation. In general, there are multiple processes for relithiation as shown in Table 98. These processes have a lithium source that compensates for the missing lithium in the cathode material. The multiple processes for relithiation are thermal, hydrothermal, redox mediator, ionothermal and electrochemical. Details of the relithiation processes are given below:

Table 98: Various Relithiation processes

Process Type	Lithium Source	Conditions	Unique features
Thermal	LiOH with knowledge of lithium vacancy concentration	Heating in 2 stages	-
Hydrothermal	LiOH/ KOH solution	Low temp. hydrothermal reaction followed by high temp. anneal	-
Redox mediator	Anode of electrochemical cell	Room Temperature	Reaction facilitated by mediator
Ionothermal	Li salt in ionic liquid	Low temp. ionothermal reaction followed by high temp. anneal	Takes place in ionic liquid
Electrochemical	Anode of electrochemical cell	Room temperature	Roll-to-roll reaction under development

Source: Gaines et. al, Direct Recycling R&D at ReCell Center

Due to rapid development of lithium-ion battery chemistries, replenishing the lithium into the cathodes will not be enough. Instead, upcycling of the cathode material by chemically changing its composition to desirable cathode formulations is necessary. After upcycling, the rejuvenated cathode can be used in the manufacturing of new batteries.

The advantages and disadvantages of direct recycling are stated below:

PROS

- Avoids lengthy and expensive purification steps which helps in reducing costs
- Advantageous for lower-value cathodes such as LMO, LFP, where manufacturing of cathode oxides is the major contributor to cathode costs, embedded energy and carbon footprint
- In principle, all battery components can be recovered and re-used after further processing (except separators)
- Most energy efficient (lower GHG vs hydrometallurgy)
- Has to potential to recover anode as well

CONS

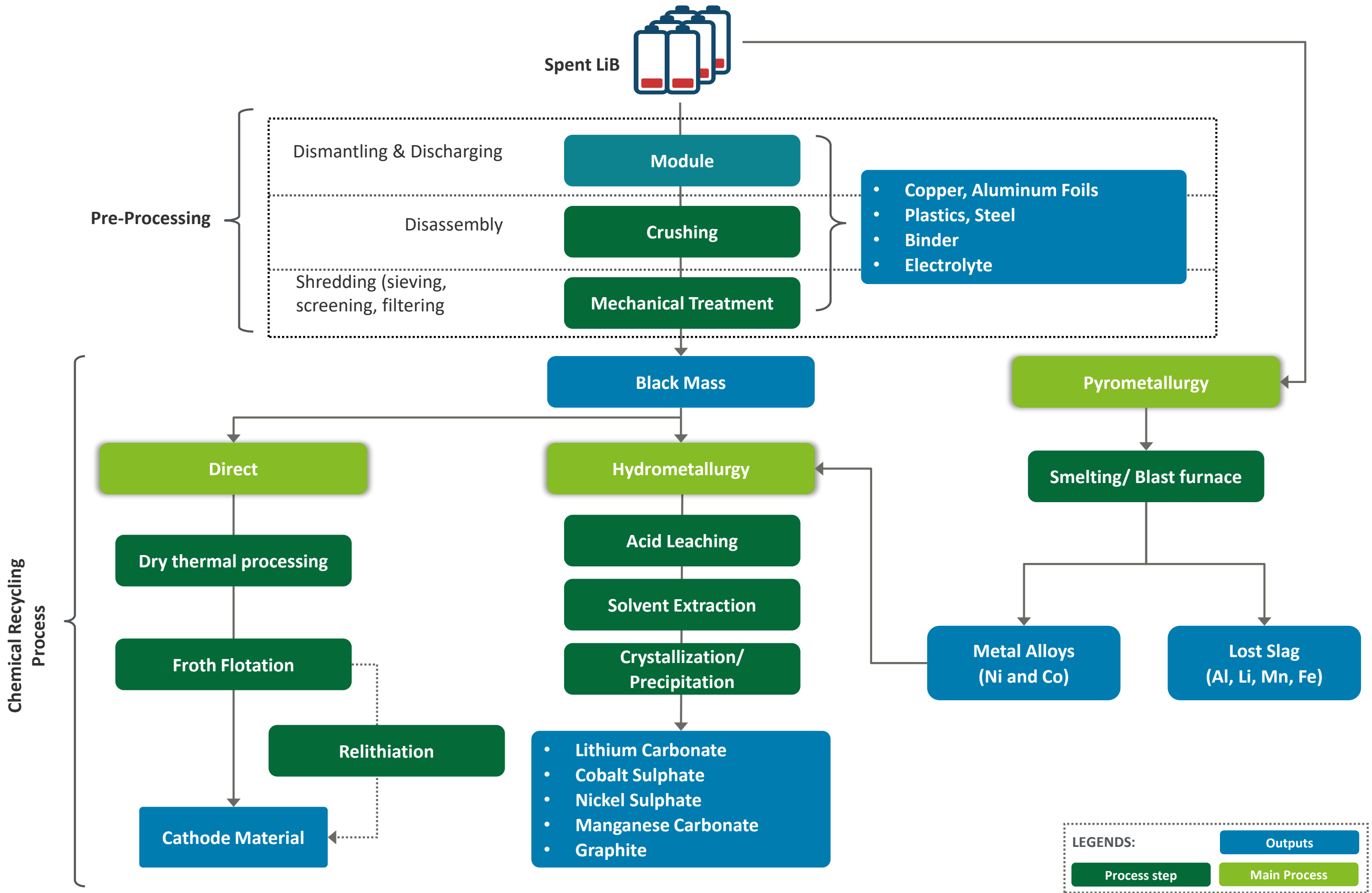
- Efficiency of direct recycling is correlated with the state of health of the battery and may not be advantageous when SOC (state of charge) is low
- Recycling of cathode coatings is highly sensitive to contamination by other metals, such as Aluminum, resulting in poor electrochemical performance
- Involves complex mechanical pre-treatment and separation.
- The performance of cathode material from direct recycling is uncertain in comparison to virgin cathode material
- As battery technologies are evolving and especially lithium-ion chemistries, there is high risk of obsolescence when the battery is returned to the market with direct recycled cathode material.

Compared to virgin material mining, direct recycling consumes 73% lower energy and emits 68% lower GHGs[107]. This makes the process most efficient in terms of emissions and energy consumption compared to hydrometallurgy and pyrometallurgy.

Comparative assessment of recycling technologies

Each of the lithium-ion battery recycling processes have their merits and demerits which have been outlined in their respective sections. A simplified workflow of LiB recycling is illustrated below:

Figure 95: Simplified workflow of LiB Recycling Processes



Pyrometallurgy is highly mature and has little process complexity but lacks in aspects such as recovering materials such as aluminum and lithium. Pyrometallurgy also has high energy input due to the use of smelters and high capital cost associated with them as well.

Hydrometallurgy technology is on the rise and has higher recovery efficiencies with lower environmental impacts. The associated capital cost and energy usage for hydrometallurgy are lower in comparison to pyrometallurgy and it has the ability to derive all the materials amongst cobalt, nickel, lithium, copper, and aluminum.

Direct recycling is in infant stage and involves high process complexity. It leads to comparatively lower emissions and energy usage, but the technology hasn't been tested in large scale unlike that of pyrometallurgy and hydrometallurgy.

Figure 96 captures the comparison amongst various recycling methods on multiple facets such as technology readiness, process complexity, recovery, and energy usage to name a few.

Figure 96: Comparative assessment of LiB Recycling methods

Method	Technology Readiness	Process Complexity	Recovered Material Quality	Recovered Material Quantity	Toxic material containment	Energy Usage	Capital Cost
Pyrometallurgy	●	●	◔	◑	◐	◔	◔
Hydrometallurgy	◕	◑	◕	◕	◑	◑	◑
Direct Recycling	◐	◔	◑	●	◕	◑	◑

Method	Battery Presorting	Cathode Material Recovery	Raw Material Recovery				
			Cobalt	*Nickel*	*Lithium*	*Copper*	*Aluminum*
Pyrometallurgy	●	x	◕	◕	x	●	x
Hydrometallurgy	◕	x	●	●	◐	◕	◕
Direct Recycling	◔	●	NA	NA	NA	NA	NA

LEGENDS	More Favorable			Less Favorable
	●	◕	◑	◐	◔

Source: Harper et.al., Recycling Lithium-ion batteries from electric vehicles, Analyst Reports

Based on the comparative assessment, it is evident that hydrometallurgical lithium-ion battery recycling process is the most attractive option as it offers a good balance of robust raw material recovery / yield potential, commercial viability, scalability, and battery/cathode technology adaptability. In India, it has been observed that many of the players are choosing hydrometallurgy owing to the higher recovery rates and because of the fact that intermediates such as black mass have several alternative applications.

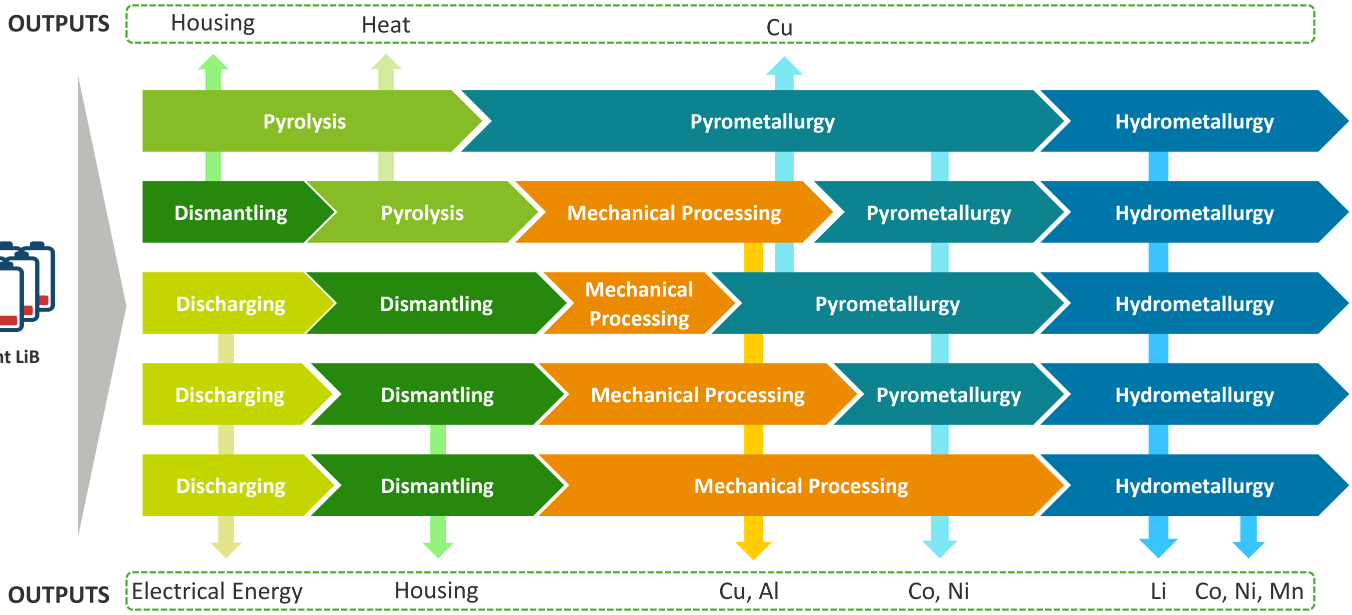
7.5 Lithium-ion recycling processes adopted globally

Companies around the world adopt a mix of processes to recover target materials from end of life (EOL) batteries. A mix of pyrometallurgy and hydrometallurgy can also be utilized to obtain higher material recoveries.

There are various steps involved in recycling lithium-ion batteries viz. dismantling, pyrolysis, mechanical processing prior to the main processes of pyrometallurgy and hydrometallurgy. Because of the inherent nature of pyrometallurgy which requires further refining, hydrometallurgy is carried out on the alloys to obtain desired metals.

The dismantling process includes the separation of the battery electricals such as battery management system and related circuits in the battery pack. Mechanical processing includes crushing and physical separation of components and recovery of the black mass, which contains valuable metals such as cobalt, nickel, manganese, lithium etc. Pyrolysis process puts the battery through high temperatures to remove organic compounds and graphite which adversely affect leaching and solid liquid separation steps of the recycling process.

Figure 97: Various routes for LiB Recycling



Source: Recycling of Lithium-ion batteries, RWTH Aachen University, VDMA, Battery LabFactory Braunschweig; Note: - Mechanical processing includes electrolyte recovery; Cu: Copper, Al: Aluminum, Co: Cobalt, Ni: Nickel, Li: Lithium, Ni: Nickel, Mn: Manganese

Figure 97, shown above, demonstrates the multiple process sequences that can be adopted to recycle lithium-ion batteries. Apart from the technologies discussed earlier viz. hydrometallurgy, pyrometallurgy and direct recycling, there are some important process steps necessary (e.g. dismantling, mechanical processing, pyrolysis) to prepare the batteries/ battery material for recycling. This combination of recycling approaches enables diverse routes for recycling that vary in effectiveness and have advantages and disadvantages depending on the focus on material recovery (such as nickel vs. lithium).

Different routes can be utilized by recyclers to recycle spent lithium-ion batteries. For instance, in the first row in Figure 97, batteries are directly put through pyrolysis (thermal treatment) to dissolve organic solvents and to get rid of their housing. Once pyrolysis is completed, the batteries are put through pyrometallurgy and hydrometallurgy to obtain Copper, Cobalt, Nickel and Lithium as signified from the arrows with the chevrons of the process. Similar to the first row, all other rows signify different method sequences that are used globally by recyclers.

In the next section, we focus on the notable battery recyclers and map their processes against their primary and secondary recoveries.

Global LiB recycling competitive landscape

Multiple global players have developed proprietary processes to recycle lithium-ion batteries. The table shown below highlights the key global players in LiB recycling.

Table 99: Global LiB Recycling competitive landscape

Company	Country	Feed	Pre-processing	Mechanical Processing	Process	Main recoveries	Secondary recoveries
Umicore	Belgium	LiB, NiMH	Dismantling	-	Pyrometallurgy + Hydrometallurgy	Co, Ni, Cu, Fe, $CoCl_2$	Slag: Al, Si, Ca, Fe, Li, Mn, REE
Sumitomo-Sony	Japan	LiB	Sorting Dismantling	-	Pyrometallurgy + Hydrometallurgy	CoO	Co-Ni-Fe alloy, Cu, Al, Fe
Retriev Technologies	USA	LiB, Primary Li	Dismantling	Wet comminution, screening, shaking table, filtration	Hydrometallurgy	Li_2CO_3, MeO	Steel, Co, Cu, Al
Recupyl Valibat	France	LiB, Primary Li	-	Crushing, Vibrating screen, secondary screen, magnetic separator, densiometric table	Hydrometallurgy	Li_2CO_3, $LiCO_2$, Li_3PO_4	Steel, Cu, Al, MeO, C
Akkuser	Finland	LiB	Sorting	1st cutting, air filtration, cutting, magnetic separator	Mechanical Processing	Co, Cu, powder Fe	Non-ferrous metals
Accurec	Germany	LiB	Sorting, dismantling	Milling, separation, agglomeration, filtration	Pyrometallurgy	Li_2CO_3 alloy	Metallic alloy
Battery resources	USA	LiB	Discharge	Shredding, magnetic separation, sieving	Hydrometallurgy	Li_2CO_3, $NMC(OH)_2$	Ferrous metals
OnTo	USA	LiB, Primary Li	Discharging, dismantling	Shredding, sieving dense media separation	Direct Recycling	Refurbished cell cathode powder	Ferrous and non-ferrous metals
Li-Cycle	USA, Canada	LiB	Discharging, dismantling	Shredding, magnetic separation, sieving	Hydrometallurgy	Li_2CO_3, Cobalt Sulphate, Nickel Sulphate, Manganese carbonate	Shredded Copper, Aluminum, Mixed plastics
Brunp	China	LiB	Discharging, dismantling	Shredding, magnetic separation, sieving	Hydrometallurgy	Co, Ni, and Mn	Shredded Copper, Aluminum, Mixed plastics
GEM	China	LiB	Discharging, dismantling	Shredding, magnetic separation, sieving	Hydrometallurgy	Co, Ni	Shredded Copper, Aluminum, Mixed plastics

Source: Martinez et. al, A critical review of Lithium-ion battery recycling processes from a Circular economy perspective; Note: LiB – Lithium-ion battery, NiMH – Nickel Metal Hydride, Co – Cobalt, Ni – Nickel, Cu – Copper, Fe – Iron, Mn – Manganese, MeO – Methoxy

The processes of Umicore and Recupyl were initially not designed for the recycling of lithium-ion batteries, but the increasing presence of these types of battery in the waste stream prompted them to redesign their processes. This has been a driving factor for other recyclers as well to modify their processes.

It can be observed from Table 99 that in China, hydrometallurgy is the preferred technology for recycling whereas in USA, Canada and European countries, both pyrometallurgy and hydrometallurgy are prevalent. Newer players in the market such as Li Cycle in USA and Canada are working on hydrometallurgy to develop high recovery rates. Many of the established European recyclers have adopted hydrometallurgy post pyrometallurgy to obtain useful metals after alloys are obtained in pyrometallurgy (e.g., Umicore). The primary reason for such arrangement is that these players had equipment designated for pyrometallurgy which was more than sufficient to address material recoveries from Lead acid and Nickel metal hydride batteries but with the advent of lithium-ion batteries, the technology lacked in recovering essential metals and had to be augmented.

Recycling efficiency of multiple technologies

All the recycling firms around the world have unique set of procedures to recover the desired materials from the battery. Each of them has their own proprietary process. Data on recovery efficiencies of these processes are not available in public domain. However, a high-level information on recycling efficiency of their technologies has been reproduced below:

Table 100: Recovery of materials by different recyclers

Company	LITHIUM		METALS	
	Lithium Product	Efficiency	Fe Casing	Al and Cu Foils
Umicore	Not Recovered	-	Fe: Recovered on alloy	Cu: recovered in alloy
Sumitomo-Sony	Not Recovered	-	Fe: Recovered on alloy	Cu: recovered in alloy
Retriev Technologies	Li_2CO_3	90%	Fe, Al, and Plastics: recovered in shaking table	Not mentioned
Recupyl Valibat	Li_2CO_3/ Li_3PO_4	Undisclosed	Fe: Recovered with magnetic separator	Al, Cu, and plastics: recovered with density separation
Akkuser	Not recovered	-	Fe: Recovered with magnetic separator Plastics: Recovered via air filtration	Al and Cu: recovered from fin powder
Accurec	Li_2CO_3	76-90%	Fe: Recovered with magnetic separator	Al and Cu: recovered via air separator
Battery resources	Li_2CO_3	67-80%	Fe: Recovered with magnetic separator	Al: recovered during leaching Cu: recovered via dense media separation and precipitation
OnTo	Li_2CO_3/cathode	Undisclosed	Fe, Al, and plastics recovered	Al and Cu: recovered
Li-Cycle	Li_2CO_3	>95%	Al, Plastics recovered	Al and Cu recovered

Source: Martinez et. al, A critical review of Lithium-ion battery recycling processes from a Circular economy perspective; Company reports, Analyst Reports

The recycling efficiency of the technologies also vary with the battery chemistries. Two of the most widely used lithium-ion chemistries i.e. LFP and NMC have separate recycling efficiencies when they go through hydrometallurgy processes in the one hand and a mix of pyrometallurgy and hydrometallurgy on the other hand. The table shown below captures the recycling efficiency of the processes.

Table 101: Percentage of material recovered in different recycling processes for NMC and LFP Chemistries

Process	Battery Type	Material Recovery (%)			
		Lithium	Nickel	Manganese	Cobalt
Pyrometallurgical and Hydrometallurgical	NMC and LFP	57	95	0	94
Hydrometallurgical	NMC	94	97	~100	~100
	LFP	81	n/a	n/a	n/a

Source: Lebedeva, N., Di Persio, F., Boon-Brett, L., Lithium ion battery value chain and related opportunities for Europe, European Commission, Petten, 2016

Because of the inherent nature of pyrometallurgy due to which it produces alloys, hydrometallurgy is a necessary step to refine those alloys into desired metals. Thus, in Table 101, material recoveries with both pyrometallurgy and hydrometallurgy have been shown against hydrometallurgy alone. It is worthwhile to note that graphite is not a major concern for recovery for many recyclers across the globe. But promoting the inclusion of graphite is essential for ensuring a circular economy.

As the battery chemistries develop at a rapid pace, the recyclers have to optimize their processes to achieve higher recycling efficiencies.

Component wise costing

The three different processes for recycling lithium-ion batteries viz. hydrometallurgy, pyrometallurgy and direct recycling have unique equipment requirement. For understanding the component wise costing of a recycling plant, we have considered annual capacity of 10,000 tons of spent battery per year.

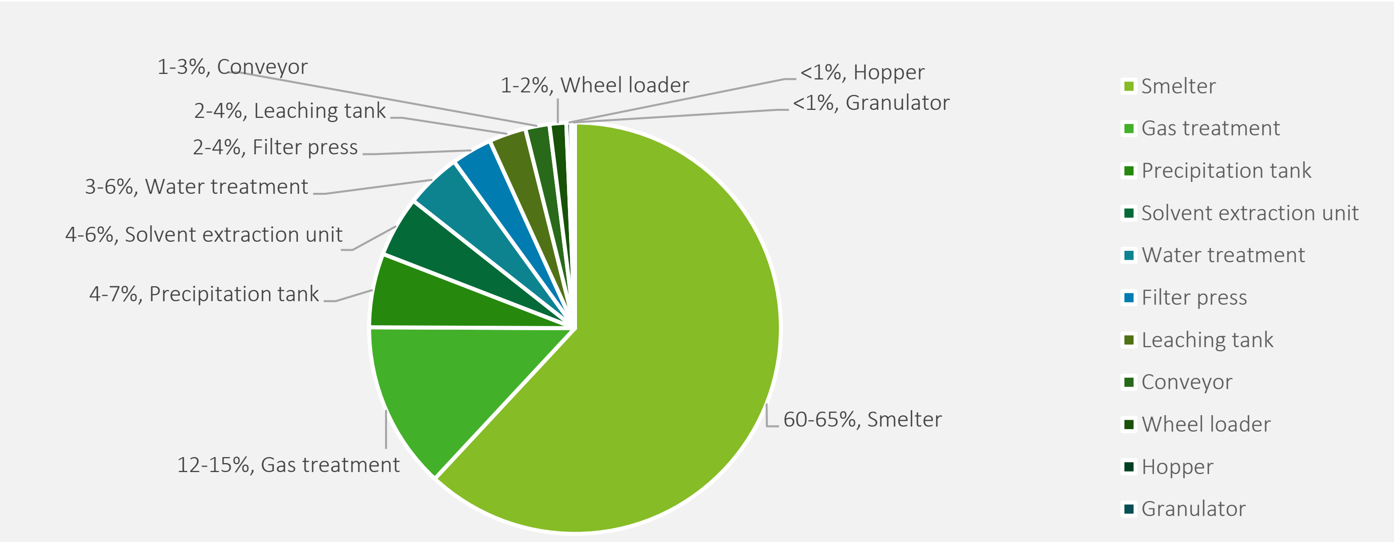
Table 102: Overall equipment cost for different LiB recycling processes

Process	Pyrometallurgy	Hydrometallurgy	Direct recycling
Overall Equipment Cost (USD Mn)	21-24	12-14	13-14

Source: Argonne National Laboratory

The equipment necessary for pyrometallurgy are smelter, conveyor, hopper, gas treatment unit, granulator, leaching tank, precipitation tank, filter press, solvent extraction unit, wheel loader, and water treatment unit. The major cost heads for the process are the smelter and the gas treatment equipment which contribute to ~75% of the component cost.

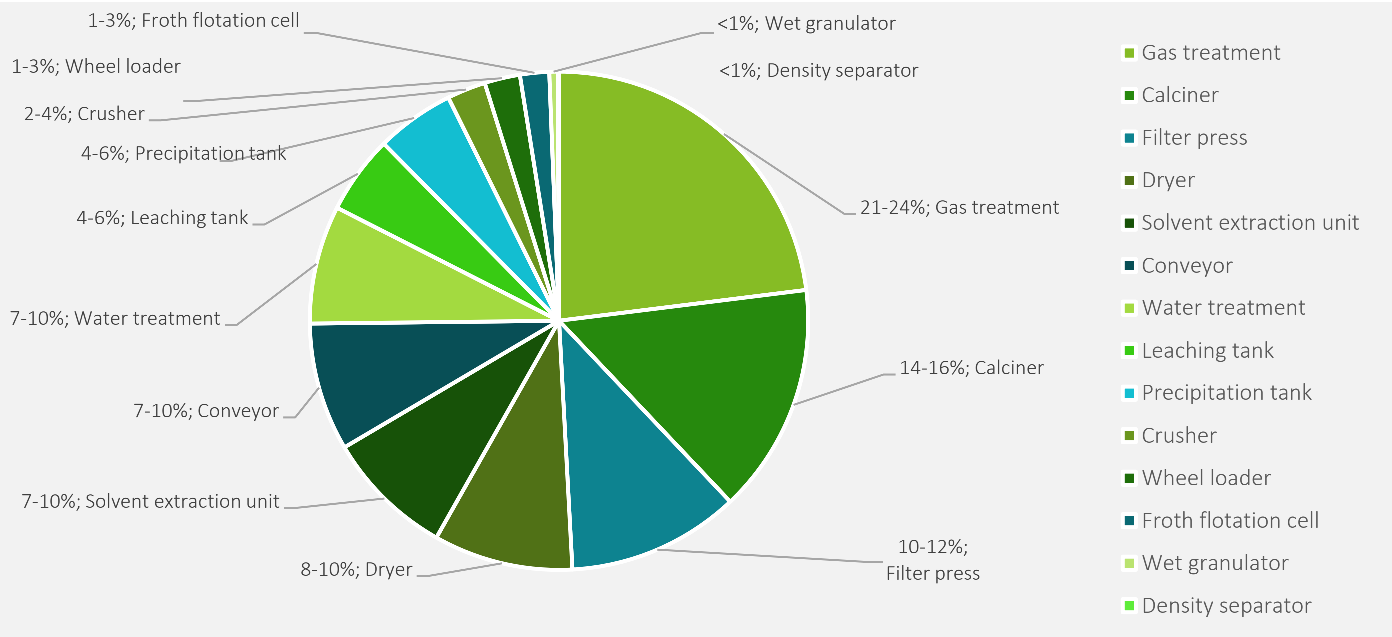
Figure 98: Component wise cost share for Pyrometallurgy



Source: Deloitte Analysis, Argonne National Laboratory

Hydrometallurgical process requires a higher number of chemical processes in comparison to pyrometallurgical and direct recycling. The major cost contributors are the gas treatment unit and the calciner which contributes to ~35-38% of the equipment cost. The chart below captures the cost estimates of the components:

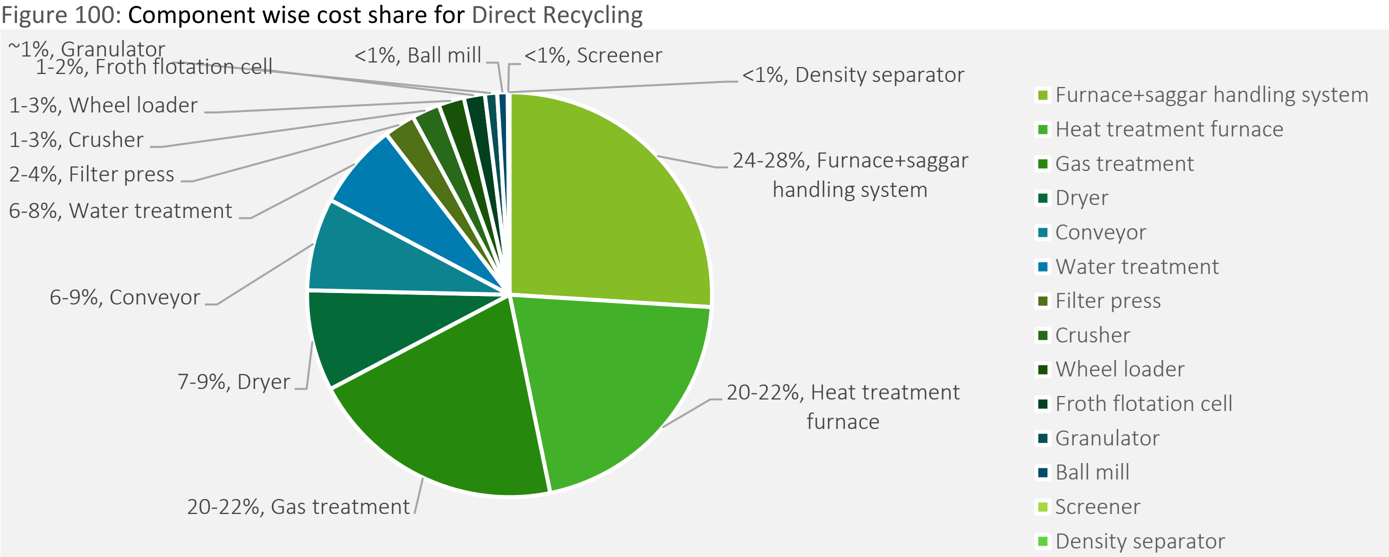
Figure 99: Component wise cost share for Hydrometallurgy



Source: Deloitte Analysis, Argonne National Laboratory

Direct recycling process employs the revitalization of the cathode material to be used again in battery manufacturing. The major cost contributors (60-70%) of direct recycling equipment are furnace, saggar handling unit, heat treatment furnace, and gas treatment unit.

Figure 100: Component wise cost share for Direct Recycling



Source: Argonne National Laboratory

The component wise cost of a battery recycling unit ranges from USD 12 Mn to USD 24 Mn. Total equipment cost of a Pyrometallurgy process ranges between USD 21-24 Mn. Hydrometallurgy and direct recycling on the other hand have lower capital investment on equipment ranging between USD 12-14 Mn. Direct recycling leads to lower costs amongst the other technologies but is not mature enough for large scale battery recycling. Thus, considering all factors at present, hydrometallurgy is considered as the most feasible and effective process for recycling lithium-ion batteries.

7.6 Recycling Nickel Metal Hydride traction batteries

Nickel metal hydride (NiMH) is one of the most advanced and commercially available rechargeable batteries. The chemistry uses Nickel oxide hydroxide in its positive electrode and hydrogen absorbing alloy (rare earth metal alloy) in the negative electrode. Recycling of NiMH battery is important because of the need to retrieve rare earth metals present in them.

There are two technologies used for recycling NiMH batteries as described briefly in the table below:

Technology	Brief
Hydrometallurgy	Mechanical pre-treatment and metal recovery by means of leaching, precipitation, solvent extraction, electrodeposition and precipitation.
Pyrometallurgy	Processing of spent NiMH at high temperature without any mechanical pre-treatment and loading batteries directly into the furnace.

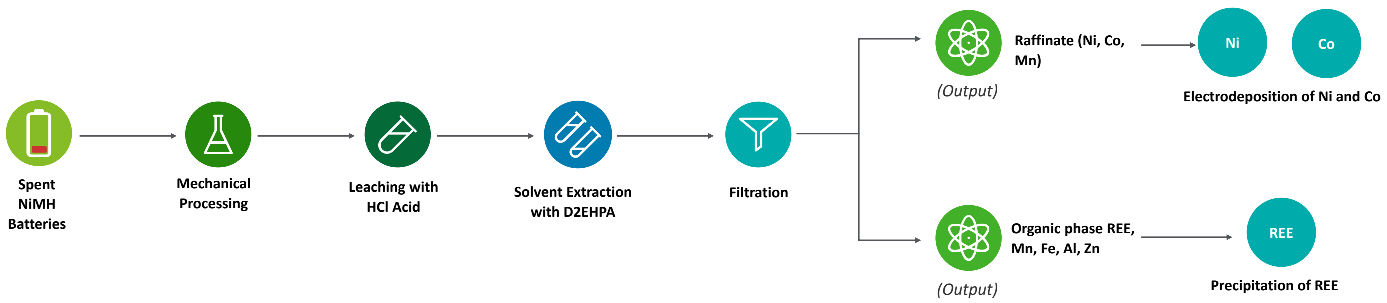
Nickel Metal Hydride recycling technologies

Hydrometallurgy

The hydrometallurgical process is based on dissolution of the NiMH batteries in acidic solvents like Hydrochloric acid. Once the acid leaching is complete, solvent extraction process is initiated which uses DEHPA (Di-(2-ethylhexyl) phosphoric acid). The solvent extraction process has two outputs viz. Nickel rich aqueous solution which is called raffinate solution and organic solvent loaded with Rare earth elements (REE) and other metals.

The raffinate solution so obtained is put though electrodeposition to obtain Nickel and cobalt. The organic solvent loaded with REE and other metals is further put through extraction technology with organophosphorus extractants. The precipitation obtained from the extraction provides REE and other metals such as manganese, aluminum, iron, and zinc are also extracted.

Figure 101: Generic process flow of Hydrometallurgical Recycling of NiMH Batteries



Source: N Tzanetakis and K Scott, Recycling of nickel–metal hydride batteries; Note:- HCl: Hydrochloric Acid; D2EHPA: Di-(2-ethylhexyl)phosphoric acid; Ni: Nickel, Co: Cobalt, REE: Rare Earth Element; Mn: Manganese; Fe: Iron; Al: Aluminium; Zn: Zinc

The advantages and disadvantages of this process are stated below:

PROS

- Lower capital investment required
- Lesser electricity consumption compared to Pyrometallurgy

CONS

- Use of acids with possibility of evaporation of gases leads to safety concerns
- Efficiency depends on the ambient / environmental conditions

PROS	CONS
• Well matured technology	

Table 103: Recovery Efficiency from Hydrometallurgical recycling of NiMH

Recoveries	Ni, Co alloy	Rare Earth Salts
Recovery Efficiency	>90% (with electrowinning)	>95%

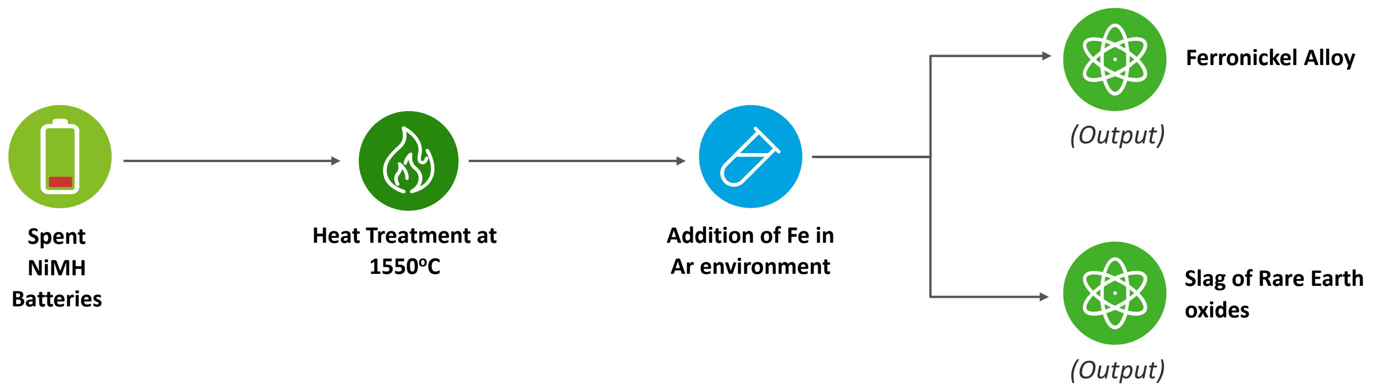
Source: NIST

Pyrometallurgy

In Ni-MH batteries, different elements are present in complex intermetallic phases. The difference is the behavior of REEs and transition metals such as iron, cobalt, and nickel in terms of their affinity towards oxygen is used to isolate REEs (Lanthanum, Cerium, Neodymium, Dysprosium, and Praseodymium) in the form of transition metal oxides at high temperature.

The anode material of NiMH battery is first oxidized in air at 1000 °C for 1 h and then reduced in Argon at 1550 °C for 1.5 hour by adding a waste developer kit (>99 wt.% iron) as the reducing agent. Due to the diffusion of nickel and cobalt into the iron, ferronickel alloys are obtained. Addition of slag materials at different high temperatures have been a subject of experimentation of multiple companies. The slag so produced can be processed to a rare earth element concentrate.

Figure 102: Generic process flow of Pyrometallurgical Recycling of NiMH Batteries



Source: M. Assefi, S. Maroufi, Y. Yamauchi, V. Sahajwalla, Pyrometallurgical recycling of Li-ion, Ni-Cd and Ni-MH batteries: A mini-review, *Current Opinion in Green and Sustainable Chemistry*

The advantages and disadvantages of this process are stated below:

PROS

- Is a quite matured technology
- No requirement for discharging batteries prior to processing leads to savings in costs
- Capability to handle multiple battery chemistries such as Lithium-ion as well, helping in attaining scale

CONS

- Higher capital investment required
- Higher emissions and electricity consumption
- Use of acids, with evaporation of gases leads to safety concerns
- Efficiency depends a lot on the ambient / environmental conditions

Companies like Accurec GmbH have recycled Iron, Nickel and cobalt at an efficiency of close to 100%[108]. The recovery efficiency from the slag generally depends on its refining process which is usually done by some other entity to whom the slag is sold by the recyclers.

Global Nickel Metal Hydride recycling processes

Nickel metal hydride batteries were dominant in the industry prior to the arrival and rapid technological advancement of lithium-ion batteries. These batteries have higher capability to perform in various environmental conditions and are widely used in hybrid electric vehicles.

Many prominent recyclers such as Umicore have modified their processes of recycling NiMH batteries to accommodate lithium-ion batteries. The table shown below captures some of the prominent players in the recycling of NiMH batteries around the world.

Table 104: Adoption of multiple recycling processes by players worldwide for NiMH recycling

Company	Country	Recycling technology implemented
Umicore	Belgium	Pyrometallurgy with electrowin
Accurec GmbH	Germany	Pyrometallurgy
Dowa	Japan	Pyrometallurgy
SNAM	France	Pyrometallurgy
Retriev Technologies	USA	Pyrometallurgy
Veolia	France	Hydrometallurgy

Source: Company websites, Secondary Research

It is evident that pyrometallurgy is the preferred mode of recycling for NiMH batteries in comparison to hydrometallurgy globally.

7.7 Recycling Lead Acid traction batteries

Lead acid batteries are the most mature chemistry in the market globally. However, owing to its lower cycle life in comparison to NiMH and Lithium-ion, the batteries are not used widely for traction purposes now a days.

Lead acid battery recycling technology

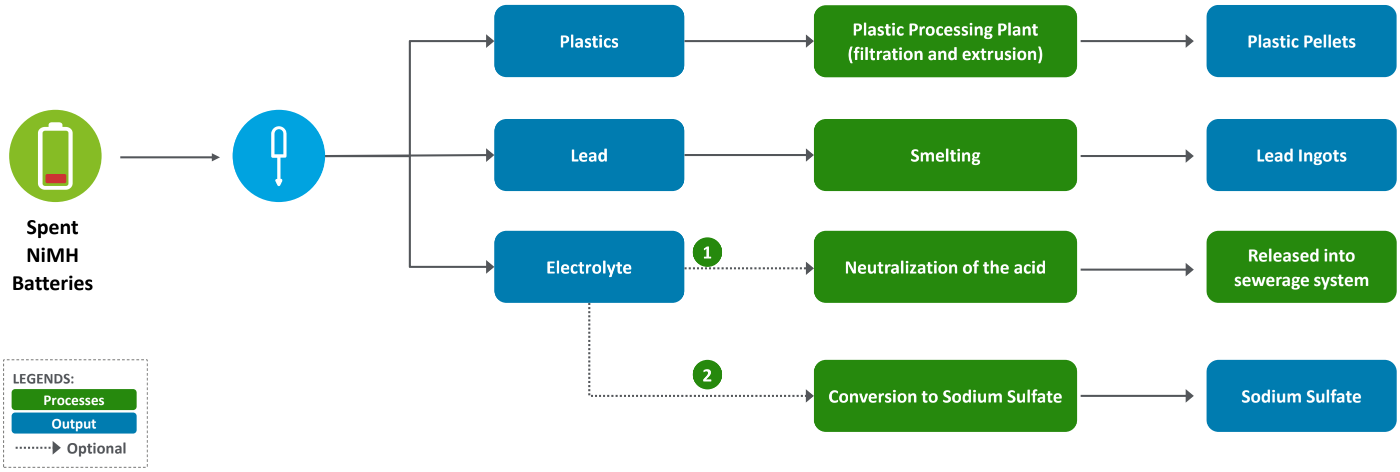
Once the spent batteries are received by the battery recycler, which is typically a secondary lead smelter, the recycling process begins. First the batteries are crushed into nickel sized pieces. The plastic components are then separated out and the same is done for the lead components of the batteries. This plastic is sent to a plastics processing plant for manufacture into new plastic products, most of which are casings for new batteries. Battery plastic tends to be the same plastic that has been recycled over and over again.

The lead, which is a fairly valuable metal, is sent to a smelter where it is converted into lead ingots. The smelter has scrubbers and filters that removes any non-lead materials. The gaseous components of sulfuric acid go up through ducts where they are cooled and condensed and then filtered into a pure enough form to be resold. Some of the smelter organizations sell the sulfuric acid as a commodity.

Once the batteries are crushed, the battery acid can be handled in two ways[109]. Either it can be neutralized with an industrial compound similar to household baking soda or else it can be processed to convert it into sodium sulfate. Neutralizing the acid converts it into water basically which can be released into sewerage system after it passes through certain test conditions. Converting the acid to sodium sulfate can help in reselling the same for applications as a detergent or for glass and textile manufacturing.

[108] Accurec GmbH (access here)
[109] Battery Council International, Recycling Lead acid batteries (access here)

Figure 103: Recycling process for Lead Acid Batteries



Source: Battery Council International

The recycling efficiency of lead acid batteries is nearly 100%. This has been possible as the chemistry has been in place since a long time and the recyclers of these chemistries had in place sufficient time to improve and optimize their recycling processes.

The advantages and disadvantages of this process are stated below:

PROS

- **Matured and commercialized** technology
- **No requirement for discharging batteries** prior to processing saving costs

CONS

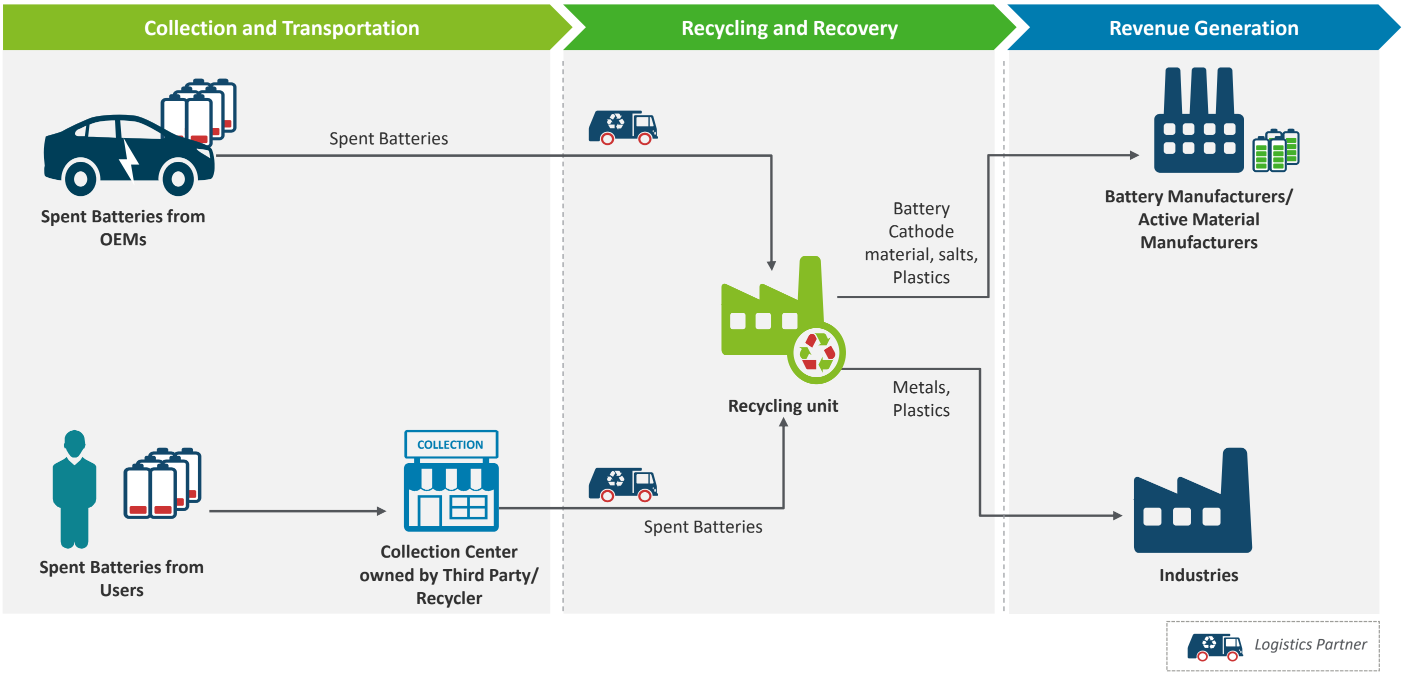
- **Lead exposure** to workers might lead to safety and health hazards, if not handled properly
- Improper handling of electrolyte can lead to **contamination of ground water**

7.8 Battery recycling industry

Organized and unorganized battery recycling

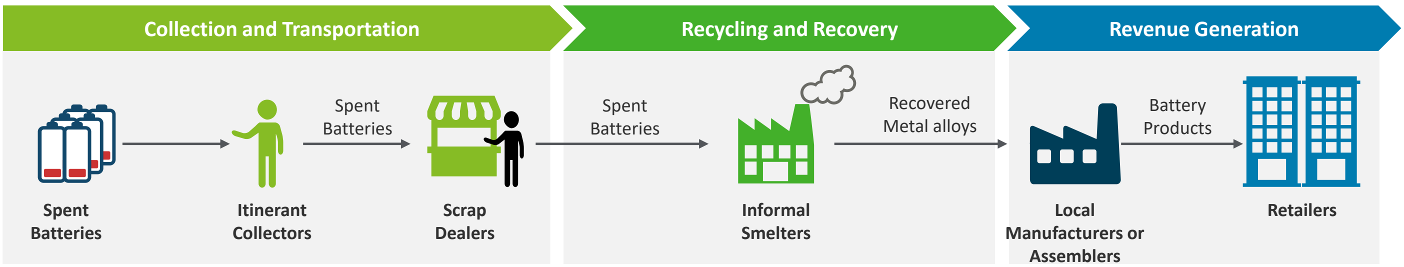
The battery recycling industry can be divided into organized and unorganized sector. While the organized sector has specific rules and regulations that the recyclers have to adhere to, the unorganized players usually include scrap dealers and informal smelter units.

Figure 104: Organized recycling industry operations



Organized battery recycling includes the flow of batteries from the end consumers to the recycling plant through appropriate and defined channels, such as battery aggregators. The collection of the batteries can also be done by the battery manufacturers or electric vehicle OEMs themselves. The recyclers in the organized segment have to comply with environmental and safety regulations set by the government. The processes used by organized recyclers are of higher efficiency with lesser emissions in comparison to the processes used by unorganized recyclers who generally use smelters.

Figure 105: Unorganized recycling industry operations



Source: CEEW

The unorganized recycling industry is different from the organized recycling industry in a sense that the collection of batteries is usually done by itinerant collectors (also known as kabadiwallas in India). These collectors take the batteries to the scrap dealers where the scrap dealers sell the batteries ahead to the informal smelters in their network. The metal extraction done by the informal smelter is then sent to the local battery manufacturers or assemblers who then sell the product ahead to retailers[110]. The informal smelters in this sector may not follow the entire set of environmental and safety norms.

Informal smelters have low metal recovery rates in comparison to organized players. For instance, in the case of lead acid battery recyclers, the lead recovery rate of informal smelters ranges from 50% to 90% whereas the organized recyclers have recovery rates upwards of 98%.

Though the recovery rates of the organized players are higher, the unorganized players have a larger market share at present. Organized recyclers incur additional costs for recycling batteries as they have to adhere to environmental standards and other

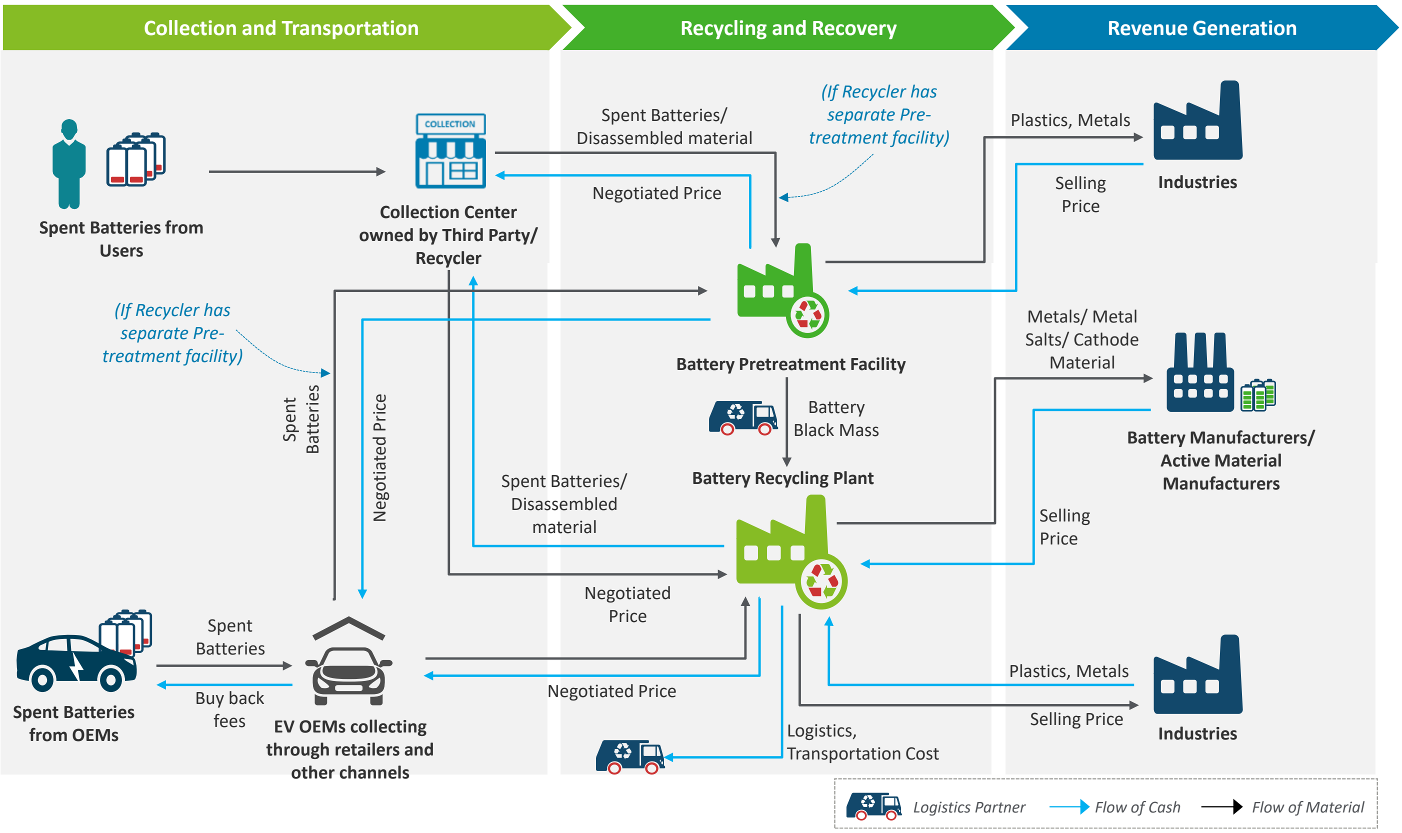
[110] CEEW, Lead acid battery recycling in India (access here)

compliances. Informal recyclers don't incur such costs and are able to procure batteries at lower costs. Apart from the price difference, the collection frequency of unorganized recycling industry through itinerant collectors is higher compared to the organized recycling industry which leads to higher volume of batteries in circulation in the unorganized sector.

Business model for battery recycling

Battery recycling as a business begins as the life of battery ends. These end of life (EOL) batteries have to be collected, transported in a safe and sound manner as per guidelines to the recyclers who can then carry out the recovery of desired metals.

Figure 106: Business Model for EV Traction battery recycling



Source: Deloitte Analysis

The figure illustrated above captures the business model for battery recycling. The batteries are collected either from battery aggregators or through the EV OEMs who have a buyback program for batteries. The batteries from the battery aggregators are received with the help of logistics partners who ensure that the batteries are safely transported to the recycling facility. Some battery aggregators have also developed capabilities of disassembling batteries and providing the recyclers with the desired battery parts only. Based on the activity and involvement of the battery aggregators, the prices are negotiated by the recyclers.

Once the recyclers receive the batteries, pre-treatment is carried out based on their preferred recycling method. After pre-treatment, the batteries go through the recycling process. The materials and compounds obtained from the recycling process are then sold to battery manufacturers, battery active material manufacturers or industries. The following table shows the various players involved in the overall business.

Table 105: Multiple stakeholders in the Recycling business model

Business Model Participation	Stakeholder	Role
Collection and Transportation	Collection Centers	• Collection centers can be operated by battery aggregators or by recyclers. The collection centers work as a drop off point for used batteries. Collection centers may also have capabilities of disassembling batteries before sending them to recyclers.
	EV OEMs	• OEMs collect traction batteries through their dealerships and send the battery across to the recyclers. This ensures that there is a steady flow of battery to recyclers.
	Logistics Partner	• Logistics partners ensure that the batteries from OEMs and Collection centers reach the recyclers.
Recycling and Recovery	Battery Pre-treatment facility	• Pre-treatment for batteries is necessary for hydrometallurgy and direct recycling technologies. Some recyclers have separate pre-treatment facilities spread across their geographies to disassemble batteries and send the black mass to recycling plants. The transportation of black mass is cheaper compared to the whole batteries.
	Battery recycling plants	• Battery recycling plants recycle the black mass, or the entire battery based on the kind of setup the company has and the preferred technology for recycling.
Revenue Generation	Battery manufacturers and active material manufacturers	• These are the off takers of the products generated from recycling. The metal salts and the cathode material obtained from recycling is sought by these companies for infusion into new batteries.
	Industries	• The plastics and metals recovered from the recycling process are sold mostly to industries.

Collection, logistics, pre-treatment, and secondary life potential of traction batteries

Transportation and logistics are a critical link in the recycling business. The business model of every recycler has to take into account the methodology employed to ensure that the end-of-life batteries reach their facility at the most optimal cost.

Collection centers are key to the collection of EOL batteries. These collection centers can either be operated by the recycler themselves or they can take the help of battery aggregators who have their own logistics for collection of batteries.

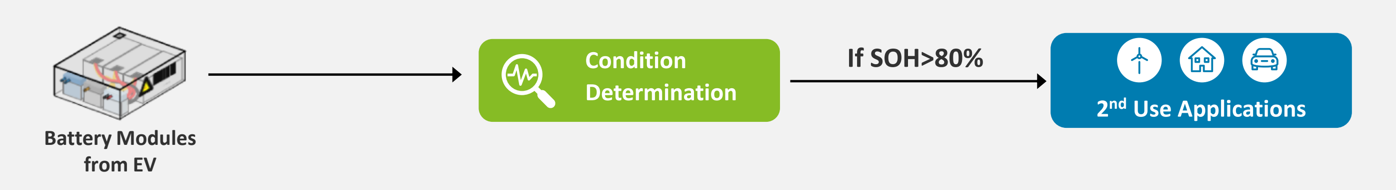
For instance, in the US, there are dedicated programs from companies such as Call2Recycle that have dedicated public drop-off locations. WeRecycleBatteries is an entity that partners with suppliers and organizations to take the used batteries. Once the battery aggregators collect the used batteries, they send the batteries to the recyclers and are paid as per their agreement on the type and quantum of used battery delivered.

Some battery aggregators also provide disassembly services (such as Battery Solutions[111]). The recyclers in such cases can focus completely on recycling and not worry about pre-treatment. This kind of arrangement is mostly sought by hydrometallurgy-based recyclers who require pre-treatment and mechanical processing prior to recycling process inception.

Another option for the recyclers is to have a dedicated logistics partner. The logistics partner helps them in collecting the batteries from individual EOL battery suppliers and bring them to the facility. However, a key enabler of this model is the need to have a large scale of supply from the individual suppliers so as to result in optimal transportation costs.

[111] Battery Solutions (access here)

Figure 107: second use application decision



Source: RWTH Aachen University

Once the batteries have been transported, the state-of-health (SOH) of the battery is determined. If the same is above ~80%, it is deemed fit for second use[112]. The second life applications include use in vehicle starting, home inverters, energy storage solutions, etc. The determination can be done either at the collection center or at the recycling plant based on the availability of testing equipment.

The model in which pretreatment is done at the collection center and the "black mass" (roughly 30-50% of the battery mass) is sent to recycling plant is known as **Hub and spoke model**. The battery recycler in this case has greater revenue options which can be realized by selling the black mass and the plastics generated after pre-treatment. Transportation of black mass only helps in reduction of transportation cost as well.

The transportation and logistics of EV traction batteries have to be monitored because of their categorization as hazardous materials. For lithium-ion batteries, specific labels are designated, such as UN 3480, which have to be attached for shipping. The batteries also have to be transferred in UN-approved drums.

Expected market size for EV battery recycling in India

We have already determined the estimated sales figures for EVs in our first section of the report. Indian roads are expected to see cumulative sales of EVs in the range of 25.7 Mn to 46.4 Mn as per Deloitte analysis. To analyze the market size of Lithium-ion battery recycling, certain assumptions have been taken as follows:

- Batteries reach their end of life in 8-10 years.
- 60% of the EOL batteries from e-2Ws, e-3Ws, e-passenger vehicles and e-commercial vehicles are available for recycling whereas 80% of the EOL batteries from e-buses are available for recycling because of ease to enforce regulatory oversight at government level.
- It is assumed that e-2Ws, e-3Ws, e-commercial vehicles, e-passenger vehicles, and e-buses use batteries of sizes 2.5 - 5 kWh, 4.5 - 10 kWh, 35 - 75 kWh, 25 - 55 kWh, and 150 – 250 kWh respectively.

The detailed assumptions taken for the market size evaluation are mentioned in Annexure section.

Based on the assumptions stated above, the table below captures the market size expected for EV Lithium-ion battery recyclers.

Particulars	2031	2036
LiB available for recycling (GWh)[113]	2 – 2.30	35 – 58

Battery recycling in India

India is on the path of adding a greater number of electric vehicles in the coming decade on the back of growing concern on GHG emissions. Although the adoption of electric vehicles has been slow, the cumulative market size of batteries by 2030 is expected to be between 268 GWh to 498 GWh[114]. This would create a need for a vibrant and well-functioning local recycling ecosystem in the country to take care of this substantial volume of batteries when they reach their end-of-life.

[112] Recycling of LiB Batteries, RWTH Aachen University
[113] Deloitte Analysis
[114] Deloitte Analysis, Battery demand from EVs in India

For lead acid batteries, the Battery Waste Management Rules (BWMR) were announced[115] in 2001. The rules outlined responsibilities of manufacturers, importers, re-conditioners, and assemblers to ensure that used batteries are collected and sent to registered recyclers. The implementation of these rules has been a challenge, as the informal sector is dominant in recycling[116].

Strengths and weaknesses of the Indian recycling system for batteries are mentioned below:

PROS

- A large network of itinerant collectors (kabadiwaalas) has larger reach for waste collection and serve both the organized and unorganized recycling sectors
- Experience with recycling of lead-acid batteries can be leveraged to develop new rules covering lithium-ion and advanced battery chemistries.

CONS

- Unavailability of a comprehensive battery waste management rules/ guidelines covering EV traction batteries such as Lithium-ion, Nickel metal hydride.
- High share of informal smelters in recycling of chemistries such as lead acid drives end-of-life batteries away from the organized recyclers. This leads to inability to operate at scale and improve profitability.
- Battery chemistries other than lead acid are governed by e-Waste Management Rules which does not cover terms of safe disposal and recycling of batteries. This leaves room for improper practices.

Lithium-ion battery recycling in India

The lithium-ion battery recyclers in India are mostly e-waste recyclers as these batteries fall under the purview of e-Waste Management Rules, 2016. Recyclers collect batteries through various channels viz. battery manufacturers, collection centers (third party run or by the recycler), and also through the informal sector which provides the recyclable batteries at the collection center.

Once the batteries have been collected, they are sent to the recycling facilities, where pre-treatment is carried out. During pre-treatment, the batteries are dismantled either manually or automatically based on the process automation levels of the recyclers. The batteries are first disassembled and shredded to the required levels as per the method applied by the recyclers. Since in India, none of the recyclers have adopted pyrometallurgy for recycling of lithium-ion batteries, the pre-treatment is a necessary step. After pre-treatment, the black mass i.e. the cathode material, is further treated for refining and recovery of the desired materials.

Most of the players in the Indian lithium-ion battery recycling business are suppliers of black mass as against being an end-to-end recycling and refining player. This is mostly due to constraints in technology, lack of demand from organized sector, unfavorable policies and lack of incentives for investments in the sector. Further, there is a strong demand of the black mass from other industries, other than battery manufacturing. Many recyclers such as TES-AMM use their Indian facilities for pre-treatment only and send the black mass to their factory in Singapore. The table below captures the various recyclers, with capabilities to recycle Lithium-ion batteries.

Table 106: Lithium-ion battery recyclers in India (non-exhaustive)

Recycler	Technology	Location in India
Attero Recycling	Hydrometallurgy	Uttarakhand
Tata Chemicals	Hydrometallurgy	Maharashtra
TES-AMM	Mechanical and Hydrometallurgy	Chennai
Exigo Recycling	Hydrometallurgy	Haryana
Sungeel	Hydrometallurgy	Andhra Pradesh

[115] CPCB Status Review Report on Implementation of Batteries (Management and Handling) Rules, 2001 (as amended thereof), 2016 (access here)
[116] Recycling of Lithium-ion batteries in India, JMK Research, 2019

Recycler	Technology	Location in India
E-Parisaraa	Mechanical	Karnataka
Ecoreco	Mechanical	Maharashtra
Surbine Recycling	Hydrometallurgy	Gujarat
BatX Energies	Hydrometallurgy	Haryana

Source: Company Websites, Secondary Research; Note: Mechanical process adopters generate black mass only and don't recover materials.

The entities who have deployed the mechanical process as the preferred technology, are involved only in the dismantling and extraction of black mass from the lithium-ion batteries. The entry of established players such as Tata Chemicals is an encouraging sign for the industry as they would possibly bring scale and try and transform the sector into an organized play. The other encouraging step which some of these players have taken is the use of hydrometallurgy for recycling which is the most environmentally friendly process for recycling lithium-ion batteries.

Licensing or registration requirements for recycling of batteries

For recyclers in India, there are two governing waste management rules i.e. Battery Waste Management Rules, 2001[117] and E-Waste Management Rules, 2016[118]. Each of the rules has specified registration requirements, compliance needs and clearance requirements for obtaining a recycling license.

Although the e-waste management rules of 2016 is the only applicable rule for batteries used in electronics i.e. in portable applications, they have been the only document providing some direction towards the recycling of battery chemistries other than lead acid batteries. As most of the players recycling lithium-ion batteries are e-waste recyclers in India, the registration and license requirements for them have been mentioned as it is expected that these players of today will be the recyclers of EV traction batteries of tomorrow.

Particulars	Battery Waste Management Rules, 2001	E-waste Management Rules, 2016
Registration	• Entity has to apply to Ministry of Environment & Forests, or an agency designated by it along-with the requisite documents.	• Entity has to apply to concerned State Pollution Control Board along-with the requisite documents.
Compliance	• Returns need to be submitted as per Form VII of the State Board • All records relating to receipt of used batteries, sources, quantities and metal yield to be submitted to the State Pollution Control Board for inspection should be made available • Application for renewal should be made at least 6 months prior to the month of expiry	• Entity has to ensure that recycling facility and processes are in accordance with the standards and guidelines prescribed by Central Pollution Control Board from time to time. • Entity has to maintain record of e-waste collected, dismantled, recycled sent to authorized recycler. • Entity has to file annual returns to the concerned State Pollution Control Board as the case may be, on or before 30th day of June following the financial year to which that return relates. • An application for renewal should be made before 120 days of its expiry.
Clearances	**Following are the clearances to be obtained:** • Valid consents under Water (Prevention and Control of Pollution) Act, 1974, as amended and Air (Prevention and Control of Pollution) Act, 1981, as amended.	**Following are the clearances to be obtained:** • Consent to establish granted by the concerned State Pollution Control Board under the Water (Prevention and Control of Pollution) Act, 1974, (25 of 1974) and the Air (Prevention and Control of Pollution) Act, 1981(21 of 1981)

[117] CPCB Battery Waste Management Rules 2001 (access here)
[118] CPCB E-waste Management Rules 2016 (access here)

Particulars	Battery Waste Management Rules, 2001	E-waste Management Rules, 2016
	• Valid authorization under Hazardous Waste (Management and Handling) Rules, 1989 as amended. • Valid certificate of registration with District Industries Centre • Proof of installed capacity issued by either State Pollution Control Board/ District Industries Centre. • The Joint Secretary, Ministry of Environment & Forests or any officer designated by the Ministry or an agency designated by it shall ensure that the recyclers possess appropriate facilities, technical capabilities, and equipment to recycle used batteries and dispose of hazardous waste generated.	• Certificate of registration issued by the District Industries Centre or any other government agency authorized in this regard • Proof of installed capacity of plant and machinery issued by the District Industries Centre or any other government agency authorized in this behalf • In case of renewal, a certificate of compliance of effluent and emission standards, treatment and disposal of hazardous wastes as applicable from the concerned State Pollution Control Board or designated agency

Lithium-ion battery recyclers currently have to adhere to the E-waste Management rules for obtaining license. A draft of Battery Waste Management Rules[119] has been in circulation from 2020 and is expected to be enforced in 2021. The draft rules cover lithium-ion batteries as well as compared to the coverage of only lead-acid batteries in Battery Waste Management rules of 2001. It is expected that the new Battery waste management rules would pave the way for advanced batteries recycling in India.

[119] MoEF Draft Battery Waste Management Rules 2020 (access here)

Success factors for battery recycling in select countries

China

China is the largest recycler of lithium-ion batteries used in electric vehicles. In 2018, nearly 100,000 tons of lithium-ion batteries were recycled across the globe out of which ~67% was undertaken in China[120]. This shows the sheer dominance of China in battery recycling. The nation has introduced a variety of policy measures to encourage/support diverse stakeholders' (*e.g.*, automakers, battery makers) participation in the recycling/utilization of spent batteries. The same are highlighted below.

1 Implementation of Plan of Extended Producer Responsibility System (2017)[121]

The plan requires producers to be responsible in resource consumption and adhere to environmental protection standards throughout the life of the product, rather than just focusing on the manufacturing process. Their responsibilities have been extended to product design, consumption, recycling, and waste disposal, according to the plan.

The prime focus for this plan is to enable battery manufacturers in covering a larger array of functions in the battery value chain other than manufacturing. Extended responsibilities provide an avenue for battery manufacturers to obtain raw materials necessary for their end products and at the same time ensure that batteries are adequately managed.

2 Interim Measures for the Management of the Recycling and Utilization of Power Batteries for New Energy Vehicles (2018)[104]

The scope of the measures includes the management of the recycling of power batteries for new energy vehicles. The measures included EPR, putting the main responsibility of battery recovery on the automobile production company. Relevant companies i.e., recyclers perform the effective disposal and recycling of batteries. The measures also outline the whole life cycle management mechanism of power battery covering the upstream and downstream links of the industrial chain such as Design, Production, Sales, Maintenance, Retirement, Recycling and so on.

3 Guidelines for Construction and Operation of New Energy Vehicle Power Battery Recycling Service Outlets (2019) [104]

The guideline requires that

- new energy vehicle production and step utilization companies (reuse implementation companies) need to build or authorize recycling service outlets
- the company needs to strengthen the tracking of information during the disposal process of waste power batteries
- recycling service outlets must maintain accurate and complete records.

4 Presence of Battery manufacturers in Battery recycling space[104]

Apart from the policy directives, China is also home to the some of the largest battery manufacturers in the world such as BYD and CATL. CATL has established a battery recycling subsidiary by the name of Brunp Recycling and BYD has completed a battery recycling factory in Shanghai[122]. Guoxuan High Tech's subsidiary Hefei Guoxuan Recycling Technology and Hefei Guoxuan New Materials Technology recover and recycle lithium batteries as well. Presence in the end-of-life segment helps the battery manufacturers source battery minerals from their recycling units and ensure the circular economy for batteries.

Collectively the industry players and their backward integration coupled with favorable policy measures have ensured efficient recycling of EV traction batteries in China.

[120] FBI CRC Australian landscape for lithium-ion battery recycling and reuse in 2020 (access here)
[121] Zhe Wang Analysis of Lithium Battery Recycling System of New Energy Vehicles under Low Carbon Background (access here)
[122] Analyst Reports, Samsung Securities

Germany

In Germany, more than 50,000 tonnes of portable batteries and accumulators are recycled every year[123]. The country has dedicated collection programmes and healthy take back quotas for portable batteries. Along with the take back quotas, there are regulations for recycling efficiency and limits on the value of harmful metals such as cadmium, lead, and mercury that can be used in batteries. The country also aims to have 7 to 10 million EVs on the country's roads by 2030. Thus, there is huge impetus to have a robust recycling infrastructure in place for batteries.

Following are various measures taken by the country in the area of battery recycling:

1 Obligation of distributors

Retailers are obliged to take batteries free of charge from consumers. This obligations spreads across all batteries be it portable, industrial (includes EV batteries) or automotive[124]. This ensures that the consumers are not burdened with the task of efficient disposal of batteries.

2 Collection Schemes for Manufacturers

Germany has a host of collection schemes, which ensure batteries are not disposed off arbitrarily. Several schemes such as GRS Batterien Foundation, CCC REBAT Germany, European Recycling Platform, and Ocerecell[123] are in place which enables third party contractors, such as logistics and disposal companies, to take back the batteries and fulfil the recovery obligations. The manufacturers of batteries can opt for any number of collection schemes and utilize the network to ensure batteries are collected and recycled.

3 Batteries Act (BattG)

Germany has implemented European Batteries Directive into their national law. The Act governs the marketing, take-back and environmentally compatible disposal of batteries and accumulators.

Keeping in track with the newer needs of battery disposal, the Batteries Act was amended in 2021 which has brought in certain amendments. The amendments include change from a notification to a registration obligation for all battery manufacturers. New responsibilities and framework conditions for approval of manufacturers' collection schemes have also be brought in. Waste electrical and electronic equipment (WEEE) register has been incorporated to look into manufacturer registration and approval of collection schemes to monitor the schemes and establishment of minimum standards for containers are also included through the new law.

4 Host of Recycling players and industry collaborations

Germany has numerous battery recyclers with advanced capabilities. Some of the notable players include Accurec Recycling GmbH, Duesenfeld GmbH, Redux Recycling GmbH, etc. Automobile giant Volkswagen AG has opened a battery recycling plant in Salzgitter[125]. SMS Group and Neometals (Australia) have created a JV for battery recycling as well. The presence of industry stalwarts and automobile companies provides a healthy ground for battery recycling in the country.

German has initiated multiple battery collection schemes, demarcated responsibilities for distributors and manufacturers and has supported multiple industry collaborations resulting in a healthy ecosystem for recycling.

[123] Federal Ministry for the Environment, Nature conservation and Nuclear Safety (access here)
[124] Federal Ministry for the Environment, Nature conservation and Nuclear Safety, Batteries Act (access here)
[125] Recycling Today, Volkswagen opens EV battery recycling pilot plant (access here)

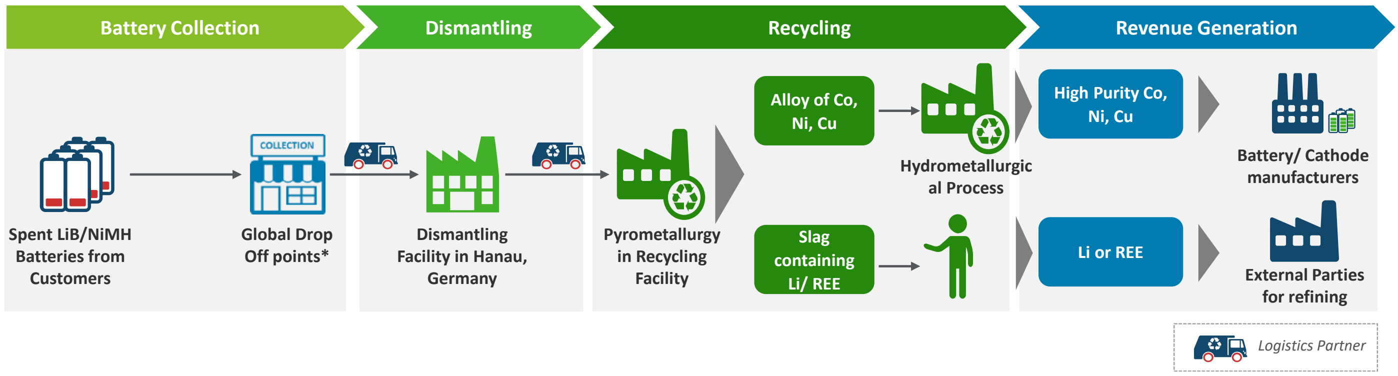
Battery recycling companies – Case studies

Umicore

Umicore is one of the most established battery recyclers in the world. The company is already a leading player in precious metal recycling and is developing a reputation as one of the preferred suppliers of NMC (nickel manganese cobalt) cathode materials for EV batteries. It has extensive relationships with OEMs and automotive producers due to its position in the auto-catalyst market.

Over the last couple of years, Umicore has invested and is involved in various projects involving EV battery recycling (with Audi, BMW, Northvolt, and LG Chem). Since 2006, the company has been recycling lithium-ion and nickel hydride batteries through a three fraction pyrometallurgical process and has capacity of 7kt per year.

Figure 108: Umicore Battery Recycling Overview



Note- *: Drop off points may be operated by Umicore or external partners

Umicore has multiple drop-off points globally to facilitate transport of batteries from vehicles. This global network of drop off points can be utilized by customers to dispose their end-of-life batteries. Umicore runs a dedicated facility for dismantling batteries in Hanau, Germany. The output is then put through the furnace giving alloy of metals and slag. The alloy is put through a hydrometallurgical process to obtain high purity metals which can be later sold to battery/ cathode manufacturers. The slag is integrated is further refined through cooperation with external parties such as Solvay.

Li-Cycle

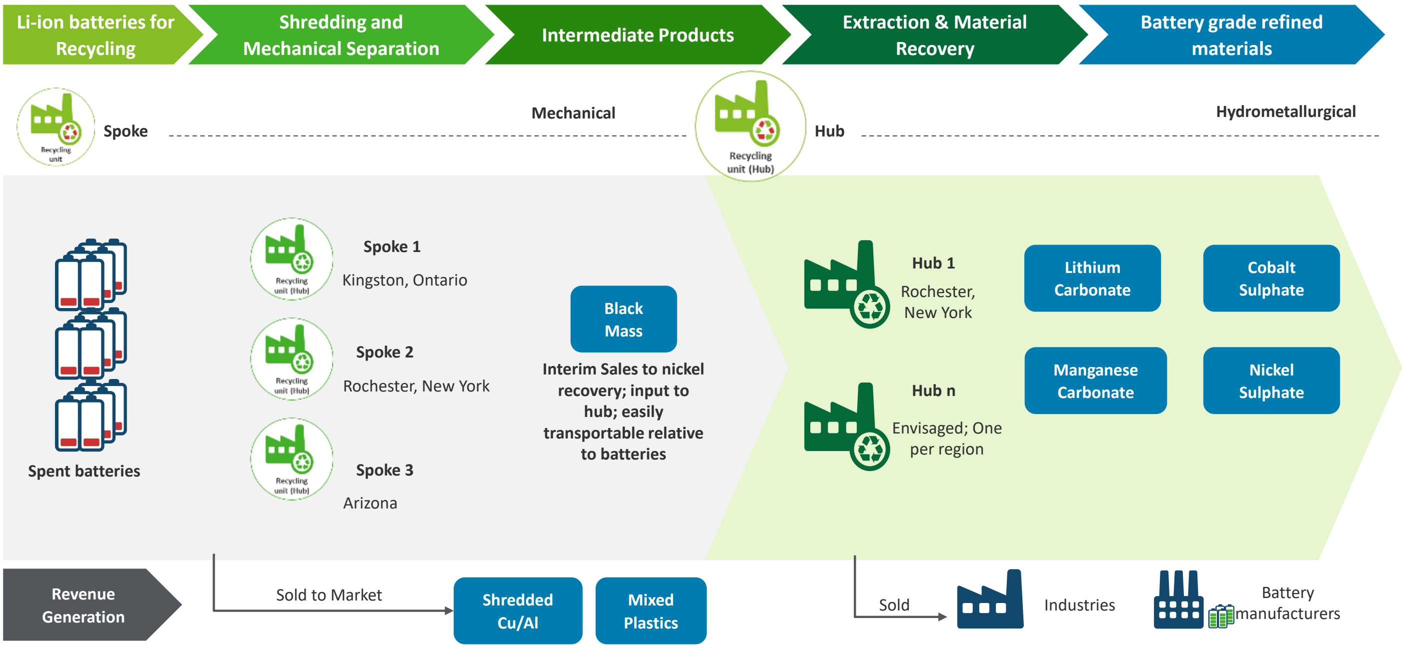
Founded in 2016 in Toronto, Canada, Li-Cycle is an industry leading lithium-ion-battery resource recovery company and one of the largest lithium-ion battery recyclers in North America. The company has ~30% market share of North America and has plans to diversify geographically to Asia and Europe.

Li-Cycle uses a hub and spoke model for battery collection and recycling. The spokes here refer to facilities that receive the batteries and process them through shredding and mechanical separation and produces black mass (battery cathode material), shredded copper and aluminum, and mixed plastics. The hub here refers to the facilities which are capable of extraction and material recovery through hydrometallurgy.

Currently, the company has three receiving facilities in Ontario, New York, and Arizona. They have one hub in Rochester, New York. At present, they have a capacity of recycling 10,000 tons per year with the spokes for separating black mass from batteries and the 60,000 tons/year capacity[126] at the hubs for recycling. The company has a current offtake agreement with Traxys which is one of the largest global metal traders of the world. The company has more than 50 commercial contracts with suppliers of end-of-life batteries and battery related manufacturing scrap for >10,000 metric tons of lithium-ion battery supply annually. Li-Cycle's commercial battery supply customers include 14 of the largest global auto and battery manufacturers. Suppliers also include battery manufacturers and battery aggregators.

[126] Li-Cycle Analyst Presentation April 2021 (access here)

Figure 109: Li-cycle battery recycling overview



Source: Li-Cycle Analyst Presentation; Note: Cu – Copper, Al - Aluminum

Li-cycle uses scalable, standard equipment at its spokes. The Lithium-ion batteries are put into a shredder with a neutralizing solution. The materials, once shredded, are put through screens which provide plastics at one stage and copper, aluminum foils at another stage. After the screening of the materials, they are put through a filter. The compound obtained after filtration is the black mass which is easily transportable.

The apparatus and process used for converting batteries into black mass is patented by Li-cycle. Two of the three outputs viz. aluminum and copper foils and plastics are sold after the processing of the batteries at the spokes. The black mass is further sent to the hub for processing. Li-cycle has a patented hydrometallurgy process which gives them a recycling efficiency of ~95%. The process is battery chemistry and charge agnostic and has zero emissions, no landfill waste or wastewater and is claimed to be future proof[126]. The outputs from the hubs are graphite, copper sulfide, gypsum, manganese carbonate, cobalt sulphate, nickel sulphate, sodium sulphate, and lithium carbonate.

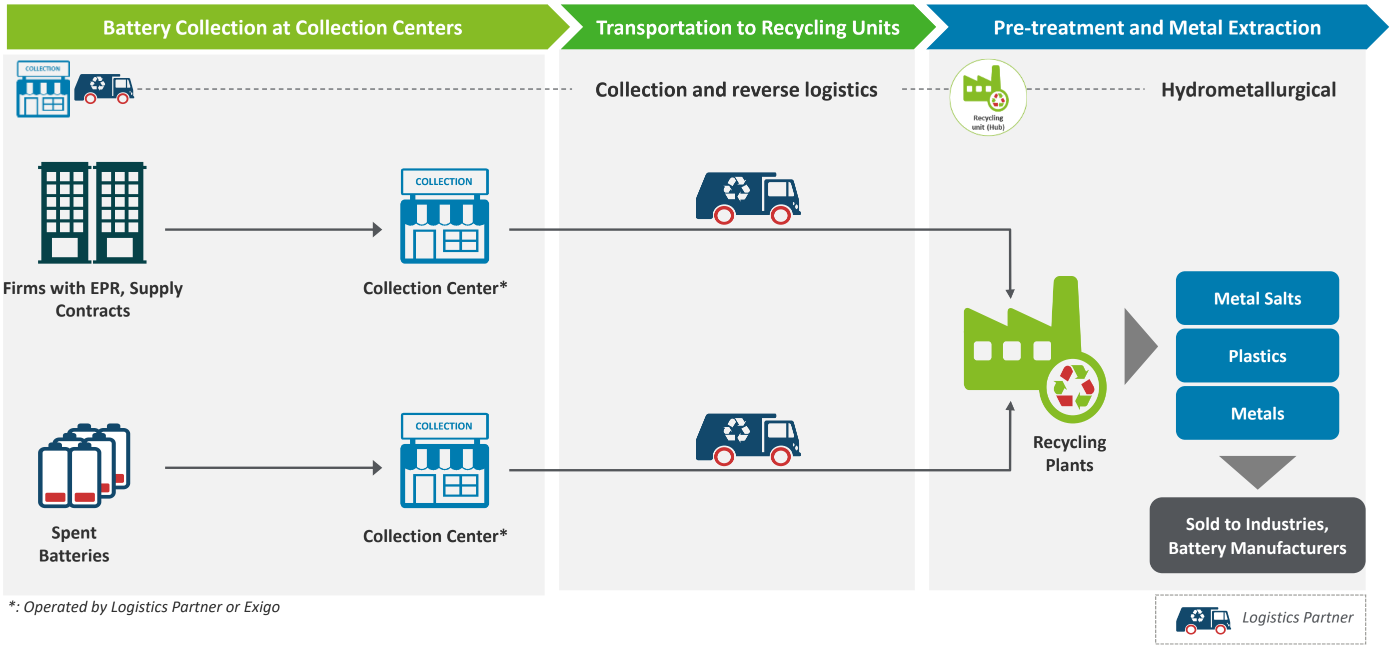
Exigo Recycling

Exigo Recycling is an e-waste recycler in India which also deals with lithium-ion traction batteries. Exigo is also equipped as a Producer Responsibility Organisation (PRO) to fulfil all the statutory compliances for producers under Extended Producers Responsibility (EPR). EPR extends responsibility to the battery producers to ensure sound management of end-of-life products through their take back system or collection centers or both.

Exigo's state-of-the-art plant is located at Panipat, Haryana and is equipped with European Machinery for the size reduction, segregation & pulverization of waste. They also have an indigenously developed hydrometallurgical plant for collection of precious metals which enables them to recycle and recover up to **98%** of recyclable products. The remaining waste is disposed off through TSDF (Treatment, Storage, and Disposal Facilities).

Exigo has two recycling units with a cumulative capacity of 24,000 tons per year (for e-waste). They employ Hydrometallurgical processes for recycling.

Figure 110: Exigo battery recycling overview



Source: Deloitte Analysis, Company website

Exigo has tie-ups with efficient logistics partners across India to transport the waste in secure and environmental-friendly way. The reverse logistics service provider for Exigo is Deliveryontime Logistics Private Limited (Bizlog) which also operates collection centers across India for Exigo Recycling. Exigo has a mix of indigenous collection centers as well as centres run by Bizlog[127]. Exigo's collection centers are located in Haryana and Maharashtra. The collection centers of Bizlog are located in the states of Gujarat, Karnataka, Haryana, Tamil Nadu, Delhi, Telangana, Rajasthan, West Bengal, Punjab, Maharashtra, Bihar, Uttar Pradesh, and Madhya Pradesh.

The company is also working towards adding more informal sector partners to collect battery waste and channelize e-waste to its recycling operations. In September 2021, Exigo formed a joint venture with MTC Group, the largest metal scrap processor in India, to form MTC-Exigo Recycling Pvt. Ltd (MERPL) to process e-wastes and ramp up recycling capacity. Headquartered in Mumbai, the plants of the venture will be operational in Bengaluru and Chennai with an investment of USD 25 million. MERPL targets to process over 2 lakh tons of e-waste annually.

7.9 Financial and economic analysis of battery recycling plant

The model for a battery recycling plant was developed to carry out the financial and economic analyses. A mix of primary and secondary research was a key enabler in reaching at suitable assumptions for the model. For the financial analysis, the model is such developed that it captures data in a comprehensive manner considering the various technologies of battery recycling, their associated operational and capital expenditures along with the environmental impact they have.

As a result of the analysis, suitable indicators such as NPV (Net Present Value) and IRR (Internal Rate of Return) were computed to enable the end user to assess the feasibility of their investments. From a developmental bank's perspective, a caveat of grant was augmented to enable another dimension into the model enabling investment support for new plants.

In the following sections, all the **assumptions**, and **financial analysis** conducted are detailed out for both **Hydrometallurgical** and **Pyrometallurgical** recycling plant.

[127] Exigo Recycling (access here)

Assumptions used for the model

The model requires multiple assumptions on an operational and capital expenditure levels for both the technologies to provide a lucid picture of the recycling plant. Basis the selection of technology, all the parameters had to be customized to reflect their influence on the business.

Operational period assumptions

For the industry discussions, it was found out that for both the technologies – hydrometallurgy and pyrometallurgy – the operational period of the recycling plant is similar.

Below table provides the assumptions on project timelines:

Table 107: Assumptions for operation period

Sl.	Particular	Description
1.	**Construction Start Date**	1st April 2022
2.	**Construction Period**	1 year
3.	**Date of Commissioning of full capacity**	31st March 2023
4.	**Plant life**	15 years

The capacity utilization of the project is assumed to be gradually increasing from first year (50%) to sixth year (95%) owing to the fact that the EV industry is still at infancy stage in India and will take few more years for large scale adoption. Post sixth year, the capacity utilization is assumed to remain constant at 95% till 15th year.

Table 108: Assumptions for Capacity Utilization for operational period

Year	1	2	3	4	5	6-15
Capacity Utilization	50%	60%	70%	80%	90%	95%

Capital expenditure assumptions

Setting up a battery recycling plant is envisaged to have capital expenditures in the form of land, plant and machinery, auxiliary infrastructure, pre-operative expenses, and certain funds allocated towards contingencies. The land parcel required for both the technologies are no different and it has been assumed based on primary research.

Table 109: Assumptions on break-up of capital expenditure of a 10,000 MTPA recycling facility

Sl.	Particular	Unit	Hydrometallurgy	Pyrometallurgy
1.	**Plant and Machinery Cost**	% of total capex*	60%	60%
2.	**Auxiliary infrastructure**	% of total capex*	20%	20%
3.	**Pre-operative expenses**	% of total capex*	20%	20%

*excluding land

From research and primary interactions, it was found out that for a 10,000 MTPA recycling plant using hydrometallurgy, the plant and machinery cost is in the range of ~INR 98 Cr whereas as for the same capacity with pyrometallurgy, the same cost is ~INR 171 Cr. Using this as a reference, the overall capital cost for the unit was determined.

Table 110: Capital expenditure of a 10,000 MTPA recycling facility for Hydro & Pyro technologies

Sl.	Particular	Unit	Hydrometallurgy	Pyrometallurgy
1.	**Capex for 10,000 MTPA (excl. land)**	INR Cr	163	285

Sl.	Particular	Unit	Hydrometallurgy	Pyrometallurgy
2.	**Cost of land**	INR Cr	3	3
3.	**Total Capex for 10,000 MTPA facility**	**INR Cr**	**166**	**288**

Note: In addition, 5% contingency cost is considered

Keeping in view the construction period of 1 year, interest during construction (IDC) was also accounted for in the CAPEX workings in the model. The IDC expenses were linked with the financing assumptions which have been explored in the later part of this report.

Because of the immediate nature of capital requirement for setting up the plant, there was no phasing of capital expenditure and the entire amount envisaged was assumed to be drawn in the first year of the project.

Note: To arrive at the capital cost of units with capacities other than 10,000 MTPA, a proration factor was considered which accounted for economies of scale based on interaction with industry players. The factor was fixed at 0.85 and the formula to arrive at the plant cost is as follows:

$$Capital\ cost\ (for\ X\ MTPA\ Plant) = Capital\ Cost\ (for\ 10{,}000\ MTPA\ Plant) \times \left(\frac{X}{10{,}000}\right)^{0.85}$$

Financing assumptions

The financing of the project has been distributed into three categories viz. Grant, Debt, and Equity. The following table captures the assumptions for the same.

Table 111: Assumptions for financing

Sl.	Particular	Value	Remarks
1.	Grant	10%	as a percentage of total capital cost
2.	Debt	70%	as a percentage of capital cost after deducting grant
3.	Equity	30%	
4.	Interest rate	12%	Based on discussion with industry players
5.	Interest rate on Working capital	12%	
6.	Loan Repayment Period	10 years	Based on discussion with industry players

Operating expenditure assumptions

Irrespective of the recycling technology implemented, there are certain factors for the operation of a recycling plant which are widely common. The assumptions on this front are tabulated below:

Table 112: Assumptions for Operating Expenditure for Recycling Plant irrespective of technology implemented

Sl.	Particular	Unit	Value
1	**O&M**		
1.1	Base O&M expenses (%ge of total investment)	%ge of total investment	5%
1.2	O&M expense escalation	%	1%
2	**Employee Expenses**		
2.1	No. of supervisory employees	nos. per tonne	0.001
2.2	No. of labor	nos. per tonne	0.009
2.3.	Annual Salary of supervisory staff	INR Cr/person/year	0.03

Sl.	Particular	Unit	Value
2.4	Annual Salary of Labor	INR Cr/person/year	0.012
2.5	Annual Salary Escalation	%	3%
3	**Transportation and Logistics**		
3.1	Transportation & Logistics expenses	INR/kg	30
3.2	Escalation	%	2%
4	**Battery Purchase**		
4.1	Battery purchase cost	INR/kg	135
4.2	Escalation	%	2%
5	**Others**		
5.1	Operating Supplies (% of O&M Cost)	%	15%
5.2	Laboratory Charges (% of O&M Cost)	%	10%
5.3	Plant Overhead Cost (% of O&M Cost)	%	50%

Other than the assumptions mentioned above, there are certain operational parameters which are dependent on the recycling technology implemented by the plant.

The table below captures the operational assumptions for Hydrometallurgy:

Table 113: Operational assumptions specific to Hydrometallurgy

Sl.	Particular	Unit	Value
1	**Raw Material**		
1.1	Ammonium Hydroxide	kg/kg of spent battery	0.031
1.2	Hydrochloric Acid	kg/kg of spent battery	0.012
1.3	Hydrogen Peroxide	kg/kg of spent battery	0.366
1.4	Sodium Hydroxide	kg/kg of spent battery	0.561
1.5	Sulfuric Acid	kg/kg of spent battery	1.08
1.6	Soda Ash	kg/kg of spent battery	0.02
1.7	Water Consumption	kg/kg of spent battery	3.78
2	**Unit Price of chemicals**		
2.1	Ammonium Hydroxide	INR/kg	34.12
2.2	Hydrochloric Acid	INR/kg	11.13
2.3	Hydrogen Peroxide	INR/kg	54.89
2.4	Sodium Hydroxide	INR/kg	29.67
2.5	Sulfuric Acid	INR/kg	4.45
2.6	Soda Ash	INR/kg	11.13
2.7	Water	INR/kg	0.03
2.8	Escalation	%	5%
3	**Energy Consumption**		

Sl.	Particular	Unit	Value
3.1	Electricity	kWh/kg of spent battery	0.035
3.2	Cost of Electricity	INR per kWh	8
3.3	Escalation	%	1%
3.4	Diesel Consumption	MJ/kg of spent battery	0.600
3.5	Cost of Diesel	INR per litre	86.67
3.6	Natural Gas Consumption	MJ/kg of spent battery	2.500
3.7	Cost of Natural Gas	Rs per litre	55.00
3.8	Escalation	%	1%

Similarly, the assumptions for pyrometallurgy are as follows:

Table 114: Operational assumptions specific to Pyrometallurgy

Sl.	Particular	Unit	Value
1	**Raw Material**		
1.1	Hydrochloric Acid	kg/kg of spent battery	0.21
1.2	Hydrogen Peroxide	kg/kg of spent battery	0.06
1.3	Limestone	kg/kg of spent battery	0.3
1.4	Sand	kg/kg of spent battery	0.15
2	**Unit Price of chemicals**		
2.1	Hydrochloric Acid	INR/kg	11.13
2.2	Hydrogen Peroxide	INR/kg	54.89
2.3	Limestone	INR/kg	9.75
2.4	Sand	INR/kg	4.50
2.5	Escalation	%	5%
3	**Energy Consumption**		
3.1	Electricity	kWh/kg of spent battery	1.3
3.2	Cost of Electricity	INR per kWh	8
3.3	Escalation	%	1%
3.4	Diesel Consumption	MJ/kg of spent battery	0.600
3.5	Cost of Diesel	INR per litre	86.67

Revenue assumptions

The revenue of a recycling plant is based on the recycling efficiency of the process chosen, selling price of the material recovered and the feed (composition of the end of life batteries in terms of chemistry) of the recycling unit. The number of material recovered is process dependent and the unit price of the recovered materials is shown below:

Table 115: Revenue and recovery assumptions for recycling plant

Sl.	Particular	Unit	Value	Recovery from Hydrometallurgy	Recovery from Pyrometallurgy
1.	Copper	INR/kg	490	65 – 90%	70 – 90%
2.	Steel	INR/kg	22	65 – 90%	80 – 90%
3.	Aluminum	INR/kg	96	65 – 90%	0%
4.	Graphite	INR/kg	21	65 – 90%	0%
5.	Plastics	INR/kg	7	50%	0%
6.	Lithium Carbonate	INR/kg	586	60 – 90%	0%
7.	Nickel	INR/kg	816	65 – 98%	70 – 98%
8.	Cobalt	INR/kg	4079	65 – 98%	70 – 98%
9.	Manganese	INR/kg	148	65 – 98 %	0%
10.	Escalation (Prices)	%	2%		

The amount of recovery from either hydrometallurgy and pyrometallurgy has been improved year on year keeping in mind the learning curve the plant would have. It is evident that in terms of the recovery of materials, hydrometallurgy has an upper hand on pyrometallurgy.

However, the feed of batteries also determines the recovery that the processes would provide. The model has been built such that the feed can be customized by the user. However, the contents of the cell chemistries have been considered as follows:

Table 116: Spent battery feed breakdown by material (kg/ kg of spent battery)

Sl.	Material	LCO	NMC 111	NMC 532	NMC 622	NMC 811	NCA	LMO	LFP
1.	**Copper**	0.161	0.168	0.174	0.181	0.186	0.188	0.113	0.159
2.	**Steel**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3.	**Aluminum**	0.081	0.085	0.088	0.091	0.094	0.094	0.061	0.083
4.	**Graphite**	0.185	0.200	0.202	0.216	0.230	0.226	0.174	0.198
5.	**Plastics**	0.025	0.022	0.028	0.024	0.029	0.025	0.015	0.021
6.	**Lithium**	0.026	0.029	0.029	0.027	0.023	0.025	0.020	0.018
7.	**Nickel in cathode**	0.000	0.079	0.118	0.131	0.152	0.166	0.000	0.000
8.	**Cobalt in cathode**	0.213	0.079	0.047	0.044	0.019	0.031	0.000	0.000
9.	**Manganese in cathode**	0.000	0.074	0.066	0.041	0.018	0.000	0.307	0.000

One fact to notice here is that we have taken the Lithium content for the batteries whereas we have computed the revenue in terms of Lithium-carbonate sales. This is due to the fact that lithium salts are obtained after the process and they have significant demand in industries other than battery. The elemental mass of lithium-carbonate has been considered to obtain the amount proportionate to the lithium content in the batteries.

Other assumptions

Depreciation

The following table highlights the assumptions used for depreciation:

Table 117: Assumptions for computation of depreciation

Sl.	Particular	Unit	Value	Remarks
1.	**Maximum Permissible Depreciation**	%	100%	Owing to the change in battery chemistries and fast technological changes
2.	**Plant and Machinery (SLM)**	%	7%	Corresponding to the project life
3.	**Auxiliary Infrastructure (SLM)**	%	7%	
4.	**Plant and Machinery (WDV)**	%	15%	As per IT Act
5.	**Auxiliary Infrastructure (WDV)**	%	15%	

Tax

The following table highlights the assumptions used for tax rates.

Table 118: Expected tax rates for financial model

Sl.	Particular	Unit	Value	Remarks
1.	**Tax rate**	%	25.17%	Corporate tax rate
2.	**MAT Rate**	%	0.0%	As per prevailing MAT structure

Working capital assumptions

The working capital assumptions are captured below:

Table 119: Working capital assumptions

Sl.	Particular	Unit	Value
1.	**Debtor**	Number of Days	30
2.	**Inventory**	Number of Days	60
3.	**Creditors**	Number of Days	30

Emission assumptions

The emission savings from recycling is computed by analyzing the emissions which would have occurred by using virgin raw material for cathode production vis-à-vis the emissions to recover the same amount of material from recycling.

Table 120: Emission savings assumptions (g/kg of cathode)

Chemistry	GHG Emissions CO2 eq			NOX			SOX			PM2.5		
	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro
LCO	17850.2	11088.3	13659.3	25.8	12.2	14.4	81.3	71.5	9.8	5.6	0.6	1.0
NMC 111	17915.4	13434.7	16201.2	28.3	14.9	17.6	341.6	81.4	32.5	4.3	0.8	1.5
NMC 532	18811.8	13461.9	16217.5	31.5	14.9	17.6	491.7	82.2	32.5	4.4	0.8	1.4
NMC 622	19783.2	13816.8	16706.5	34.0	15.4	17.8	566.0	88.9	32.6	4.7	0.8	1.4
NMC 811	21959.5	15363.7	18690.2	39.1	17.0	19.2	733.8	101.1	33.7	5.2	1.0	1.6

Chemistry	GHG Emissions CO2 eq			NOX			SOX			PM2.5		
	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro	Virgin Material	From Hydro	From Pyro
NCA	23399.4	15737.9	18649.6	41.2	17.4	19.7	748.3	100.9	36.6	5.5	1.0	1.5
LMO	19617.5	14019.3	16953.8	33.2	15.6	18.0	533.2	88.4	32.8	4.7	0.8	1.5
LFP	21959.5	15363.7	18690.2	39.1	17.0	19.2	733.8	101.1	33.7	5.2	1.0	1.6

Results

The model has two perspectives of technology viz. hydrometallurgy and pyrometallurgy. The cost and revenue aspects of the technologies vary significantly. The results are summarized below.

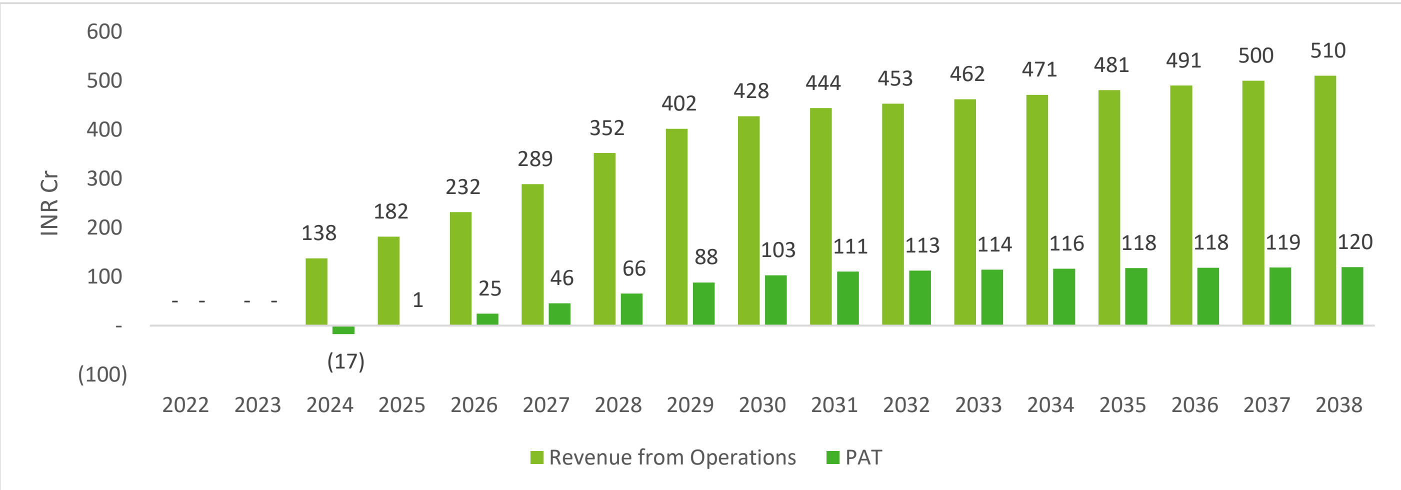
With Hydrometallurgy

Key Results

The results of the model are based on certain assumptions as follows:

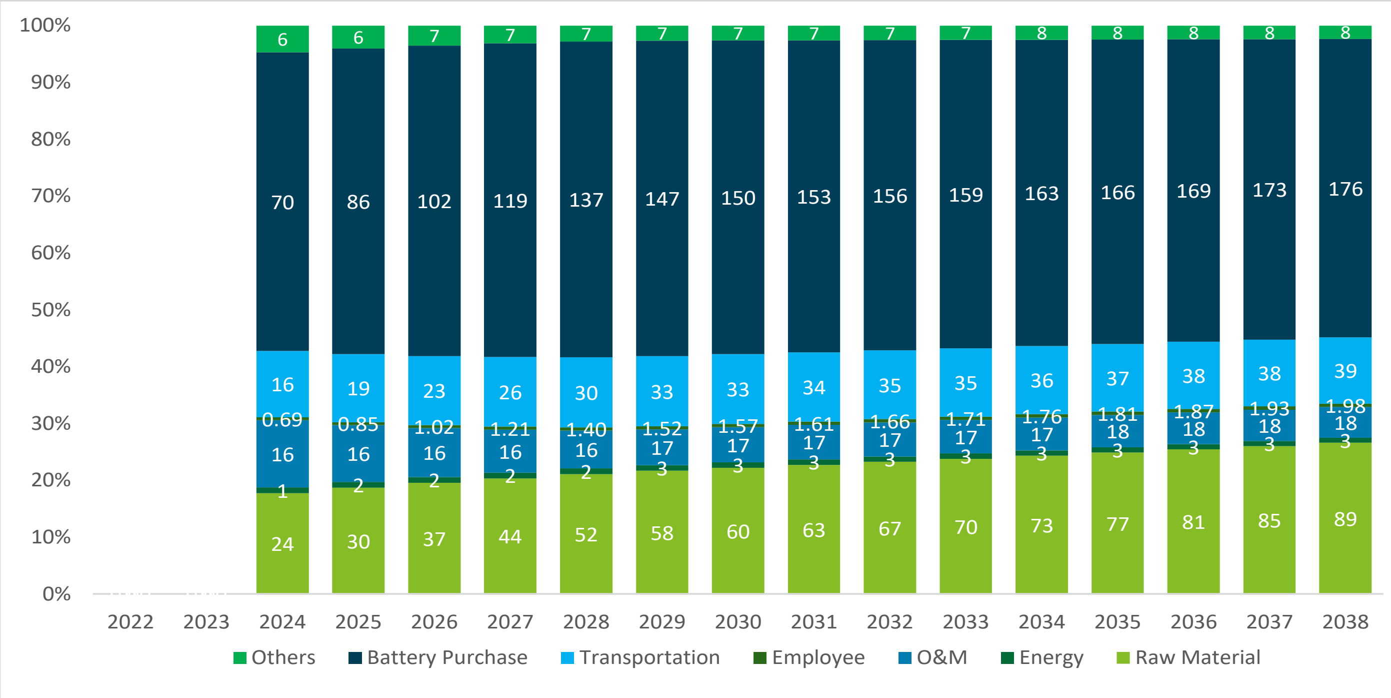
- Plant Capacity: 10,000 MTPA
- Capacity: As shown in Table 80
- Battery feed is divided amongst NMC 111, NMC 532, NMC 622, NMC 811, and LFP the most widely used chemistries presently
- Battery purchase cost is assumed to be INR 135/kg and Transportation cost is assumed to be INR 30/kg for the first year and the associated escalations are taken into consideration.

Figure 111: Revenue from Operations and PAT for 10,000 MTPA Hydrometallurgical Recycling Plant



It can be observed that the revenue from operations is on a rise with the rising utilization of the plant but the profit after tax stagnates in the range of INR 111-120 Cr for the same time period. The distribution of the expenses is shown below:

Figure 112: Cost Breakdown of 10,000 MTPA Hydrometallurgical Recycling plant



The three major cost contributors for the plant are battery purchase cost, transportation cost, and raw material (chemicals).

The table below summarizes the Project IRR, Project NPV to provide a firsthand view of the viability of the project at multiple capacities:

Table 121: Summary of key results for Hydrometallurgical Recycling Plant

Sl.	Capacity (MTPA)	Total Capex (INR Cr)	Project NPV (INR Cr)	Project IRR (%)
1.	1,000	28	33.6	25.2%
2.	3,000	67	117.8	30.1%
3.	5,000	102	205.5	32.2%
4.	10,000	181	431.6	34.9%
5.	15,000	254	663.1	36.5%
6.	20,000	324	897.7	37.6%

Note: Considering 10% Grant on overall Capex Amount

Financial Ratios

To assess the financial position of the plant, multiple financial ratios have been assessed. The table below summarizes the average values obtained for some of the key financial parameters of the plant.

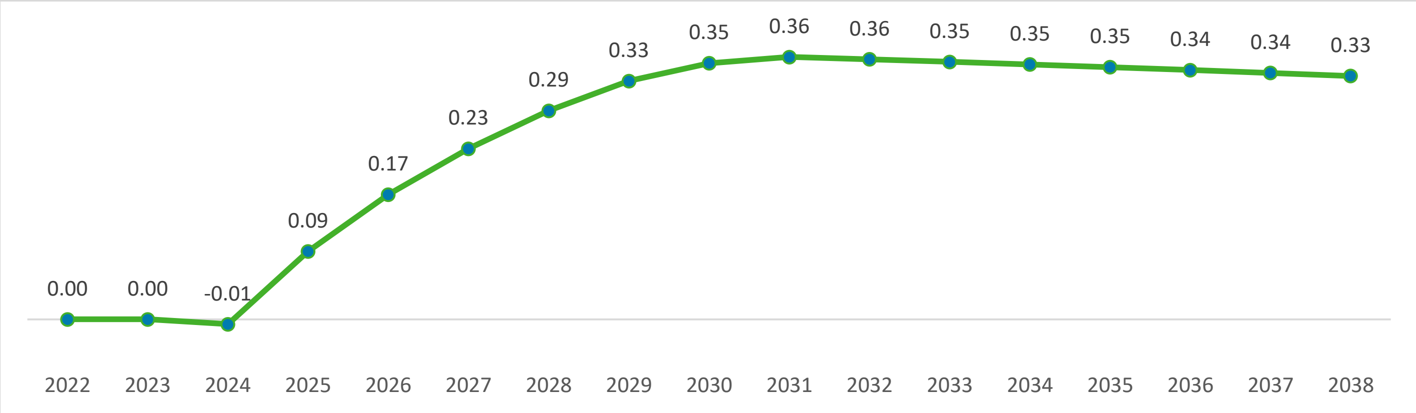
Table 122: Key financial ratios for 10,000 MTPA Hydrometallurgical Recycling Plant

Sl.	Particular	Average Value
1.	Operating Margin	26.5%
2.	Profit Margin	17.2%
3.	DSCR	1.64

Sl.	Particular	Average Value
4.	Interest Coverage	12.43

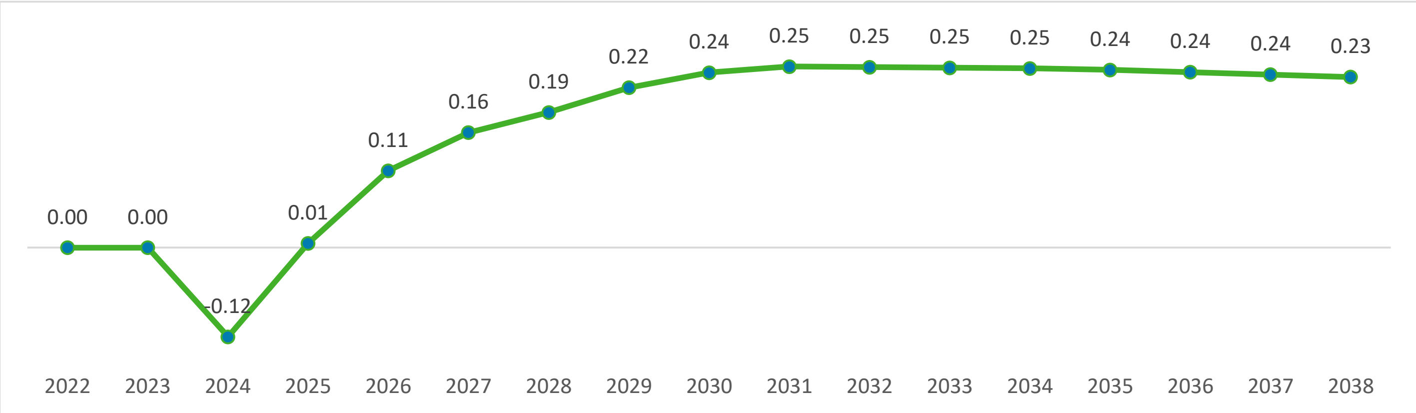
The **operating margin** of the plant varies between -1% to 36% for the operating period of the plant with an average of 26.5%. The margins have an increasing trend until 2031 post which they see a marginal decline till 33% in 2038. The trend can be observed in the figure below.

Figure 113: Operating Margin for 10,000 MTPA Hydrometallurgical recycling plant



The **profit margin** of the plant sees larger variations compared to operating margins as it ranges from -12% to 25% for the operating period with an average of 17.2%. The plant starts to be profitable from FY25 and continues the trend until FY34 post which it hovers around 25-23%.

Figure 114: Profit Margins for 10,000 MTPA Hydrometallurgical recycling plant



The **DSCR and the interest coverage** of the plant point towards its ability to generate sufficient operating income to cover its annual debt and interest payment. The trend of the ratios is shown below.

Figure 115: DSCR for 10,000 MTPA Hydrometallurgical recycling plant

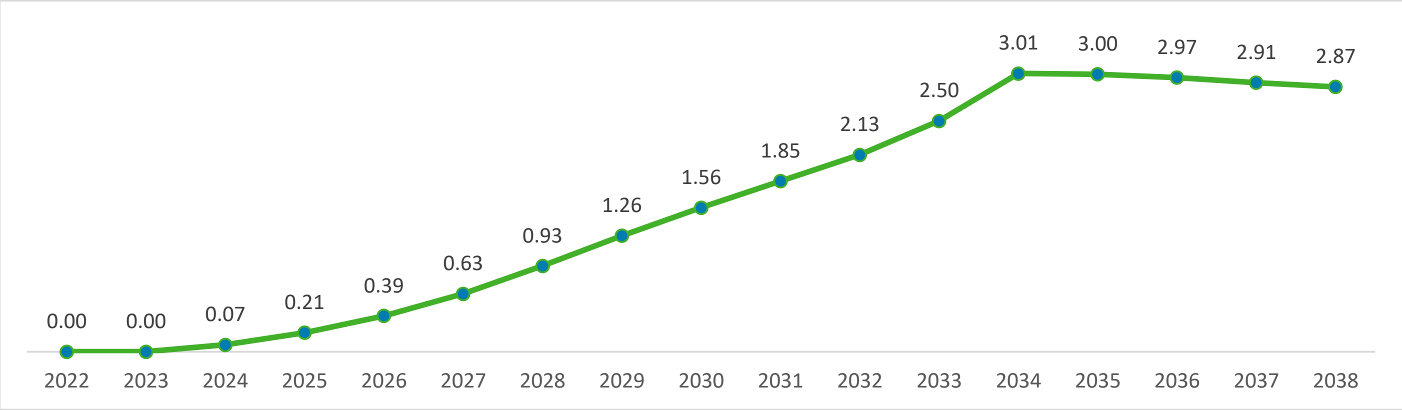
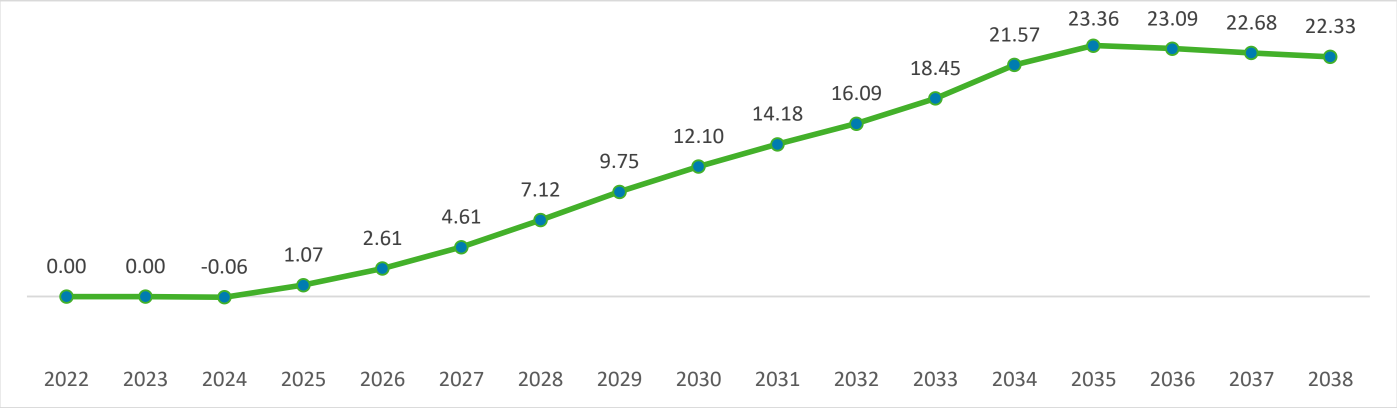


Figure 116: Interest Coverage for 10,000 MTPA Hydrometallurgical recycling plant



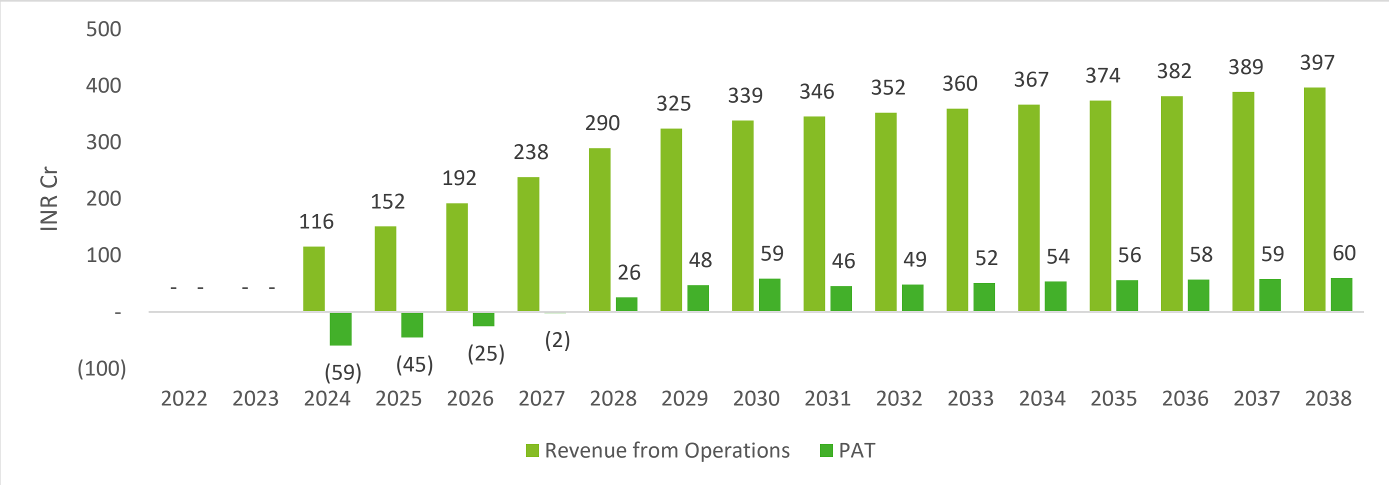
With Pyrometallurgy

Key Results

The results of the model are based on certain assumptions as follows:

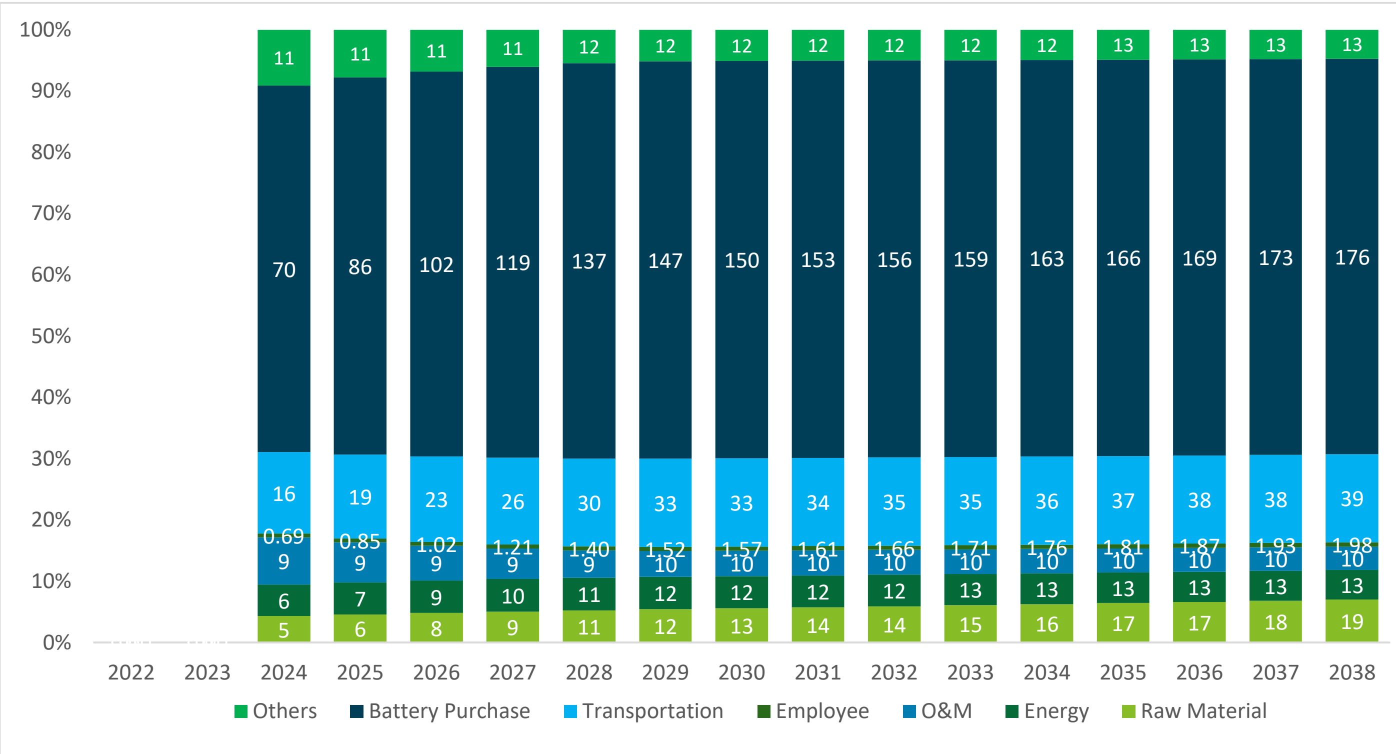
- Plant Capacity: 10,000 MTPA
- Capacity: As shown in Table 80
- Battery feed is divided amongst NMC 111, NMC 532, NMC 622, NMC 811, and LFP the most widely used chemistries presently
- Battery purchase cost is assumed to be INR 135/kg and Transportation cost is assumed to be INR 30/kg for the first year and the associated escalations are taken into consideration.

Figure 117: Revenue from Operations and PAT for 10,000 MTPA Pyrometallurgical Recycling Plant



It can be observed that the revenue from operations is on a rise with the rising utilization of the plant but the profit after tax stagnates in the range of INR 46-60 Cr for the same time period. The distribution of the expenses is shown below:

Figure 118: Cost Breakdown of 10,000 MTPA Pyrometallurgical Recycling plant



The two major cost contributors for the plant are battery purchase cost, transportation cost. The energy cost and raw material cost of the process are on similar levels but a point to observe here is that the energy cost contribution here is higher compared to hydrometallurgy and conversely raw material cost contribution is lower.

The table below summarizes the Project IRR, Project NPV to provide a firsthand view of the viability of the project at multiple capacities:

Table 123: Summary of key results for Pyrometallurgical Recycling Plant

Sl.	Capacity (MTPA)	Total Capex (INR Cr)	Project NPV (INR Cr)	Project IRR (%)
1.	1,000	48	0.9	11.1%
2.	3,000	116	28.3	14.5%
3.	5,000	177	62	16%
4.	10,000	316	158.4	17.9%
5.	15,000	445	264.1	19.1%
6.	20,000	568	375.3	19.9%

Note: Considering 10% Grant on overall Capex Amount

Financial Ratios

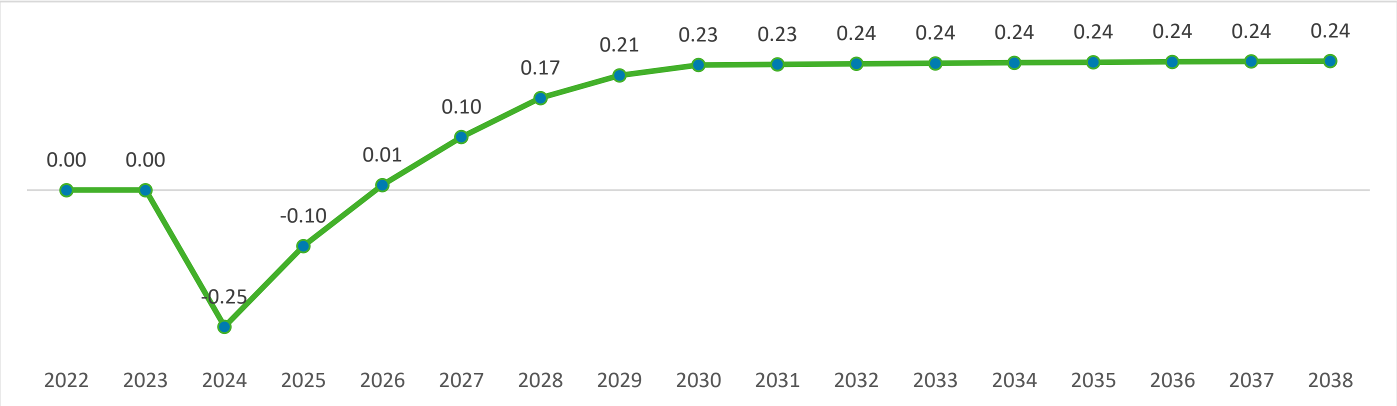
To assess the financial position of the plant, multiple financial ratios have been assessed. The table below summarizes the average values obtained for some of the key financial parameters of the plant.

Table 124: Key financial ratios for 10,000 MTPA Pyrometallurgical Recycling Plant

Sl.	Particular	Average Value
1.	**Operating Margin**	15.9%
2.	**Profit Margin**	5.9%
3.	**DSCR**	0.76
4.	**Interest Coverage**	5.16

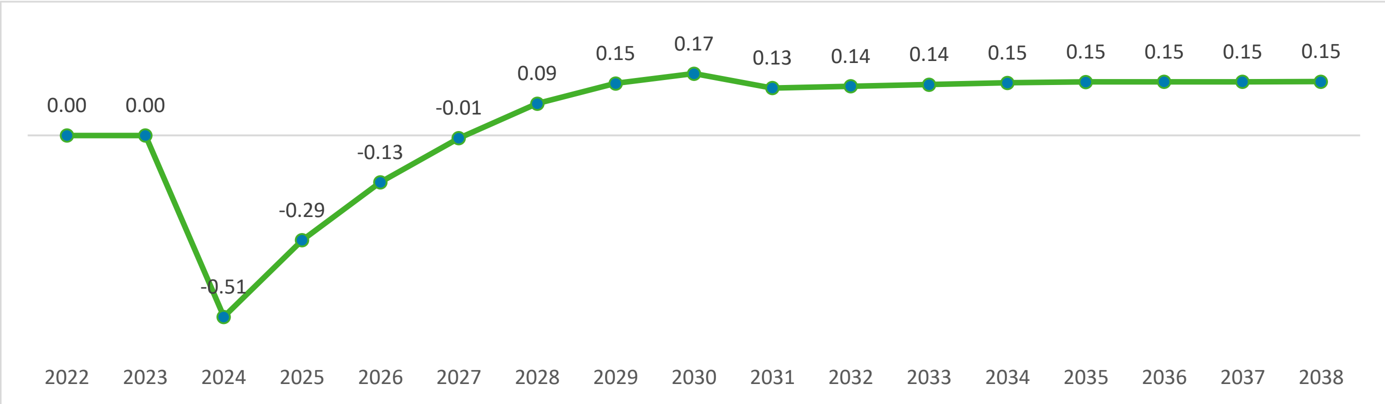
The **operating margin** of the plant varies between -21% to 25% for the operating period of the plant with an average of 15.9%. The margins have an increasing trend until 2029 post which it stagnates at ~25%.

Figure 119: Operating margin for 10,000 MTPA Pyrometallurgical recycling plant



The **profit margin** of the plant sees larger variations compared to operating margins as it ranges from -44% to 17% for the operating period with an average of 5.9%. The plant starts to be profitable from FY27 and continues the trend for the operating period.

Figure 120: Profit margin for 10,000 MTPA Pyrometallurgical recycling plant



The average **DSCR** of the plant is below 1 up to FY32 post which it surpasses the ideal number of 1 and maintains the trend until the end of operations. The interest coverage on the other hand is greater than 1.5 from FY28 onwards and maintains the characteristic for the entire operating period.

Figure 121: DSCR for 10,000 MTPA Pyrometallurgical recycling plant

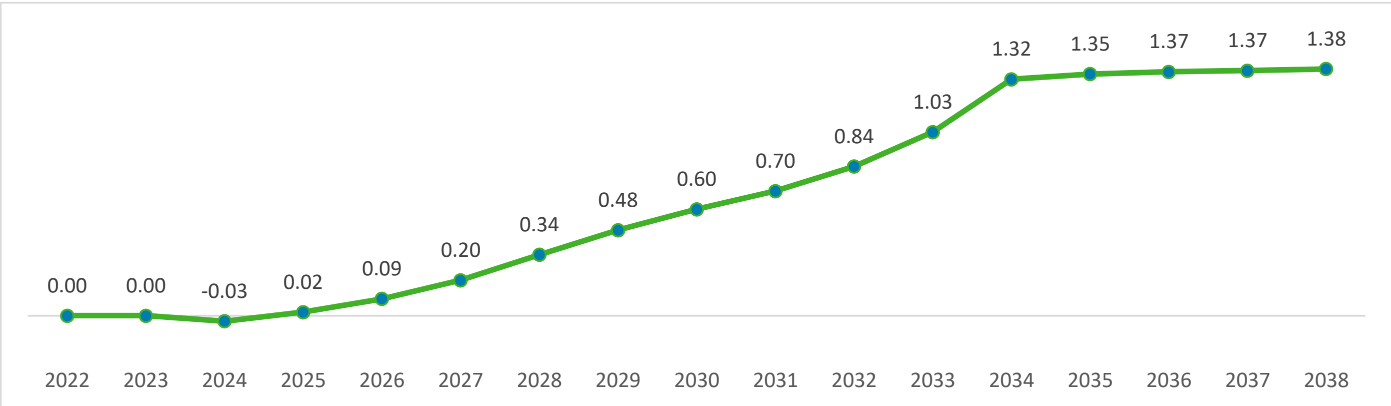
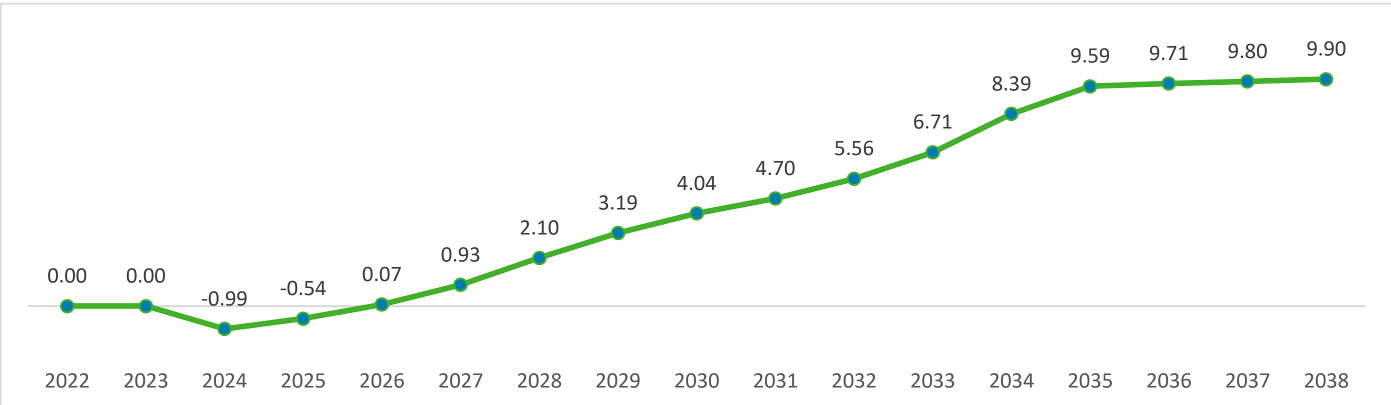


Figure 122: Interest Coverage for 10,000 MTPA Pyrometallurgical recycling plant



Sensitivity analysis

Basis the capacity chosen for the recycling plant, Table 121 and Table 123 provide a view of the NPV and IRR for each of the capacities. As it can be observed in Figure 112 and Figure 118 that the major cost contributors for the plant are battery purchase cost followed by the transportation cost associated with the reverse logistics of the entire process.

Keeping these two costs in view and the view of financing through a grant, we have developed sensitivities based on **transportation cost, battery purchase cost, and the grant facilitated by the bank**. The sensitivity looks into the Net Present Value (NPV) and Internal Rate of Return (IRR) of the project and helps in determining the boundary conditions under which the project is feasible.

Before delving into the analysis, it is to be noted that the assumptions mentioned earlier in the report are the same and unless stated they haven't been changed.

Transportation Cost vis-à-vis Battery Purchase Cost

a) Hydrometallurgy

An analysis based on the two major cost contributors for a battery recycling unit are shown in the tables which follow. For parity in the analysis, grant has assumed to be 0% to provide a view of the business without the provision of support which eases the cost aspects of the project by reducing interest payments.

Table 125: Sensitivity analysis (NPV) based on transportation cost and battery purchase cost for 10,000 MTPA hydrometallurgical recycling plant

NPV (INR Cr)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
BATTERY PURCHASE COST (Rs/kg)	135	420	396	372	347	323	298	275	249	224	199
	145	371	347	322	298	274	249	223	199	176	150
	155	322	297	274	248	223	198	175	149	122	99
	165	273	248	222	198	175	149	122	98	74	47
	175	222	197	174	148	121	98	73	46	22	-4
	185	174	147	121	97	73	46	22	-4	-30	-56
	195	120	97	72	45	21	-5	-30	-56	-82	-108
	205	71	45	20	-5	-31	-57	-82	-109	-136	-166
	215	20	-6	-31	-57	-83	-109	-136	-166	-198	-229
	225	-32	-58	-84	-110	-137	-167	-198	-229	-261	-292

Table 126: Sensitivity analysis (IRR) based on transportation cost and battery purchase cost for 10,000 MTPA hydrometallurgical recycling plant

IRR (%)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
BATTERY PURCHASE COST (Rs/kg)	135	32.8%	31.6%	30.4%	29.2%	28.0%	26.7%	25.5%	24.2%	22.9%	21.6%
	145	30.4%	29.1%	27.9%	26.7%	25.5%	24.2%	22.9%	21.6%	20.4%	19.0%
	155	27.9%	26.6%	25.4%	24.1%	22.8%	21.6%	20.4%	19.0%	17.6%	16.3%
	165	25.4%	24.1%	22.8%	21.5%	20.3%	19.0%	17.5%	16.3%	14.9%	13.5%
	175	22.7%	21.5%	20.3%	18.9%	17.5%	16.2%	14.9%	13.4%	12.0%	10.6%
	185	20.2%	18.9%	17.4%	16.2%	14.9%	13.4%	12.0%	10.5%	9.1%	7.5%
	195	17.4%	16.2%	14.8%	13.3%	12.0%	10.5%	9.0%	7.5%	5.9%	4.3%
	205	14.8%	13.3%	11.9%	10.5%	9.0%	7.4%	5.9%	4.2%	2.5%	0.4%
	215	11.9%	10.4%	9.0%	7.4%	5.8%	4.2%	2.5%	0.4%	-2.1%	-5.0%
	225	8.9%	7.4%	5.8%	4.2%	2.5%	0.4%	-2.2%	-5.1%	-8.6%	-13.5%

It can be concluded from above that till a battery purchase cost of INR 165 per kg of spent battery, the project feasibility is ascertained by the entire range of positive NPVs whereas from the cost of INR 175/kg, the component of transportation cost starts to play a vital role.

b) Pyrometallurgy

Similarly, the data table for pyrometallurgy plant is shown below:

Table 127: Sensitivity analysis (NPV) based on transportation cost and battery purchase cost for 10,000 MTPA Pyrometallurgical recycling plant

NPV (INR Cr)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
BATTERY PURCHASE COST (Rs/kg)	135	116	90	65	39	13	-13	-40	-66	-93	-120
	145	64	38	12	-13	-40	-67	-94	-121	-148	-176
	155	12	-14	-41	-68	-94	-121	-149	-176	-208	-239
	165	-41	-68	-95	-122	-149	-177	-208	-240	-271	-302
	175	-96	-123	-150	-178	-209	-240	-272	-303	-334	-365
	185	-150	-179	-210	-241	-272	-304	-335	-366	-397	-429
	195	-210	-242	-273	-304	-335	-367	-398	-429	-460	-492
	205	-274	-305	-336	-367	-399	-430	-461	-492	-524	-555
	215	-337	-368	-399	-431	-462	-493	-524	-556	-587	-618
	225	-400	-431	-463	-494	-525	-556	-588	-619	-650	-681

Table 128: Sensitivity analysis (IRR) based on transportation cost and battery purchase cost for 10,000 MTPA Pyrometallurgical recycling plant

IRR (%)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
BATTERY PURCHASE COST (Rs/kg)	135	15.8%	14.7%	13.6%	12.5%	11.4%	10.2%	9.0%	7.7%	6.4%	5.0%
	145	13.6%	12.5%	11.3%	10.2%	8.9%	7.7%	6.4%	5.0%	3.6%	2.1%
	155	11.3%	10.2%	8.9%	7.6%	6.3%	5.0%	3.5%	2.1%	0.1%	-2.1%
	165	8.9%	7.6%	6.3%	4.9%	3.5%	2.0%	0.1%	-2.1%	-4.6%	-7.7%
	175	6.3%	4.9%	3.5%	2.0%	0.0%	-2.1%	-4.7%	-7.7%	-11.7%	-18.1%
	185	3.5%	2.0%	0.0%	-2.2%	-4.7%	-7.7%	-11.7%	-18.1%	n.a.	n.a.
	195	0.0%	-2.2%	-4.7%	-7.8%	-11.8%	-18.2%	n.a.	n.a.	n.a.	n.a.
	205	-4.8%	-7.8%	-11.8%	-18.2%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	215	-11.8%	-18.3%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	225	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

It can be observed that the room for feasibility of a pyrometallurgical plant is very narrow in comparison to the hydrometallurgical plant. The narrow nature can be attributed to the lower recovery out of the process and the high capital investment that flows into the process in the beginning which results in higher financial expenses as well.

Transportation Cost vis-à-vis Grant

a) Hydrometallurgy

The provision of grant enables the recycling plant operator to have the necessary flexibility in the initial years to act on developing the capacity utilization by easing the financial expenses. The tables shown below capture the essence of the analysis.

Table 129: Sensitivity analysis (NPV) based on transportation cost and grant for 10,000 MTPA hydrometallurgical recycling plant

NPV (INR Cr)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
GRANT (as a percentage of CAPEX)	0%	420	396	372	347	323	298	275	249	224	199
	2%	422	398	374	350	325	301	277	252	226	202
	4%	424	400	377	352	328	303	279	254	229	204
	6%	427	403	379	355	330	306	282	257	231	206
	8%	429	405	381	357	333	308	284	260	234	209
	10%	432	408	384	359	335	310	286	262	236	211
	12%	434	410	386	362	337	313	289	265	239	214
	14%	436	412	388	364	340	315	291	267	241	216
	16%	439	415	391	366	342	318	293	270	244	219
	18%	441	417	393	369	345	320	296	272	246	221

Table 130: Sensitivity analysis (IRR) based on transportation cost and grant for 10,000 MTPA hydrometallurgical recycling plant

IRR (%)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
GRANT (as a percentage of CAPEX)	0%	32.8%	31.6%	30.4%	29.2%	28.0%	26.7%	25.5%	24.2%	22.9%	21.6%
	2%	33.2%	32.0%	30.8%	29.5%	28.3%	27.0%	25.8%	24.5%	23.2%	21.9%
	4%	33.6%	32.4%	31.2%	29.9%	28.6%	27.3%	26.1%	24.8%	23.5%	22.1%
	6%	34.0%	32.8%	31.5%	30.3%	29.0%	27.7%	26.4%	25.1%	23.7%	22.4%
	8%	34.4%	33.2%	31.9%	30.6%	29.3%	28.0%	26.7%	25.4%	24.0%	22.7%
	10%	34.9%	33.6%	32.3%	31.0%	29.7%	28.4%	27.1%	25.8%	24.3%	23.0%
	12%	35.3%	34.0%	32.7%	31.4%	30.1%	28.7%	27.4%	26.1%	24.6%	23.2%
	14%	35.8%	34.5%	33.2%	31.8%	30.5%	29.1%	27.7%	26.4%	24.9%	23.5%
	16%	36.3%	34.9%	33.6%	32.2%	30.9%	29.5%	28.1%	26.8%	25.3%	23.8%
	18%	36.8%	35.4%	34.0%	32.7%	31.3%	29.9%	28.4%	27.1%	25.6%	24.1%

Due to the higher revenue potential of Hydrometallurgical plant, the project seems to be feasible with no grant irrespective of the transportation cost which was risen to INR 75 per kg of spent battery.

b) Pyrometallurgy

Table 131: Sensitivity analysis (NPV) based on transportation cost and grant for 10,000 MTPA pyrometallurgical recycling plant

NPV (INR Cr)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
GRANT (as a percentage of CAPEX)	0%	116	90	65	39	13	-13	-40	-66	-93	-120
	2%	125	99	73	48	21	-5	-31	-58	-85	-112
	4%	133	107	82	56	30	4	-23	-50	-77	-104
	6%	141	116	90	64	38	12	-14	-41	-68	-95
	8%	150	124	98	73	47	20	-6	-33	-60	-86
	10%	158	133	107	81	55	29	3	-24	-51	-78
	12%	167	141	115	90	64	37	11	-16	-42	-70
	14%	175	150	124	98	72	46	19	-7	-34	-62
	16%	184	158	132	107	81	54	27	1	-26	-54
	18%	192	167	141	115	89	62	36	9	-18	-46

Table 132: Sensitivity analysis (IRR) based on transportation cost and grant for 10,000 MTPA pyrometallurgical recycling plant

IRR (%)		TRANSPORTATION COST (Rs/kg)									
		30	35	40	45	50	55	60	65	70	75
GRANT (as a percentage of CAPEX)	0%	15.8%	14.7%	13.6%	12.5%	11.4%	10.2%	9.0%	7.7%	6.4%	5.0%
	2%	16.2%	15.1%	14.0%	12.9%	11.8%	10.6%	9.3%	8.1%	6.7%	5.4%
	4%	16.6%	15.5%	14.4%	13.3%	12.1%	11.0%	9.7%	8.4%	7.1%	5.7%
	6%	17.0%	16.0%	14.8%	13.7%	12.5%	11.3%	10.1%	8.8%	7.5%	6.1%
	8%	17.5%	16.4%	15.3%	14.1%	13.0%	11.7%	10.5%	9.2%	7.9%	6.5%
	10%	17.9%	16.8%	15.7%	14.6%	13.4%	12.2%	10.9%	9.6%	8.3%	6.9%
	12%	18.4%	17.3%	16.2%	15.0%	13.8%	12.6%	11.3%	10.0%	8.7%	7.3%
	14%	18.9%	17.8%	16.6%	15.4%	14.2%	13.0%	11.7%	10.4%	9.1%	7.7%
	16%	19.4%	18.2%	17.1%	15.9%	14.7%	13.4%	12.1%	10.8%	9.5%	8.0%
	18%	19.9%	18.7%	17.6%	16.4%	15.1%	13.9%	12.6%	11.3%	9.9%	8.4%

Compared to a hydrometallurgy plant, there are some of the price points in transportation cost for pyrometallurgy that make the project financially unviable. A transportation cost of INR 55/kg of spent battery cannot be reversed unless a grant of 4% or more is provided. However, with cost more than INR 70/kg irrespective of the grant amount up to 18%, the project cannot be made viable.

Battery Purchase Cost vis-à-vis Grant

a) Hydrometallurgy

Battery purchase cost forms the most significant portion of the plant’s operational cost irrespective of the technology choices made. Batteries are collected through both formal and informal channels and each channel has its own set of expenses.

From a business perspective, the overall battery purchase cost from each of the channels have to be balanced to ensure the financial viability of the project which can be driven through the tables shown below for hydrometallurgical and pyrometallurgical recycling plants.

Table 133: Sensitivity analysis (NPV) based on battery purchase cost and grant for 10,000 MTPA hydrometallurgical recycling plant

NPV (INR Cr)		BATTERY PURCHASE COST (Rs/kg)									
		135	145	155	165	175	185	195	205	215	225
GRANT (as a percentage of CAPEX)	0%	420	371	322	273	222	174	120	71	20	-32
	2%	422	374	324	275	224	176	122	74	22	-30
	4%	424	376	327	278	227	178	125	77	25	-27
	6%	427	378	329	280	229	181	127	79	27	-25
	8%	429	381	332	282	232	183	130	82	29	-22
	10%	432	383	334	285	234	185	132	84	32	-20
	12%	434	385	336	287	236	188	135	87	34	-17
	14%	436	388	339	289	239	190	138	89	36	-15
	16%	439	390	341	292	241	192	140	92	39	-12
	18%	441	392	343	294	244	194	143	94	41	-10

Table 134: Sensitivity analysis (IRR) based on battery purchase cost and grant for 10,000 MTPA hydrometallurgical recycling plant

IRR (%)		BATTERY PURCHASE COST (Rs/kg)									
		135	145	155	165	175	185	195	205	215	225
GRANT (as a percentage of CAPEX)	0%	32.8%	30.4%	27.9%	25.4%	22.7%	20.2%	17.4%	14.8%	11.9%	8.9%
	2%	33.2%	30.7%	28.2%	25.7%	23.0%	20.5%	17.6%	15.0%	12.1%	9.1%
	4%	33.6%	31.1%	28.5%	26.0%	23.3%	20.7%	17.8%	15.2%	12.2%	9.2%
	6%	34.0%	31.5%	28.9%	26.3%	23.6%	20.9%	18.0%	15.3%	12.4%	9.3%
	8%	34.4%	31.9%	29.2%	26.6%	23.8%	21.2%	18.3%	15.5%	12.5%	9.5%
	10%	34.9%	32.3%	29.6%	26.9%	24.1%	21.4%	18.5%	15.7%	12.7%	9.6%
	12%	35.3%	32.7%	30.0%	27.2%	24.4%	21.7%	18.7%	15.9%	12.8%	9.7%
	14%	35.8%	33.1%	30.3%	27.6%	24.7%	21.9%	19.0%	16.2%	13.0%	9.9%
	16%	36.3%	33.5%	30.7%	27.9%	25.0%	22.2%	19.2%	16.4%	13.2%	10.0%
	18%	36.8%	34.0%	31.1%	28.3%	25.4%	22.5%	19.5%	16.6%	13.3%	10.2%

The hydrometallurgical unit can operate with a battery purchase cost up to INR 215 per kg of spent battery based on the other parameters at the predefined levels. The second most significant cost contributor i.e. the transportation cost is kept at INR 30 per kg for the first and suitable escalations are added up on it.

b) Pyrometallurgy

Table 135: Sensitivity analysis (NPV) based on battery purchase cost and grant for 10,000 MTPA pyrometallurgical recycling plant

NPV (INR Cr)		BATTERY PURCHASE COST (Rs/kg)									
		135	145	155	165	175	185	195	205	215	225
GRANT (as a percentage	0%	116	64	12	-41	-96	-150	-210	-274	-337	-400
	2%	125	73	20	-33	-87	-142	-203	-266	-329	-392
	4%	133	81	29	-25	-79	-133	-195	-258	-321	-384

NPV (INR Cr)		BATTERY PURCHASE COST (Rs/kg)									
		135	145	155	165	175	185	195	205	215	225
	6%	141	89	37	-16	-71	-126	-187	-250	-313	-377
	8%	150	98	46	-7	-62	-118	-179	-242	-305	-369
	10%	158	106	54	1	-53	-109	-171	-234	-298	-361
	12%	167	115	62	9	-45	-101	-163	-227	-290	-353
	14%	175	123	71	17	-37	-92	-155	-219	-282	-345
	16%	184	132	79	26	-29	-84	-148	-211	-274	-337
	18%	192	140	88	34	-21	-77	-140	-203	-266	-329

Table 136: Sensitivity analysis (IRR) based on battery purchase cost and grant for 10,000 MTPA pyrometallurgical recycling plant

IRR (%)		BATTERY PURCHASE COST (Rs/kg)									
		135	145	155	165	175	185	195	205	215	225
GRANT (as a percentage of CAPEX)	0%	16%	14%	11%	9%	6%	3%	0%	-5%	-12%	n.a.
	2%	16%	14%	12%	9%	7%	4%	0%	-4%	-11%	n.a.
	4%	17%	14%	12%	10%	7%	4%	1%	-4%	-11%	n.a.
	6%	17%	15%	12%	10%	7%	5%	1%	-4%	-10%	n.a.
	8%	17%	15%	13%	10%	8%	5%	1%	-3%	-10%	n.a.
	10%	18%	16%	13%	11%	8%	5%	2%	-3%	-9%	-27%
	12%	18%	16%	14%	11%	9%	6%	2%	-3%	-9%	-25%
	14%	19%	17%	14%	12%	9%	6%	2%	-2%	-9%	-23%
	16%	19%	17%	15%	12%	9%	6%	3%	-2%	-8%	-21%
	18%	20%	18%	15%	12%	10%	7%	3%	-2%	-8%	-20%

For a pyrometallurgical unit on the other hand, up to battery purchase cost of INR 155 per kg of spent battery has no effect on the financial feasibility whereas above it, the project starts to be unviable and asks for more than 18% grant to be viable.

Conclusion

At an overall level, the recycling plant's feasibility and flexibility in developing utilization is highly dependent on the choice of the technology done by the operator. Hydrometallurgical recycling makes seems to be the go to technology of the industry players in India at present and their choice is validated from the results obtained from our model.

From a cost perspective, the two major pain points that were highlighted by the industry players in the name of transportation and battery purchase costs have been suitably captured in the model which can be offset by the financing institutions through suitable grants.

Going forward, hydrometallurgy is expected to be the mainstay for the recycling of lithium-ion batteries owing to its lower energy consumption, higher emission savings, and capability to extract higher number of battery minerals in comparison to pyrometallurgy. Impetus must be given to develop this technology and supportive policy measures for ensuring the feed (spent batteries) to the upcoming and present recycling plants to place India as a recycling hub of the world.

7.10 Key recommendations

It is necessary to have a robust recycling and disposal ecosystem for batteries in India. As the electric vehicles start gaining traction, necessary channels for utilizing end of life batteries would be important to ensure a healthy and steady flow of battery raw materials and avoid shortage during manufacturing.

To develop a thriving battery collection system, following steps are being recommended:

Extended Producer Responsibility (EPR)

It should be made mandatory for battery manufacturers to tie-up with recycling players or producer responsibility organizations to develop a collection mechanism for used traction batteries. The manufacturers of EV traction batteries can be required to have take-back arrangements with automobile OEMs to whom they supply batteries. Such arrangements would ensure that batteries are taken back from the after-sales service centers of OEMs for recycling. Appropriate regulations and rules should be formulated in this regard. This can be observed in Europe where guidelines for EPR and institutionalization of a register (Waste Electrical and Electronic Equivalent) is being carried out. EPR would enable battery manufacturers to internalize treatment and disposal costs so that they have an added incentive to design products that last longer and are easily treated after use.

Utilizing the informal sector

Informal sector can be leveraged to develop e-waste (inclusive of batteries) collection channels. Reference can be made to the programs being run by Exigo Recycling which is exploiting the presence of informal sector to improve the overall recycling volume. A formal communication channel has been established between the collection centers of the recycler with that of informal battery collectors. The informal collectors are made aware of the kind of batteries Exigo is looking forward to recycling and only such batteries are submitted by the informal collectors for recycling.

Design for reuse and recycling

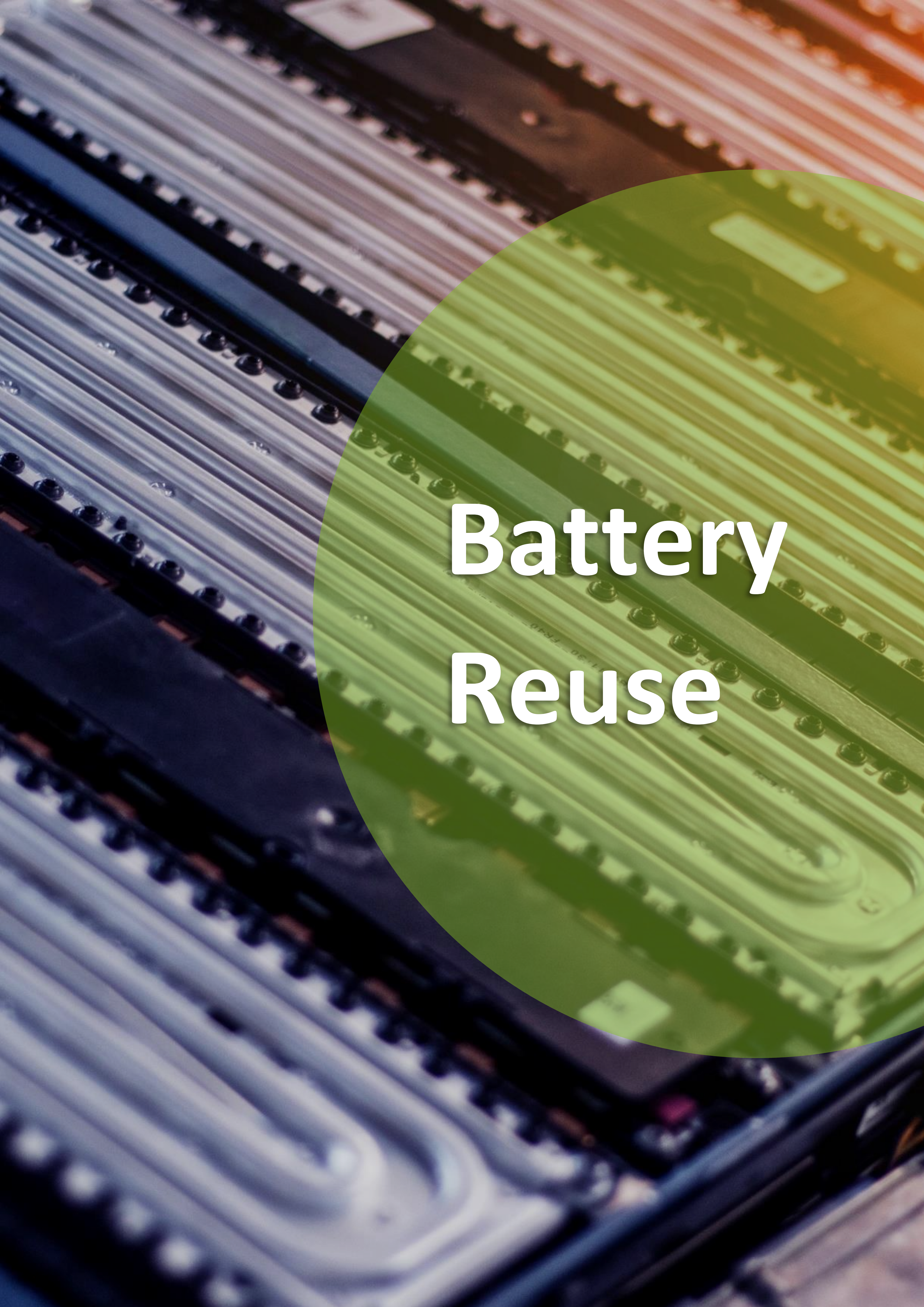
There has to be increased focus on battery designs which make them more reusable and recyclable. For instance, inter-cell welding could be replaced with nuts and bolts making the battery packs reusable and recyclable. Involvement of battery recyclers in the designing process of batteries would help in designs that would ensure efficient recycling. China, for instance, has CATL and BYD who have recycling subsidiaries. Having such subsidiaries helps in understanding the nuances of recycling and understanding the design parameters which cause difficulties in dismantling of batteries.

Institutionalizing Recovery rates

The upcoming battery waste management rules (presently at draft stage) is silent on the amount of material recovery expected from the batteries. Specifying minimum recovery rates can help drive the batteries away from the informal sector towards the formal sector and can also help in developing a healthy supply of raw materials for battery manufacturing. The recovery rates can be set higher for matured chemistries and lower for new technologies which should be suitably reviewed and updated continuously. For instance, the European Union, through Batteries Directive for instance has set recovery rates for batteries which has been able to drive the process efficiencies by the players. The Batteries Directive has also set target recycling efficiencies for various battery chemistries (65% for lead acid, 75% for Nickel Cadmium and 50% for all other chemistries). Such a directive ensures recyclers invest in making their processes efficient.

Battery reuse register

Only targeting the battery manufacturers through EPR is a prudent way for ensuring battery collection and recycling for chemistries like lead-acid and nickel cadmium which don't possess the ability for reuse. Lithium-ion batteries on the other hand house significant reuse capability and applications. Thus, it is necessary to ensure that the batteries are reused are recycled after their second life usage. A registry similar to the Waste Electrical and Electronic Equivalent (WEEE) in Europe can be developed in India to keep track of reuse and recycling of batteries.



Battery Reuse

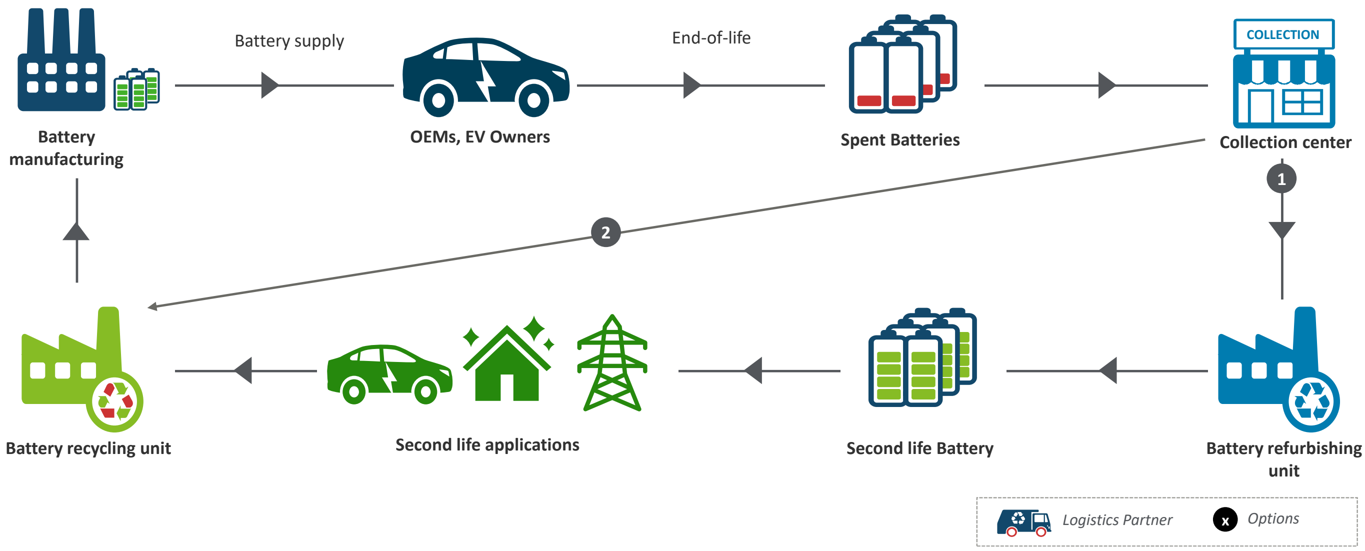
Chapter 8. Overview of battery reuse

EV batteries are subjected to changing discharge rates, extreme operating temperatures, and many partial cycles throughout its life. This results in substantial degradation of traction batteries (more so lithium-ion batteries) mainly in the first five years of their life. Traction batteries are designed such that their useful life lasts around a decade. Post that, when these batteries do not meet the performance standards required by an electric battery, these batteries still maintain 80% capacity and a self-discharge of 5% while at rest[128]. They can thus be suitable for second-life applications.

Recycling processes have not been able to stand out ecologically as well. The recycling of lithium-ion batteries is still expensive and under-developed. Battery recycling costs are higher by three times as compared to sale of reclaimed materials. Due to this, lithium ends up as a byproduct which is not fit for reuse in second life applications post smelting. It can be reclaimed with additional procedures which are very expensive. Due to this, only 3% of lithium-ion batteries were recycled as compared to 90% of lead acid batteries in 2019. Because of this, there is a need to explore alternatives to recycling in the form of business models to support the extension of lifetime of a battery in second life applications.

The upfront cost of second life batteries was around $50/KWh in 2019. These prices will remain competitive at least until 2025, when the cost of a new battery is expected to be around $90/KWh. These end of life batteries can be subjected to reconditioning / refurbishing / repurposing / reusing procedures for use in less demanding applications. [129]

Figure 123: Circular economy of batteries



8.1 Battery reuse methods/processes

End-of-life EV batteries can be reused in both stationary and mobile applications. This involves splitting the spent battery down to the cell or pack level or maintaining the unit and removing low performing cells and replacing them with new or reconditioned cells.

[128] Source: McKinsey & Company (access here)
[129] Capgemini Invent (access here)

There are several methods to reuse spent EV batteries:

a. **Reconditioning:** Battery reconditioning or regeneration refers to restoring the standard level of electrolytes in a battery pack and a battery packs' full capacity to charge. The battery module is discharged repeatedly, and the cells which are unable to hold charge, are identified and are reconditioned to increase their life.

e. **Refurbishing:** Refurbishing involves opening up the battery, replacing the degraded parts and re-designing the BMS depending on the second life application, etc.

f. **Repurposing:** This involves replacement of some cells or packs for use in totally different set of application.

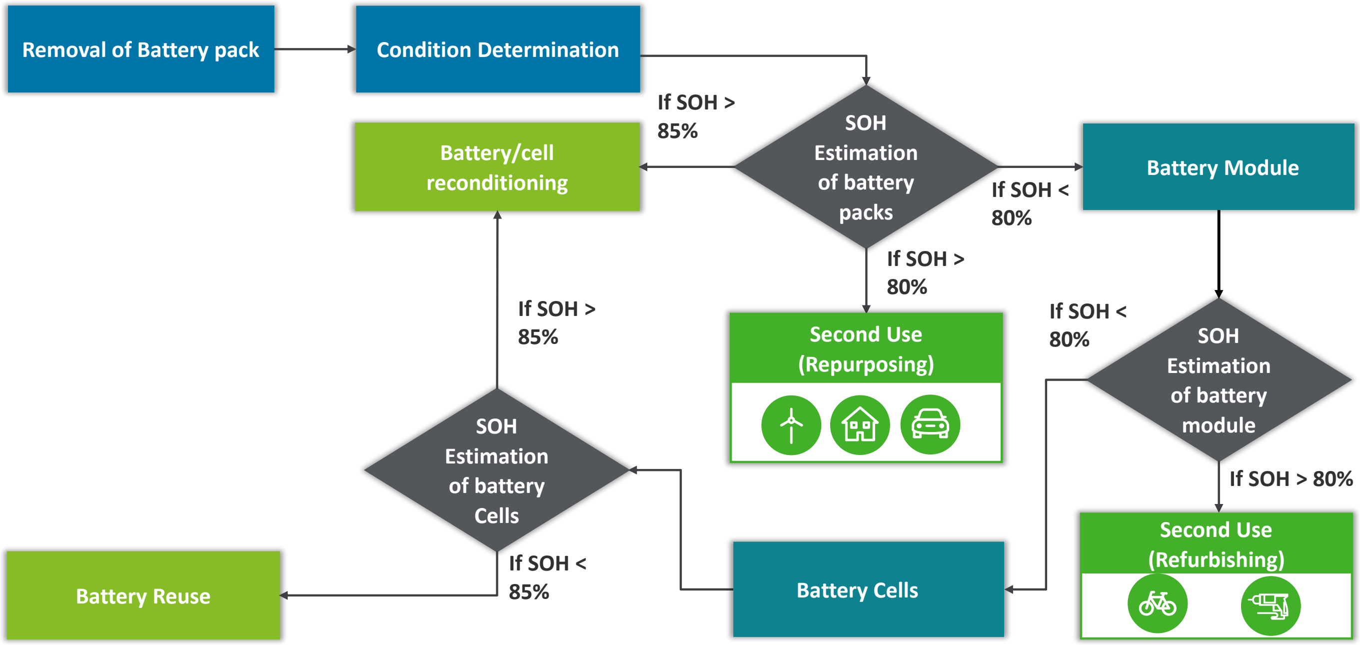
g. **Reusing:** This involves splitting of the battery down to the cell or pack level post which the individual cells or packs are reused directly in a wide variety of applications.

Table 137: Comparison of Battery Reuse methods/processes

Particulars	Battery Reconditioning	Battery Refurbishing	Battery Repurposing	Battery Reuse
Value Proposition	Reconditioned batteries can be directly used in EVs by replacing degraded cells	Refurbished batteries have a lower capacity but also have a lower price than a new battery	Repurposed battery packs can be used in stationary energy storage system in commercial and industrial energy storage	Second life battery cells can be used in a range of consumer electronics applications
Customer Segments	Professional or private customers interested in minimized downtime and performance	Price sensitive customers: when residual value of the EV does not justify the purchase of a new LIB	Environmentally conscious B2B or B2C customers, large energy consumers, utility and real estate companies, EV charging networks	E-cigarette companies or vaping companies and other consumer electronics company
Customer Relationships	Close relationships with the customers	Close relationship with its customers	Close/transactional relationship	Transactional relationship
Key Partners	Dealers, spare parts supplier	Dealers, refurbishing partners, spare parts suppliers	Energy utilities, repurposing partners, energy trading companies	Dealers. Consumer electronics companies, reusing partners
Channels	Dealers	Dealers	Direct contact for pilot projects or Distribution network of partner companies	Direct contact or contracts between companies
Revenue flows	Reconditioned batteries/ monthly payments through leasing contracts	Refurbished products/ monthly payments through leasing contracts	Sale of storage solution, leasing of LIB packs or modules, revenue from services provided and energy arbitrage	Sale of battery cells/ payments based on contracts with consumer electronics companies

An important step in all the above is diagnosis and classification. This step is done before the reconditioning/ refurbishing/ repurposing/ reusing process to find out the degree of ageing, damage, or degradation. Several systems are put in place to assist in the decision making of the appropriate method to be adopted among the four highlighted above. In the diagnosis phase, qualitative analysis and safety screening is done for the battery packs. A root cause analysis is also done to determine the issues with the battery pack. Post diagnosis, the classification will depend on the Remaining Useful Life (RUL), State of Health (SoH), specific reparation costs and safety conditions. A decision tree analysis is done based on the custom classification and grading process employed by different companies to decide between reconditioning/refurbishing/repurposing/reuse.

Figure 124: Flowchart illustrating the diagnosis and classification of EOL batteries



Battery reconditioning

Battery reconditioning generally refers to increasing the life of EV batteries by bringing back the full charging capacity of the battery. This process considers the fact that a battery is comprised of cells and inability of small number of cells to hold charge leads to a battery being considering inappropriate to use. Reconditioning involves identifying such cells and reconditioning them.[130]

The EV batteries are sent for reconditioning if the State of Health (SoH) of the battery cells is more than 85% or if it still meets the performance standards of the EV. Reconditioning the battery pack involves two primary elements:

I. Charging/balancing the battery pack
II. Deep discharging the battery pack

The charging/balancing process and deep discharging process are combined to recondition the battery pack. This process breaks down voltage depression in the battery cells. This restores the lost battery capacity equalizing the voltage levels of the cells and thereby extending the battery life. In certain scenarios, the battery does not recover from the initial reconditioning process due to the existing condition and levels of degradation of battery cells prior to the initial reconditioning treatment. In those cases, the battery reconditioning treatment is not enough as one or more modules inside the battery pack might have experienced a hard failure.

The failed modules are replaced, and a secondary battery reconditioning treatment should be done to ensure that new modules are equalized with rest of the modules in the battery pack. The failed modules are subsequently sent for recycling.

Spiers New Technologies reconditions batteries for clients such as Nissan, Ford, and General Motors. Battery M.D. Inc. specializes in battery reconditioning HEV batteries for GM, Ford, Chrysler, and Toyota.

The challenges faced during battery reconditioning are as follows:

I. **Safety and Regulatory issues:** The safety and regulatory issues regarding reconditioned cells and batteries are still not clarified properly.

[130] MNTRC (access here), Kelleher environmental (access here)

II. **Restrictions imposed by several countries:** Not all countries allow reconditioning of batteries or use and/or transport of such batteries. Countries like USA have federal laws which do not allow the import or export of reconditioned batteries

Battery refurbishing

A refurbished battery can also offer acceptable parameters as against a reconditioned battery, and hence serve as a replacement battery or can be integrated into a new electric vehicle. Refurbished batteries are cheaper and have demand particularly if the residual value of the EV does not justify purchasing a new battery. If the SOH of the battery pack is below 80%, the battery pack cannot be used as whole in second life applications or reused in EVs as it would not meet the performance standards. Hence such batteries are dismantled to retrieve the battery modules. The SOH of individual modules is further tested. The modules which have SOH below 80% are replaced with modules (SOH > 80%) of other spent battery packs. Hence the refurbished battery pack will now only have modules with SOH > 80%. The batteries are further reassembled with the remaining components. Post verification and testing such battery packs can be reused in EVs.

Following are the various processes in battery refurbishing:

a) **Screening:** This involves identification of degraded and damaged cells in the EV battery pack. Critical information such as State of Health (SoH) of a battery can be collected from the BMS of the EV battery pack.
b) **Disassembly:** This step includes opening the battery, removing mechanical and electrical connections between various components, and removing auxiliary electronic parts.
c) **Cell replacement & refill:** This step involves replacing defective cells and verifying and refilling the entire electrical including control wiring, power cables and connectors. All installed cells should have similar operating characteristics to ensure safe operation. Post cell replacement, the BMS should be programmed or reprogrammed to ensure a safe operation.
d) **Reassembly:** The reassembly process is similar to disassembly process, if the refurbished battery packs are used for an application similar to its use in first life. Furthermore, additional modification is not required for BMS, TMS and equalization management system in such cases. If the second life battery is designed for a different application as compared to its first life, a new BMS, TMS and EMS must be added.
e) **Testing:** This is done to verify the battery pack performance for second use.

Companies like Renault usually diagnose the battery pack down to the module level. Nissan takes apart the battery module completely, diagnoses the modules and then reassembles the battery pack based on their state of health.

The challenges faced during battery refurbishing are as follows:

I. **Safety and liability concerns:** Battery refurbishing is marred with various uncertainties such as complexities arising out of non-standardized battery modules, variability in refurbishing of various chemistries, complexity of each battery pack, type of failure, etc. This affects the safety aspects during removal, testing and assembly stages of refurbishing.
II. **Economic feasibility:** Economic feasibility of battery refurbishing in the EV value chain still remains a challenge. The benefits are largely dependent on the price of several spare parts and shows high sensitivity to volume of spent batteries. Refurbishing has a much lower net present value as compared to battery repurposing. To be preferred instead of new batteries, refurbished batteries should have a lower price. Such a model is valid as long as the price of batteries does not decrease. But in the coming years the price of batteries will decrease further, thereby affecting this market significantly.

Battery repurposing

Repurposing of EV batteries involves transforming an end-of-life EV battery to use it in a completely different application (for example, energy storage systems). The spent batteries are sent for repurposing if the SOH is more than 80%. Battery repurposing requires testing, assessment, auditing cells, and refabrication before the battery can be made available for an off-road application. The battery health will depend on the health of the lithium-ion cells present within the battery pack. The assessment of the health of the battery needs to be done in a non-invasive manner to ensure that no damage is caused to the cells. The various methods used by battery developers to assess the health including tracking the electrical charging and discharging rate, parsing data, and thermal imaging from the battery management system, etc.

Repurposed batteries can be used in stationary storage applications for grid support. The applications include grid support and management, RE capacity firming, peak shaving, frequency support, power (load) backup, etc. Other applications include mobile and off grid applications such as streetlamps, forklifts, refrigerated vehicles and hybrid and electric propulsion ships. Some OEMs viz. Nissan, Renault and Daimler sell the spent batteries to third parties who use them in modular energy storage containers. While original battery packs are used for large scale energy storage, the modules, or cells (after dismantling the battery pack) are repurposed and reassembled with new components in a newer casing. For instance, Volkswagen's mobile charging stations makes us of repurposed batteries.

The technical challenges in repurposing are highlighted below:-

a) **Absence of standardization in Li-ion EV Batteries:** Estimating the remaining useful capacity and SoH becomes difficult due to the differences in the make of different EV batteries with regard to size, format, and electrode chemistry. Individual batteries are also subjected to different levels of wear and tear and conditions during their life. Hence, entities involved in battery repurposing face a challenge in accounting for the design differences of spent batteries.
b) **Lack of standards for Second Life Batteries:** Absence of widely accepted second life battery standards has made many potential buyers wary of opting for second life batteries. Furthermore, standards for quality, performance and safety are being worked upon in many levels.
c) **Competing with new batteries:** Advances in technology have led to significant enhancement of new battery performance and decline in battery prices. Although the cost of second life repurposed batteries is much lower than cost of new batteries in the current scenario, in the long run, the battery prices will decline further. Hence, new batteries could potentially pose as a competitor for repurposed batteries.[131]

Battery reuse

Battery reusing involves splitting the battery down to the cell or pack level. Companies like Tesla design their original EV batteries with standard cells which were easily available in the market to avoid risk of shortage. Battery OEMs manufacture billions of standard cells for various applications. The cells in the spent batteries hold enough charge. They can be used in a broad range of applications such as laptops, cell phones post disassembly.

Companies such as Spiers New Technology and IT Assets Partner carry out battery reuse by using the cells of spent EV battery packs. Some smaller companies or individual operators also carry out these operations without standards or oversight applications.

Applications

Following are the major second-life applications of EV batteries and a brief overview of key companies and the application they cater to:

Particulars								
Application	Reuse in EVs	In other battery applications (wheelchair, drones)	Residential energy storage (combined with solar PV)	Commercial and Industrial energy storage	Grid scale energy storage	Renewable energy systems	Backup power	EV charging
Methodology used	Battery Reconditioning/ Refurbishing	Direct reuse	Battery Repurposing	Battery repurposing	Battery repurposing	Battery repurposing	Battery repurposing	Battery repurposing

Table 138: Applications of second life batteries by various companies

Sl. No.	Company	EV Battery Reuse Application	Location
1.	**Acceleron**	Acceleron Energy storage	Acceleron Energy storage UK, Barbados

[131] EV Reporter (access here)

Sl. No.	Company	EV Battery Reuse Application	Location
2.	**Audi**	Audi Forklifts and factory tugs Ingolstadt, Germany	Ingolstadt, Germany
3.	**Audi Battery**	Battery storage	Berlin, Germany
4.	**BJEV**	EV charging and back-up power	_
5.	**BMW**	Energy storage farm	Leipzig, Germany
6.	**BMW**	Grid scale energy storage, back-up power	_
7.	**BMW and Pacific Gas and Electric (PG&E)**	BMW iChargeForward Project – Using second life EV batteries in demand response (DR) to stabilize the grid	San Francisco Bay area
8.	**Box of Energy**	Storing energy from rooftop solar panel to run lights and elevators	Sweden
9.	**BYD**	Energy storage	Shenzhen, China
10.	**Chevrolet**	Back up at GM's Enterprise data center	Michigan, US

Reuse in EVs

The supply chain of end-of-life EV batteries is controlled by auto manufacturers and auto dismantlers. The auto mechanics and auto repair shops also feed in small amounts of end-of-life EV batteries. The business for refurbished and reuse batteries is carried out by informal recyclers, small businesses and do it yourself (DIY). There are DIY communities which collect spent batteries and offer them second life. DIY builders use older batteries as makeshift powerwalls (integrated battery systems to store energy) to power their homes amongst other applications. But since DIY battery reuse can go mostly unmonitored, this could cause a lot of damage to people and environment. Hence, this should generally be avoided.

Auto dismantlers generally sell the EOL EV battery they receive to auto dealers or brokers or repair shops. The brokers further deploy these batteries into reuse applications. Smaller operators create a new battery from those packs and cells which have sufficient charge remaining. Some professional and established companies such as Spiers New Technology grade the cells and packs through a systemic process for various applications including EV batteries. Nissan collects the end-of-life batteries used in its leaf model in Japan to test and refurbish those batteries. The rationale behind this is that these refurbished batteries can be used in a vehicle which has a few years of life remaining. Hence, Nissan uses this to retain customers as well in Japan.[132]

Reuse in energy storage systems

Reusing spent EV batteries can provide value when there is a demand for using batteries in stationary energy storage applications. More so, there applications should require less frequent battery cycling (say 100-300 cycles in a year). Based on this premise, EV batteries can be reused in the following applications:

a) **Grid support and management:** Repurposed batteries can be used in stationary energy storage systems which can store energy during periods of lower demand and release it during peak demand (shaving or levelling mechanism). These batteries can also be used to support energy arbitrage and grid frequency regulation.
b) **Renewable energy storage and grid integration:** The repurposed batteries can be used in stationary energy storage systems to balance the fluctuations in the grid due to the increasing share of renewables in electricity generation. Using retired EV batteries in such applications can bring down the cost of BESS.
c) **Power load backup:** Retired EV batteries can be used to provide backup power in commercial buildings or residential complexes whether access to reliable energy generation or distribution networks is limited.

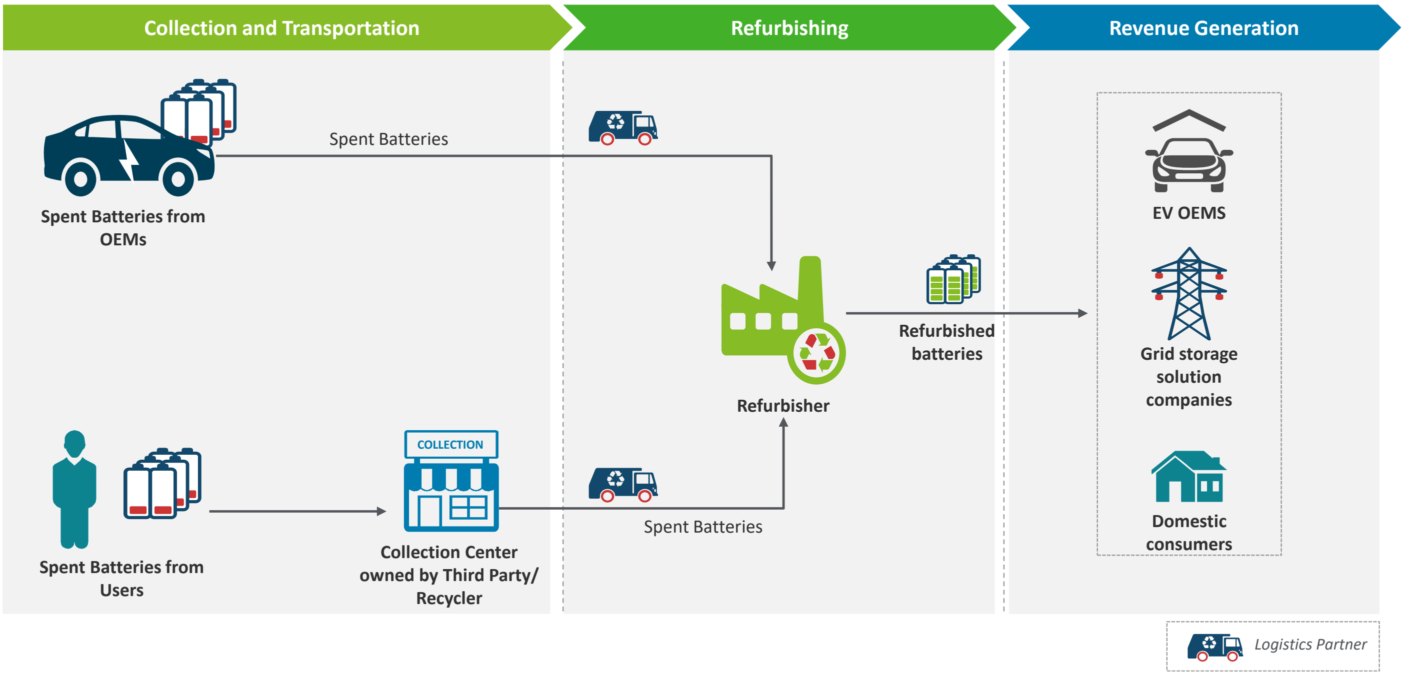
[132] Kelleher Environmental (access here)

Reusing EV batteries can extend the life of EV battery from 6-15 years. By 2025, the cost of using second life batteries as compared to newer batteries will be 30-70% less expensive in such applications.[133]

Organized and unorganized Battery reuse

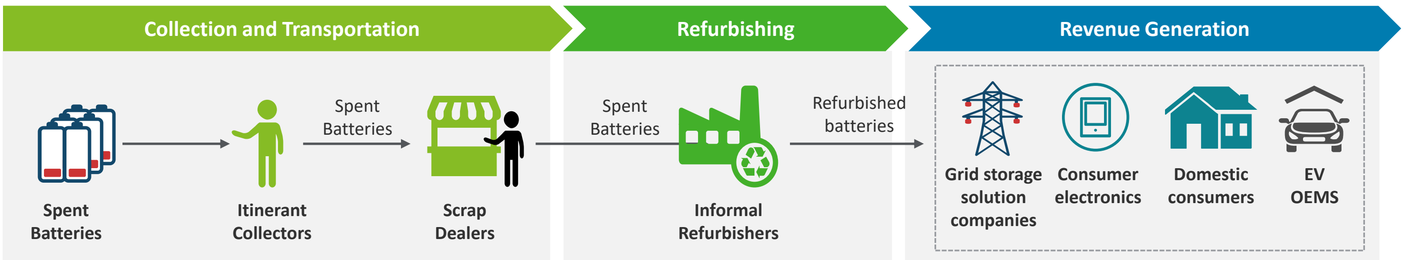
While the organized sector has specific rules and regulations that the reusers must adhere to, the unorganized players usually include scrap dealers and informal reusers which may not follow the specified rules and regulations.

Figure 125: Organized battery reuse industry operations



Organized battery reuse industry has well established channels which includes the flow of batteries from the end consumers to the refurbishing plant through battery aggregators or battery collection center of the battery manufacturers or electric vehicle OEMs. The refurbishing process in the organized segment has to comply with the appropriate environmental and safety regulations. The processes used by organized reusers are of higher efficiency with lesser emissions in comparison to the processes used by unorganized reusers who generally use smelters. This is solely because of the fact that the organized sector is subject to adequate oversight and testing.

Figure 126: Unorganized reuse industry operations



The unorganized reuse industry is different from the organized reuse industry. In the unorganized sector, the collection of batteries is usually done by itinerant collectors (also known as kabadiwallas in India). These collectors take the batteries to the scrap dealers where the scrap dealers sell the batteries ahead to the auto dealers or brokers or repair shops. The brokers further deploy these

[133]Source: Mckinsey (access here)

batteries into reuse applications. Smaller operators create a new battery from those packs and cells which have sufficient charge remaining. These operators carry out these operations without standards or oversight.

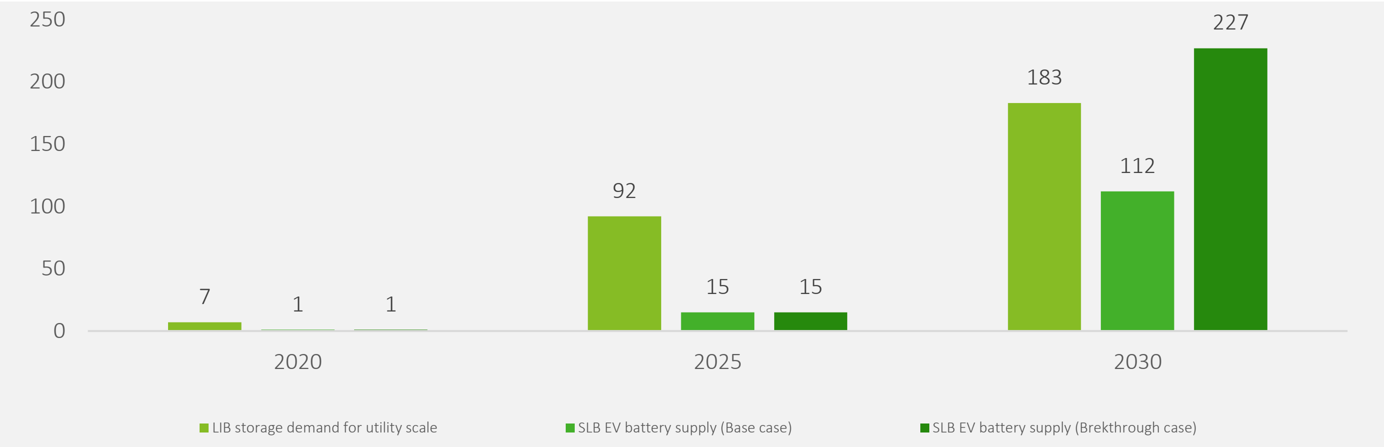
Unorganized sector is not subject to proper oversights, standards, and management which leads to safety concerns. Serious concerns have been raised regarding the reuse of EV batteries in vaping equipment and e-cigarettes as they tend to explode. This happens because the device, cells, and BMS are not integrated as they are manufacturing by different companies.

8.2 International Landscape for EV battery reuse

Lithium-ion battery reuse

Electric vehicles have experienced a rapid increase in demand over the last decade and will experience an even faster growth over the next decade. This will result in an increasing market for second life batteries. As per Multidisciplinary Digital Publishing Institute (MDPI), the supply of second life batteries was 1 GWh in 2020 as compared to 7 GWh demand of lithium-ion batteries for utility scale storage. By 2025, the supply of second life batteries will reach 15 GWh per year in both base case and breakthrough scenarios. By 2030, the supply of second life batteries from EV could exceed 200 GWh/year (breakthrough scenario) and will exceed the demand of lithium-ion batteries for utility scale storage (low-cycle and high-cycle applications). Estimates suggest that USA, Europe, and China will be the major suppliers of second life batteries in the coming decade.

Figure 127: Utility scale lithium-ion battery storage demand and second life EV battery supply (GWh/y)



Source: MDPI (access here)

Following table illustrates how various companies have gone about reusing spent EV batteries:

Table 139: Various applications of second life lithium-ion batteries

Sl. No.	Company	EV Battery Reuse Application	Location
1.	**Nisan/EDF Energy**	• Partnership to combine used Nissan Leaf batteries with the demand side response offers from EDF	UK
2.	**Belectric**	• Large scale storage systems (40 MW) from used EV batteries and new batteries to provide frequency response	UK, Germany
3.	**BMW**	• Using EOL batteries in a storage farm in Leipzig in wind energy generation systems	Germany
4.	**BMW/ Bosch/ Vatenfall**	• First second-life battery storage systems in Europe with 2MW capacity from test fleet batteries of BMW	Germany

Sl. No.	Company	EV Battery Reuse Application	Location
5.	**Daimler/ Mercedes Benz Energy/ GETEC Energie/ The Mobility House**	• Two second life battery storage systems to provide for the German Energy Market	Germany
6.	**PSA/ EDF/ Mitsubishi/ Forsee Power**	• Demonstration facility in France to store energy from EVs and solar panels using second life batteries	France
7.	**BMW/PG&E**	• Pilot project to provide for grid services for California utility using used BMW i3 batteries	USA

Source: Capgemini Invent (access here)

Testing and Evaluation methods for Battery Reuse

Spent lithium-ion batteries have a huge potential in on-grid ESS and backup supply applications. However, there are certain technical challenges which essentially hinder the reuse of end-of-life lithium-ion batteries. The technical barriers in the entire process are highlighted below.

1. **Safety test:** Safety test and evaluation approach for second life batteries are very critical in ensuring their reuse potential in second life applications. Safety tests such as over discharging, short circuit, heating, over charging, puncturing, squeezing, etc. are typically carried out before ascertaining fitment for reuse. To further guarantee the safety of the batteries, several assessment techniques such as state of safety (SOS) and failure analysis are conducted. SOS refers to probability that a battery works safely in the given time. Failure analysis methods includes Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA). These methods can analyze risks and discover potential areas of failure in several applications.
2. **Evaluation method:** These methods obtain the performance characteristics of spent batteries and help in determining if the spent batteries are worthy of reuse. High scoring batteries can be used in reconditioning/refurbishing or in grid related ESS which are more demanding applications. Low scoring batteries can be used in forklifts or electric scooters which are fewer demanding applications. The evaluation methods used are State of health (SOH) estimation, predicting remaining useful life (RUL), and life cycle assessment (LCA).
   a. **SOH estimation:** The various approaches for SOH estimation are direct assessment approach, empirical approach, model driven approach, data driven approach and hybrid approach. The details of the same have been listed below.

Table 140: Various approaches for SOH estimation

Sl. No.	Approach	Brief
1.	**Direct assessment**	• Measures the capacity or internal resistance directly and obtaining the SOH value. Recent methods to directly measure SOH include Incremental capacity analysis (ICA), differential voltage analysis (DVA), and other methods like acoustic - ultrasonic guided waves.
2.	**Empirical estimation**	• This approach describes the relationship between various ageing stress factors and SOH by simplified mathematical expressions.
3.	**Model driven estimation**	• Model driven methods can estimate the SoH of spent batteries by identifying health sensitive model parameters based on electrochemical models (EM) or equivalent circuit models (ECM). EM methods can account for the electrothermal behavior of batteries and thereby estimate the SOH of battery. ECM methods can establish a relation between the external characteristics exhibited by the battery and the internal state of the battery. This is further evaluated to estimate the SoH.

Sl. No.	Approach	Brief
4.	**Data driven approach**	• Data driven approaches do not depend on the electrochemistry or physical aspects of the battery. These approaches use methods like regression based on feature selection to estimate the SoH of batteries
5.	**Hybrid methods**	• Hybrid methods combine the advantage of different approaches such as Entropy weight method (EWM) and grey relation analysis (GRA) to assess SOH. GRA methods first selects certain health indices based on the spent battery. EWM method is then used to evaluate the weight of the health indices selected using the GRA method. Subsequently this was matched with reference battery to estimate the state of health.

b) **Remaining Useful Life (RUL) prediction**: Spent lithium-ion batteries need to be evaluated in a way which ensures cost efficiency, strong generalization, and high accuracy. Many SOH estimation methods can also be used for RUL prediction, such as: empirical methods, model-driven methods, data-driven methods, and hybrid methods.

Table 141: Various approaches for RUL prediction

Sl. No.	Approach	Brief
1.	**Empirical estimation**	• This approach uses a simple structure and involves low computational complexity. It includes several fixed parameters which may result in large errors while studying the nonlinear ageing process
2.	**Model driven estimation**	• This approach estimates RUL by using mathematical models which describe the degradation process. Following are various model driven estimation models: • -ECM Method: It can establish a relation between the external characteristics exhibited by the battery and the internal state of the battery to estimate the RUL. It has a low computational cost and good scalability. The challenge lies in calibrating the model parameters to suit RUL estimation • -EM based method: This method reviews the electrochemical behavior of the battery to estimate the RUL of the battery. This approach has high accuracy and high generalization ability but involves high computational cost and knowledge about mechanisms.
3.	**Data driven approach**	• This approach can use historical data to extract few hidden information and use it to predict the RUL without going through the degrading mechanism as in model driven methods. This model has good flexibility but low generalization ability.
4.	**Hybrid methods**	• Combines the advantage of different approaches to make satisfactory predictions about the RUL. But the combination of different approaches results in a complex structure with increased possibility for errors.

2. **Screening and regroup technology:** To guarantee performance safety, improvement in system life and homogeneity in battery pack, screening and regrouping processes are adopted for lithium-ion batteries.

a) **Screening approaches:** Spent batteries need to be first visually inspected to remove cells with deformation defects or leaks. The batteries will then be screened based on difference of properties or parameters or other data driven approaches. Several screening indexes such as voltage, capacity, and internal resistance are used to select batteries. Several approaches can be used viz. hybrid pulse power characterization (HPPC), Piecewise Linear Fitting (PLF) and BP neural networks. PPC technique can be used to sort the spent EV batteries by using current pulses to evaluate response time and flow of ions related to capacity and power density. It has the ability to discriminate the difference in batteries in 80 seconds. PLF method uses information on series charging to screen spent EV batteries. PLF method is more effective in screening small scale spent EV cells and has an error percentage less than 3%.

b) **Regrouping approaches:** The cells and modules which meet the standards set during screening are further segregated into clusters based on their performance. They are then reassembled into packs for second life applications. The battery or module with the worst performance will constrain the performance of the final battery pack. Hence the internal resistance, capacity and voltage of each modules should be closely matched.

3. **Management:** After spent batteries are screened and reassembled, installation of Battery Management System, Thermal Management System and Equalization Management System is carried out. If the second life application of the second-life battery is similar to its first life, the BMS might need minor modifications or programming. If the second-life application is different as compared to its first life, then a new BMS, TMS and EMS should be added based on the requirement of the application.

   a. **BMS functions:** BMS is critical to ensure reliability, safety, and efficiency of lithium-ion batteries. BMS must ensure reliable estimation of Status of health (SOH), state of power (SOP), and state of charge (SOC). Direct calculation, data driven approach and model-based approach are some of the approaches used for SOC estimation. SOP is estimated by several methods such as: Characteristic map (CM) based methods and model-based methods. Majority of methods used for SOH estimated under evaluation methods can be integrated into BMS as well.

   b. **Equalization management:** Equalization refers to the controlled battery overcharging. In lithium-ion batteries Voltage Equalization can maximize the capacity of the battery pack and ensure that cells are not damaged in an event of overcharging or over discharging. This would reduce maintenance costs and maintain consistent operating conditions. There are two types of equalization systems viz. Active and passive. Active mode is widely preferred due to large balancing capacity and higher efficiency. Passive equalization ensure that all batteries essentially have the same state of charge, but it cannot improve the run time of a system powered by batteries.

   c. **Thermal management:** Spent batteries will inevitably suffer from degradation which poses a challenge towards design and implementation of TMS. Hence the TMS should be chosen based on the reuse applications' specific requirements. TMS is required to dissipate heat which increases the battery performance and control the temperature thereby preventing thermal runaway.[134]

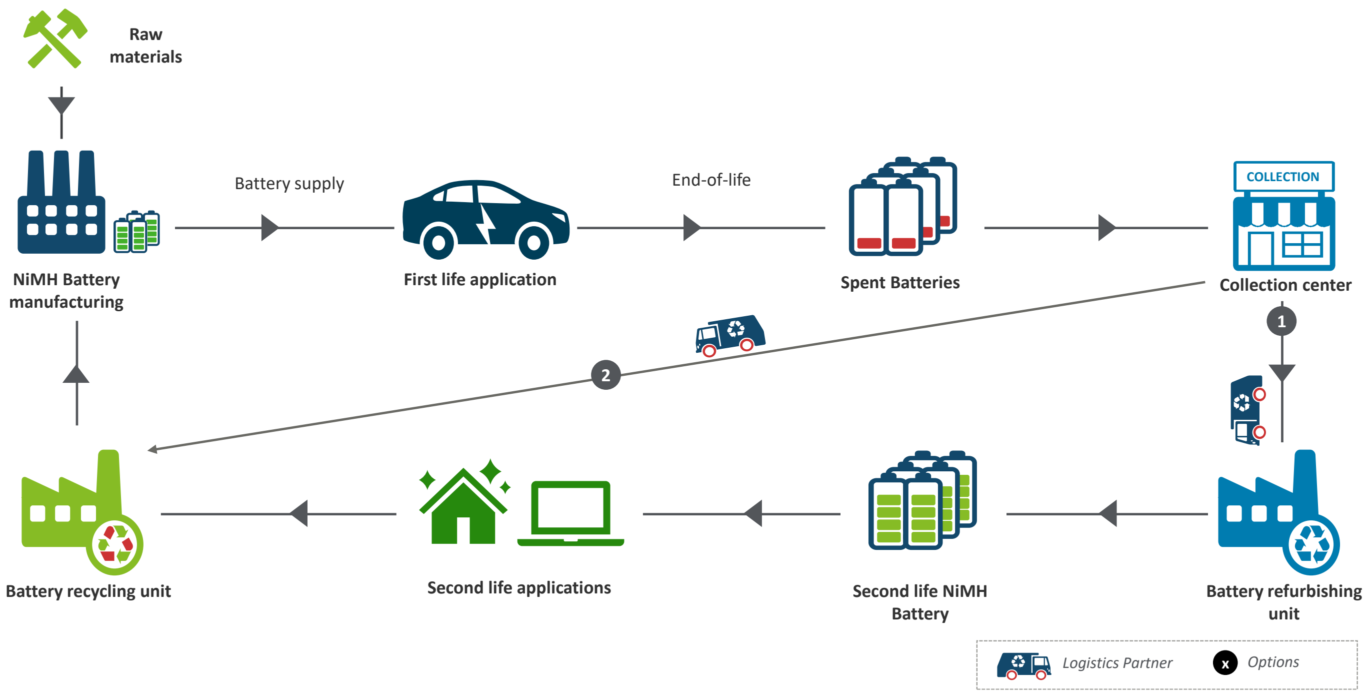
Nickel metal hydride battery reuse

Ever since their commercialization in 1990s, NiMH batteries are used in various electronic devices including EVs. This has led to accumulation of an increasing number of spent NiMH batteries. Many recycling processes such as pyrometallurgy and hydrometallurgy are in place to recover Nickel, Cobalt, and rare earth metals from NiMH batteries.

It has been observed that the recycling efficiency of NiMH batteries are not promising and hence, reuse of NiMH batteries can become a possible option of dealing with spent batteries.

[134] Elsevier (access here)

Figure 128: Nickel Metal Hydride battery reuse



1. **Collection of NiMH batteries:** Once NiMH batteries are spent and do not meet the performance standards of the EV, they are dismantled from the EV by End-of-Life Vehicle (ELV) dismantlers or authorized vehicle dealers. These spent batteries are further sent to facilities for battery reconditioning/ refurbishing/ repurposing/ reusing.
2. **Function test for waste NiMH batteries:** The battery reconditioning/ refurbishing/ repurposing/ reusing operator will dismantle the spent NiMH batteries into battery modules. The capacity of individual battery module will be tested. These tests consume about 2KWh per spent NiMH battery (capacity: 8.8 KWh). The modules which are found to be non-recoverable or non-reusable are sent to the battery recycling facilities.
3. **Reconditioning/ Refurbishing/ Repurposing/ Reusing waste NiMH batteries:** In this step, the operator adds in newer modules (or from other spent batteries) to the modules recovered and reconditions or refurbishes the battery by running multiple cycles of charging and discharging. This process consumes around 10KWh of electricity per refurbished NiMH battery pack (capacity: 8.8 KWh). The reconditioned NiMH battery has 80% of the capacity as compared to a brand-new NiMH battery. This reconditioned battery can be used for a period of 5 years.[135]

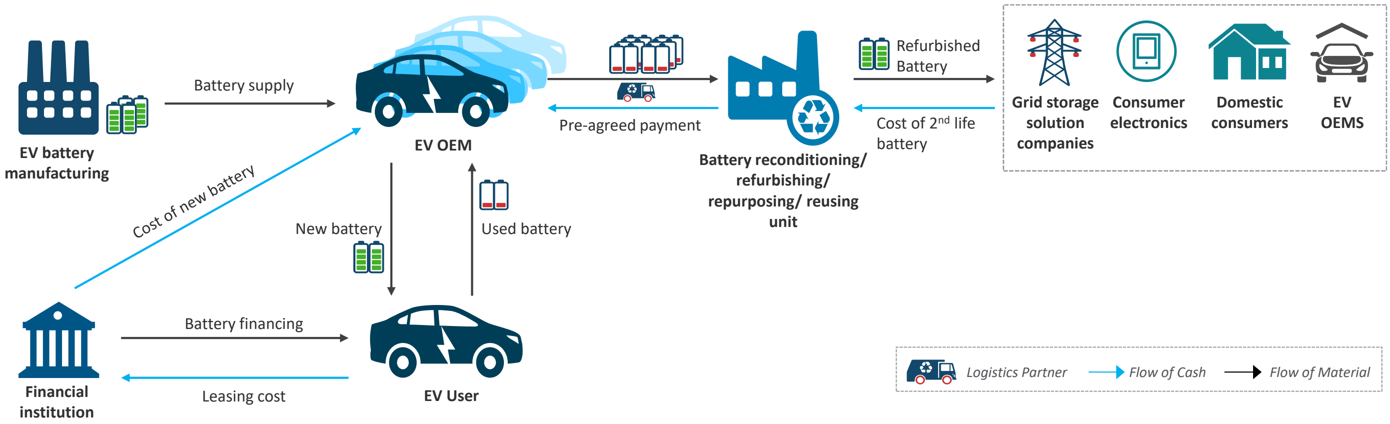
Business model

Integrated business model

Integrated business model for battery reuse refers to a market whereby an automotive manufacturer/OEM includes second-life battery applications into its entire value chain process. The OEM operates as a focal point within the value chain of traction batteries. It retains ownership of battery systems during the period of automotive usage and controlling the most important processes within the battery lifecycle.

[135] Wiley (access here)

Figure 129: Integrated business model for EV battery reuse



The pros and cons of such a model are highlighted below:

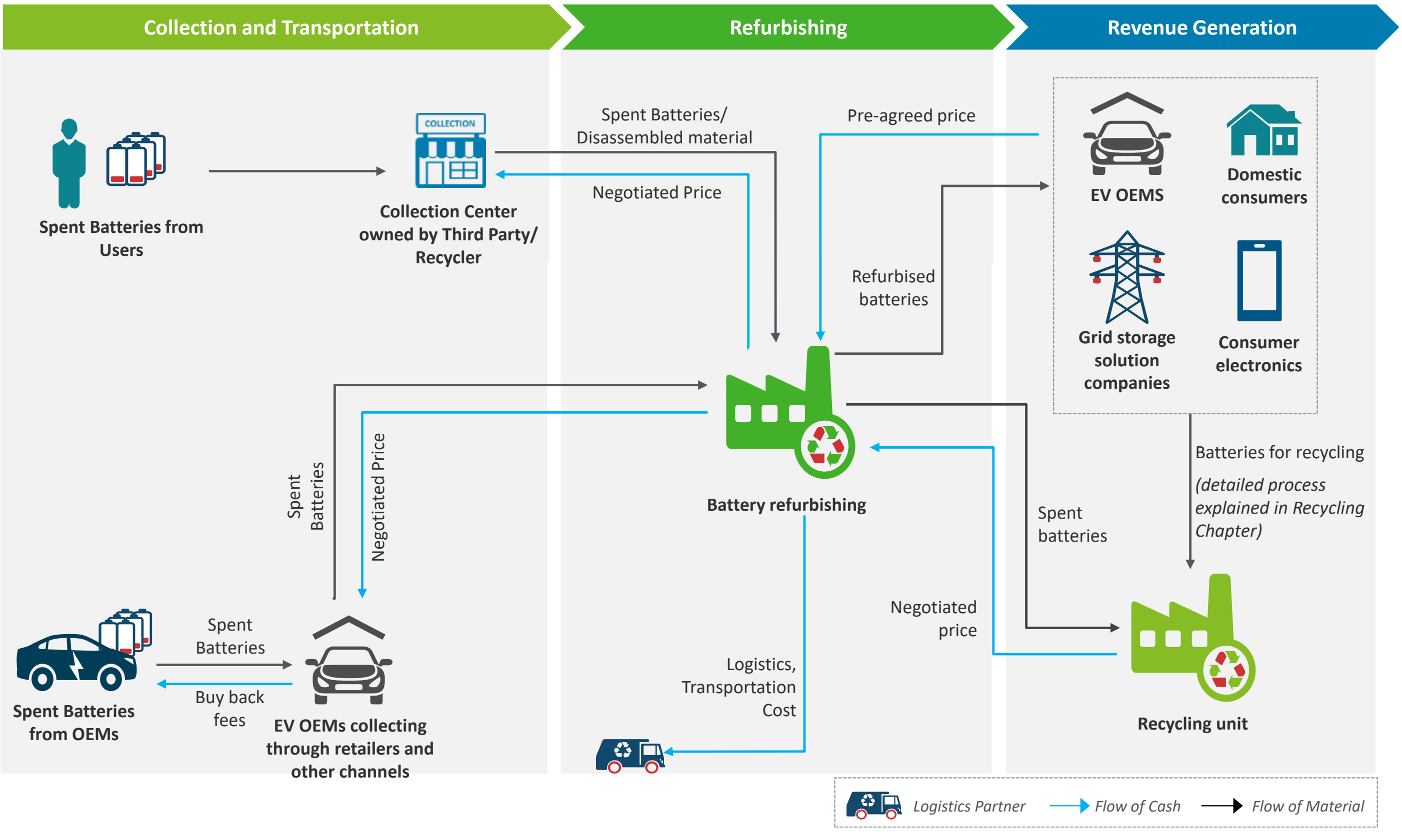
PROS	CONS
• Increased vertical integration and diversification • OEM retains battery ownership throughout its life cycle • Ensures monitoring key battery parameters during automotive usage • Decreasing initial cost for EVs due to battery leasing	• Vertical integration and diversification could lead to decreasing influence of OEMs in the battery value chain

Multi-agent business model

It was observed that there are three common factors deciding EV battery reuse: **Battery ownership, inter-industry partnership** and **government support.** In a battery reuse system, the control over the battery is very important. An EV OEM manufactures and further sells the EV to the customer. Once the batteries are spent, if it chooses to collect the batteries back through various channels, it has control over the battery life cycle from manufacturing to end-of-life. Alternately, batteries can also be collected in a collection center which are set up by battery aggregators.

Both EV OEMs and collection centers sell the spent batteries to the battery reconditioners/ refurbishers/ repurposers / reusers at a price which is set through agreements. The battery refurbishers also need to pay for the logistics and transportation cost to the logistics partner. Based on the type of activity conducted, the business model will change. For instance, for **battery reconditioning and refurbishing**, the second life batteries will be sold to the **EV OEMS**. For a business model involving **battery repurposing**, the second life batteries will either be sold as **stationary storage** or for other **consumer electronics**.

Figure 130: Multi-agent business model for EV battery reuse



Given the wide range of applications and the complex nature of second life applications, inter-industry partnership is also a key factor for the success of such a business model. There needs to be a cooperative relationship between the EV industry and energy services partner to ensure potential profits from battery second use. Examples include 4R Energy which is a JV between Nissan and Sumitomo. Nissan is an automobile giant and a manufacturer of EVs while Sumitomo has extensive business operations in industries such as Electronics, Energy & Environment, automobiles, etc. Nissan provides batteries while Sumitomo has developed technologies to quickly measure the performance of used batteries. Nissan also provides spent batteries to the startup FreeWire, which provides EV charging solutions. The spent batteries will be used by Freewire Technologies to build a smart charging network.

Currently, there are no uniform regulations governing the EV battery reuse industry globally. Only battery collection targets are set forth. Moving ahead, subsidies are the need of the hour to promote the growth of infrastructure with regard to battery reuse. Furthermore, a clear set of guidelines and rules should be drafted and included in specific battery waste management policies of different countries.

The pros and cons of such a model are highlighted below:

PROS

- **Shared liability:** Multi-agent business model ensures that the liability owing to the complexity of second life batteries and wide potential application is shared
- **Market based pricing:** Second-life battery users could buy refurbished batteries on an open market with market-based pricing which could lead to cost savings.

CONS

- **Battery ownership is not retained by the EV OEM** through its life cycle
- **Higher upfront costs** due to lack of battery leasing
- **Uncooperative relationship** between EV and energy sectors could block potential profits for battery reuse

Global stakeholders

The business model of EV battery reuse is complex due to the involvement of a wide range of stakeholders, ranging from the electric vehicle industry to the energy industry. The various stakeholders involved in battery reusing have been listed down below:

Table 142: Various stakeholders involved in EV battery reuse

Business Model Participation	Stakeholder	Role
Collection and Transportation	**Collection Centers**	• Collection centers can be operated by battery aggregators. The collection centers work as a drop off point for spent batteries. Collection centers transport these spent batteries to battery reconditioners/ refurbishers/ repurposers/ reusers for further processing.
	EV OEMs	• OEMs collect traction batteries through their dealerships and send the battery across to the reconditioners/ refurbishers/ repurposers/ reusers.
	Logistics Partner	• Logistics partners ensure that the batteries from OEMs and Collection centers reach the recyclers with adequate transportation safety and within regulations. Logistics partners also have capabilities of handling damaged batteries along with bulk spent batteries.
Reconditioning/ Refurbishing/ Repurposing/ Reusing	**Battery Reconditioning**	• Involves identification of degraded cells and replacement of these cells with cells which can hold sufficient charge. The cells used for replacement could be taken from another spent or EOL battery. Sending the cells which could not hold sufficient charge to recycling centers.
	Battery Refurbishing	• Battery refurbishers carry out screening, disassembly, cell replacement and refill, reassembly, and testing. These batteries are then deployed into reuse applications, while the degraded cells are sent for recycling.
	Battery Repurposing	• Battery repurposers conduct several processes such as: disassembly, diagnostics, repurposing process including reassembly, designing BMS/TMS/EMS suitable for energy storage applications, cooperation with energy utilities, monitoring, customer services.
	Battery Reusing	• Battery reusers conduct disassembly and diagnostics. When cells which have sufficient charge are found, they are sold into the market. Remaining cells are either sent for disposal or accumulated for recycling
	Battery recycling	• Battery recycling is typically done by the same company who is involved in battery reuse. The recycling process begins with shredding where plastic, aluminum and copper are separated from the black mass. Post the same, chemical refining enables recovery of 95% of the raw materials in the form of Cathode (Li, Co, Ni, Mn) and Anode (Graphite)
Revenue Generation	**EV OEMS**	• The reconditioned and refurbished batteries are sold to EV OEMs. These batteries can be used in second hand EVs or in other applications within the EV.
	Energy Storage/ Power companies	• The repurposed batteries are sold to the energy storage companies or power companies. They further sell these batteries for applications such as backup power for residential purposes, energy storage systems in grids, etc.
	Consumer electronics	• Battery reusers sell the healthy cells from the spent batteries. These can be used in various applications viz. e-cigarettes, vaping machines, mobile phones, etc.
Recycling and recovery	**Battery manufacturers and active material manufacturers**	• These are the off takers of the products generated from recycling. The metal salts and the cathode material obtained from recycling is sought by these companies for manufacturing new batteries.
	Industries	• The plastics and metals recovered from the recycling process are sold mostly to industries.

International battery standards for battery reuse

The standards mentioned in this section cover the major EV markets in the world namely Europe, USA, etc. Standards specified by organizations such as IEC (International Electrochemical Commission), ISO (International Organization for Standardization), CENELEC (European Committee for Electrotechnical Standardization), QC/T (Chinese standards), UN have been taken into account. It is important to note that the IEC standards being referred to here are currently under preparation and will be completed in the upcoming years.

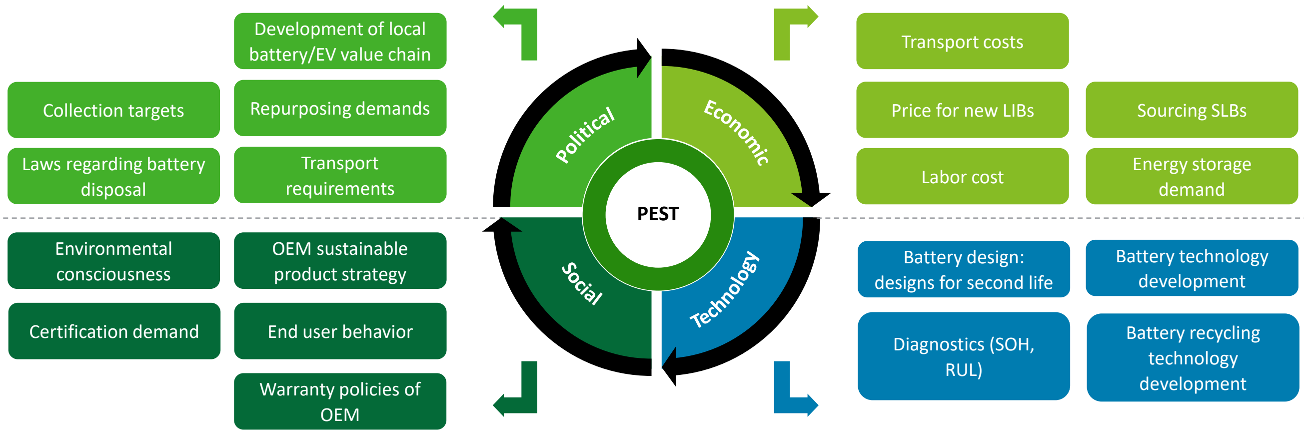
Sl. No.	Organization	Standard	Type	Standard description and coverage
1.	**IEC**	**IEC 63330**	**Global**	• This standard lists down the requirements for repurposing battery systems, battery packs, modules, and secondary cells manufactured for use in applications such as mobility. It also specifies the procedure to evaluate performance and safety parameters of batteries for repurposing. It does not cover redox flow batteries.[136]
2.	**IEC**	**IEC 63338**	**Global**	• This standard gives a general guidance regarding the reuse of batteries and secondary cells[137]
3.	**UL**	**UL 1974**	**Global**	• This standard specifies how to evaluate batteries for repurposing based on BMS measurements. This standard also covers the processes for sorting and grading of battery packs, modules, cells and electrochemical capacitors which were originally configured for EV propulsion.

Potential use in India

PEST analysis

A pest framework was followed in order to understand and analyze the factors influencing battery reuse in India.

Figure 131: PEST framework for battery reuse in India



a. Political factors

Policies such as Faster adoption and Manufacturing of Hybrid and EVs in India (FAME) and National Program on Advanced Chemistry Cell (ACC) are driving the local EV and battery value chain in India. This in turn will give rise to a number of spent batteries which will drive the battery reuse market in future. The Draft Battery Waste Management Rule, 2020 also does not mention guidelines regarding refurbishing/repurposing. Battery repurposers /refurbishers /reconditioners /reusers could be considered in further amendments. Dealers and manufacturers will be required to ensure that the transport of used batteries to registered repurposers /refurbishers /reconditioners /reusers cause no harm to the environment during this process. Moreover, since there

[136] Source: IEC (access here)
[137] Source: IEC (access here)

are no specific collection targets for industrial or EV batteries, it is difficult to track the rate of collection of spent batteries. Reaching higher collection targets remains a challenge and affects the battery reuse market as well.

There has been certain licensing and registration requirements set forth for e-waste refurbishers which also includes battery refurbishing under E-Waste (Management) Rules, 2016. This requires the refurbisher to be registered either under the Factories Act,1948 or the Company Act, 1956 or in both and have a one-time authorization from the concerned State Pollution Control Board. As of now, spent batteries are not classified before transporting. Hence, there is a requirement to classify the batteries (Reuse, Recycle or Disposal) before transporting. Clear instructions must be provided for transporting and packaging of each type of battery.

b. Economic factors

There are certain economic factors which influence the EV battery reuse market. A high price of new batteries results in increasing attractiveness of the reuse market. But if the battery price is too high, the demand of EV would reduce, affecting the market in the long run.

Higher costs of transports for spent batteries are also an obstacle for EV battery reuse. Sourcing or acquisition of second life batteries is the major cost for EV battery reuse. Hence, increase or decrease in such costs will drive the market in a similar way.

c. Social factors

Social expectations are not a dominant factor for EV battery reuse; however they can still impact the reuse market. The transition to electric mobility is also driven by a societal perception for environment friendly vehicles. Handling the spent batteries in an environmentally responsible manner is also dependent on customer's environmental and societal concerns. In addition, whether an end user chooses the organized or unorganized sector of the EV battery reuse value chain is an important factor in determining the scope of EV battery reuse.

d. Technology factors

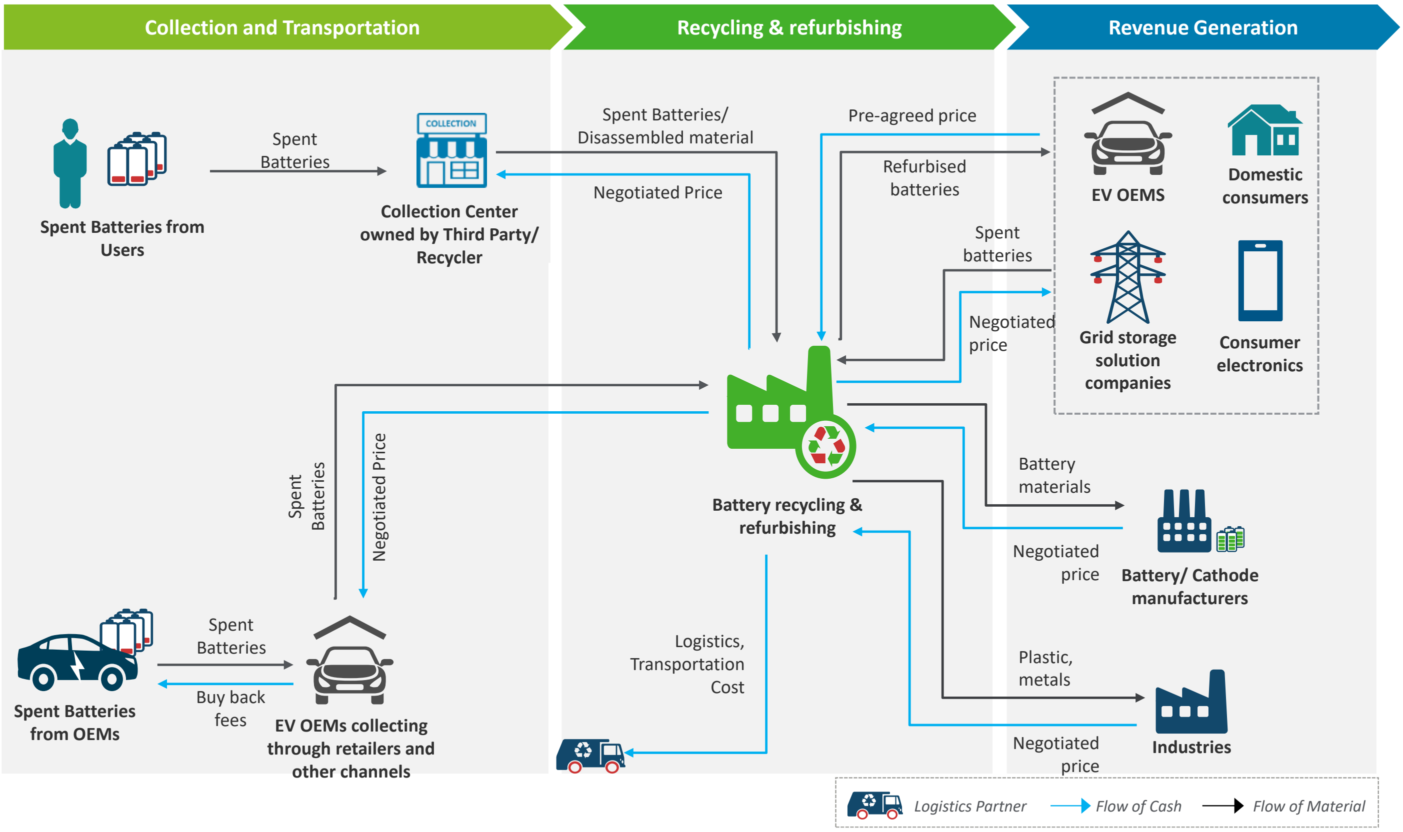
Technology development will have a huge impact in the EV battery reuse. The rate of adoption of battery reuse will be determined by various factors such as: the development of newer chemistries, variability in chemistries, etc. Such factors shall also determine the scope of the battery recycling and reuse market. Estimating the SoH and RUL of a spent battery is a labor-intensive step and leads to higher costs. If the determination of such factors could be made easier, it would lead to lower costs of battery reuse which may impact the market positively.

Moreover, battery repurposing also would require redesigning BMS, TMS and EMS and their subsequent integration into the battery system. Future technical developments could also be designed to help in easier integration of these parts. The reuse market can also be negatively impacted by technological advancement as well.

Battery reuse business model

Companies such as Lohum and Ziptrax have integrated operations for reusing and recycling. The batteries are collected through collection centers which are either set up by the company or by battery aggregators. The batteries are further sent to the companies, wherein they are first segregated, tested and the usable batteries are reconditioned/ refurbished/ repurposed/ reused in second life applications such as in Energy storage systems, residential applications, etc. When the second life batteries are spent, they are collected and recycled by the same company to recover rare earth metals. The critical materials recovered are then either sold to battery manufacturers or used by the same company if it is involved in battery manufacturing.

Figure 132: Business model of battery reuse in India (integrated with battery recycling)

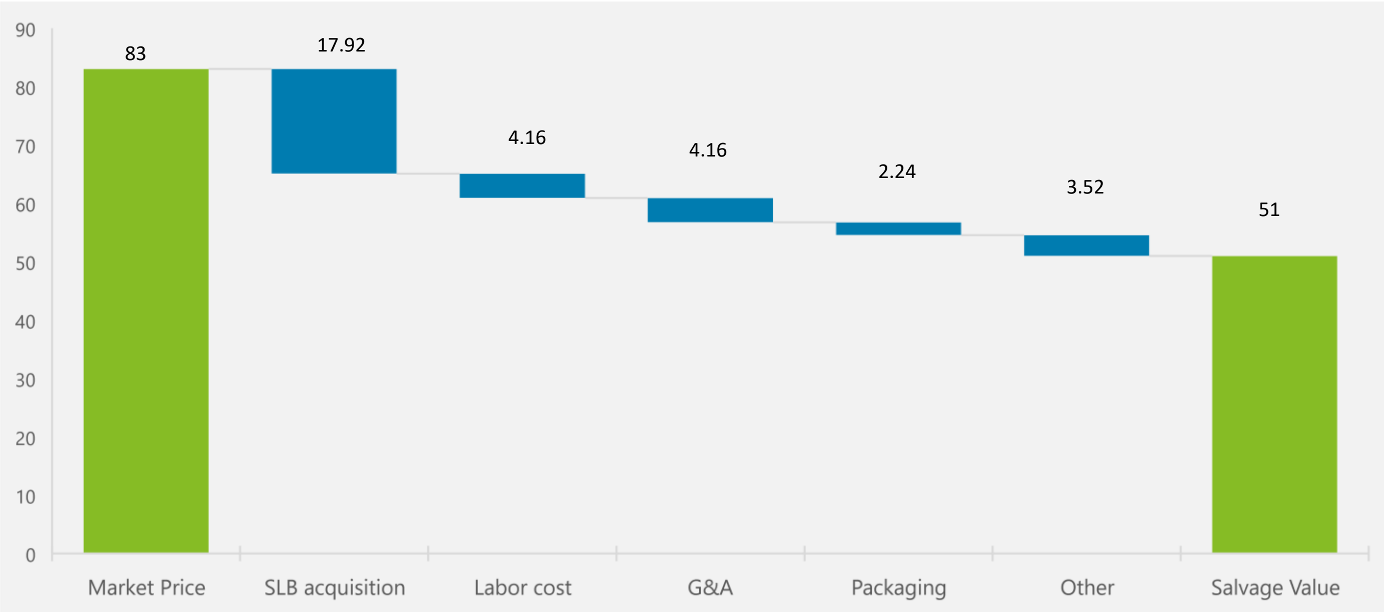


Cost of EV battery reuse

The major contributors of EV battery reuse costs are highlighted below:

a) **Acquisition of second life batteries:** Cost associated with acquisition of spent EV batteries account for 56% of the cost of EV battery reuse.
b) **Labor:** The cost of labor will depend on the labor cost in the country. Based on the US market, labor contributes to ~13% of the EV battery reuse cost.
c) **General & administrative:** Along with labor, the cost associated with General & Administration also contributes to ~13% of the total EV battery reuse cost. This includes costs associated with utilities, rent, day to day expenses associated with battery reuse.
d) **Packaging material:** Packaging material contributes to ~7% of the total cost of EV battery reuse.
e) **Other costs:** Various miscellaneous costs contribute to ~11% of the total cost. This includes costs associated with warranty, insurance, testing equipment, Rent, Capital recovery, earnings, and taxes.

Figure 133: Cost breakdown of second life EV battery (per KWh)



Source: MDPI (access here); Market price indicates the market price of repurposed battery

Table 143 lists down the cost estimates of EV battery reuse. Through this estimate, it was found out that:

1) Small differences in depth of discharge of second life batteries can bring about large differences in the salvage value and health factor of second life batteries.
2) Since many costs scale with total purchases or sales, selling price has a huge impact on the cost of repurposing.
3) Acquisition costs of second life batteries is the major contributor to the expenses.
4) Technician handling time has a huge impact on the overall costs as compared to testing time.
5) Cell fault rates below 0.001% enables cost-effective repurposing of larger modules. It is not economically feasible to replace cells with a fault rate of above 0.001%. It would require a technician and labor is a major cost component.

Table 143 shows the cost of reuse by comparing different scenarios based on the price of new batteries, depth of discharge of spent batteries, and type of vehicle. As highlighted in the table below, BEV75 refers to a battery electric vehicle with a range of 120 Km. PHEV20 refers to a plug-in hybrid electric vehicle with a range of 30 kms. The second life health factor is a ratio of the throughput of a new battery as compared to that of a spent battery.

Table 143: EV Battery reuse cost estimates

Price of New Battery	DoD of second life	Vehicle	Second life health factor	Refurbished Battery Market Price ($/KWh)	Salvage value of used batteries ($/KWh)	Cost of reuse($/KWh)
$250/KWh	60%	BEV75	0.33	83	51	32
		PHEV20	0.29	73	43	30
	50%	BEV75	0.72	180	131	49
		PHEV20	0.65	163	117	46
$150/KWh	60%	BEV75	0.33	50	24	26

Price of New Battery	DoD of second life	Vehicle	Second life health factor	Refurbished Battery Market Price ($/KWh)	Salvage value of used batteries ($/KWh)	Cost of reuse($/KWh)
		PHEV20	0.29	44	19	25
	50%	BEV75	0.72	108	72	36
		PHEV20	0.65	98	64	34

Source: Kelleher Environmental (access here)

Licensing or registration requirements

Refurbishing centers in India are mostly involved in repairing used electrical and electronic equipment (including batteries) to extend its working life and returning the same to the owner or selling it in the market. Refurbishing centers in India must adhere to the E-Waste (Management) Rules, 2016 which covers the regulations regarding all the battery chemistries except that of lead-acid batteries. [138] Gist of the same is given below for reference:

Registration

- The refurbisher must be registered under the Factories Act,1948 or the Company Act, 1956 or in both
- The refurbisher needs to have a one-time authorization from the concerned State Pollution Control Board

Compliance

- The refurbisher must ensure that the facilities are in accordance with the standards or guidelines issued by Central Pollution Control Board from time to time
- The refurbisher must ensure no harm or adverse effect is inflicted on the environment or health during the entire process
- The refurbisher must ensure that no damage is caused to the environment during storage and transportation of e-waste
- The refurbisher must file annual returns to concerned SPCB on or before 30th June of the concerned financial year
- The refurbisher must maintain records of the handled e-waste and make the records available for scrutiny by the appropriate authority

8.3 Battery reuse – Case studies

BMW, Bosch, and Vattenfall (Global)

BMW, Bosch and Vattenfall have launched a Second Life Batteries Alliance. The alliance has set up a large-scale storage system in Hamburg with 2 MW / 2.8 MWh capacity. Through this project, these companies aim to learn more about the storage capacity and ageing characteristics of used lithium-ion battery modules.

This facility reuses lithium-ion batteries from EVs in energy storage systems for frequency response services. In this Alliance, Bosch integrates batteries and manages the system. The battery packs are sourced from used battery packs of BMW Active Es and i3 vehicles. They are further reassembled into one ESS post which they are used for grid support.

Vattenfall already has an existing virtual power plant, and this energy storage solution will be a part of the same. Currently the facility comprises of 2600 modules taken from 100 electric vehicles. This storage facility renders primary control reserve power as and when necessary in the grid. The primary control reserve power is used in the power grid to balance the short-term fluctuations in frequency.

Along with this storage system, two other measures have also been taken in Hamburg's HafenCity district which utilized second-life batteries from EVs:

a) Providing charging source for fast charging stations

[138] E-Waste (Management) Rules, 2016: (access here)

b) Maximizing energy consumption from a photovoltaic facility of the district heating station by storing surplus energy injected by the facility into used batteries during low demand / sunny periods and discharging the same as and when required.[139]

MG Motor – Exicom Tele-Systems (India)

MG Motors had partnered with Exicom Tele-Systems prior to the launch of their ZS EV. When the ZS EV batteries would reach their end of life, they will go through a controlled process which involves evaluation, disassembly, and repackaging. Custom battery packs would then be designed to be used non-automotive applications: home inverters, renewable energy storage and commercial & industrial UPS. [140]

Lohum (India)

Lohum Cleantech is the only company in the globe which has a fully integrated circular battery technology. Lohum is involved in manufacturing lithium-ion batteries for stationary and low power mobility applications, repurposing used battery packs, modules and cells and recycling lithium-ion battery to extract battery materials. Through its business model, Lohum ensures maximization of battery cell life through repurposing, creates the supply of raw material for new batteries through recycling, reduces CO2 emissions and energy demand and drives reductions in costs through sustainability

Lohum has a dedicated battery collection center which collects spent lithium-ion batteries from a network of responsible suppliers. Lohum then segregates different types of lithium-ion batteries based on their form factor and chemistry. The battery is then prepared for cell and module testing. Rigorous testing of cells is carried out to sort the useable cells from non-useable cells. The usable cells are then isolated and analyzed based on their chemistries and form factors which are then repurposed into second life lithium-ion batteries which are used in energy storage systems, for commercial or residential purposes and telecom solutions. The non-useable cells are further sent for material extraction through which Lohum extracts the maximum amount of rare earth metals. These critical materials are then used for manufacturing new lithium-ion batteries. [141]

8.4 Policy note on battery reuse

The note is envisaged to help policymakers in identifying the key parameters and measures to develop a healthy ecosystem for battery reuse in the entire scheme of battery value chain in India.

The demand for Lithium-ion batteries is rising on the back of increasing electric vehicle adoption and use in grid storage projects. India is very new to the lithium-ion battery manufacturing space and has made strides towards the industry through the ACC (Advanced Chemistry Cell) PLI (Production Linked Incentive) scheme which has awarded 50 GWh of battery manufacturing capacity to four players[142].

Battery manufacturing lags the growing demand of electric vehicles owing to which OEMs and battery pack manufacturers are dependent on imports to satisfy the demand of lithium-ion cells[143]. Additional to this, India only has reasonable reserves for Manganese and Graphite and lacks the reserves for Lithium, Cobalt, and Nickel. Having only two out of five essential minerals for lithium-ion batteries strengthens the case for battery reuse and recycling.

Challenges in Indian battery reuse ecosystem

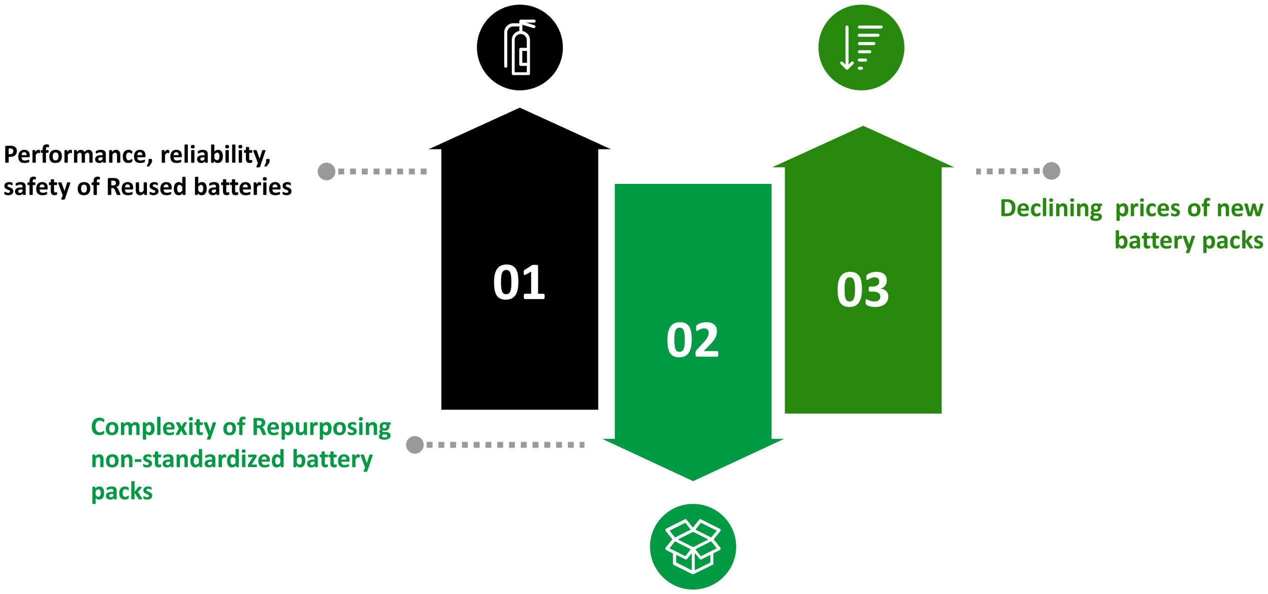
The reuse industry of India like all other nations is in its nascent stages. The EV batteries in circulation are yet to reach their end-of-life and it is of paramount importance to have a reuse ecosystem in place to ensure that the batteries are used to their maximum extent before sending them for recycling.

Market side challenges

Some of the key challenges with the industry are highlighted in Figure 134.

[139] Better World Solutions (access here), Greentech Media/Wood Mackenzie: (access here)
[140] Exicom: (access here), mint: (access here)
[141] Lohum : (access here)
[142] PIB (access here)
[143] India Trade Portal, Imports for Lithium-ion cells (HSN 850760)

Figure 134: Key Challenges with Battery reuse industry in India



Unproven performance, reliability, and safety of reused batteries

There are concerns regarding battery degradation over the first-life-period and degradation of individual battery cells within the pack is not uniform. Mixing battery cells with different status of health (SOH) can increase battery aging and overall risk of a safety issue occurring. Therefore, packs/modules need to be dismantled to sort reused packs to have cells with similar SOH levels, or for the outright removal and replacement of degraded cells.

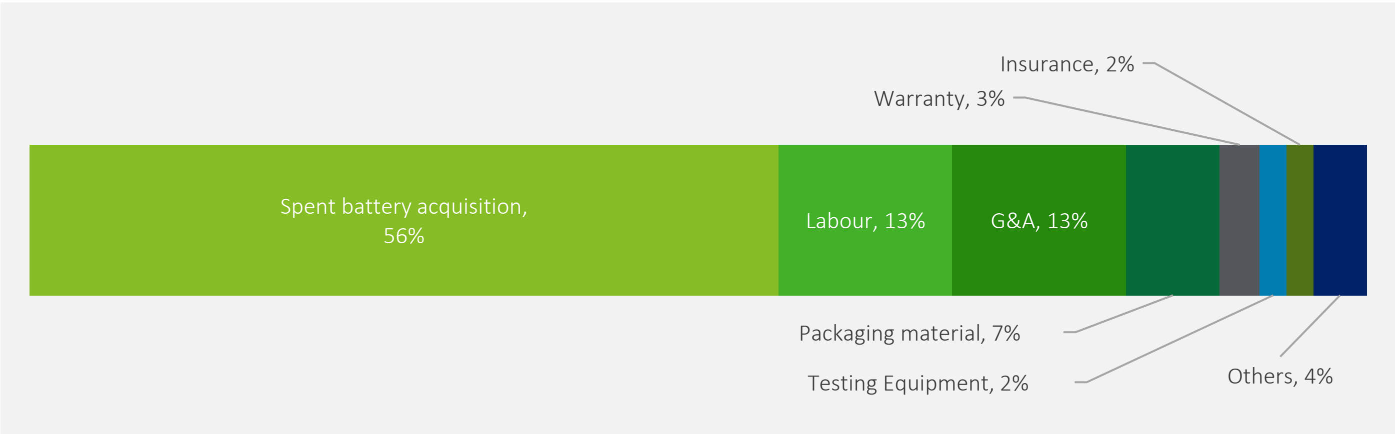
Complexity of repurposing non-standardized battery packs

The refurbishment of retired lithium-ion batteries for reuse is highly complex and costly which is exacerbated by a lack of lithium-ion battery pack standardization. Battery packs vary in design, size, and format (cylindrical, prismatic, pouch), which makes LIB re-purposing for reuse quite complex. Spent batteries must be dismantled (in controlled atmosphere environments to avoid cathode oxidization) to isolate non-degraded cells, which varies in cost and reusable cell yield depending on first life battery degradation, and to remove other battery components such as the BMS and TMS that also need to be replaced.

Cells must then be tested to assess the cell capacity, voltage, SOH, physical properties, etc. to determine if they are fit for reuse. Remaining cells are then sorted to have similar SOH levels to optimize reuse performance before being reassembled into a new battery pack (including a new BMS) to be fit for energy storage applications.

Owing to such complex processes, the breakdown of battery repurposing cost for reuse is shown below:

Figure 135: Breakdown of >$30kWh Battery Repurposing Costs for Reuse



Source: BMO Capital Markets Research

Declining prices of new battery packs

Continued new Lithium-ion battery pack prices reduction lowers implied net residual value of battery reuse. Technological advancement and scale advantages continue to push lithium-ion battery pack costs down to reduce the gap between new and used lithium-ion batteries which diminishes the attractiveness to buy reused lithium-ion batteries.

Other than the three primary challenges mentioned, most of the reuse projects in India remain at pilot stages given the small number of batteries feeding into the companies. Ziptrax for instance is supplying reused batteries for 20 e-rickshaws in Delhi[144]. However, we are yet to see grid scale reused battery usage in India.

Policy side challenges

Rules for waste Lithium-ion batteries management are still in the draft stages which was released in 2020 for industry consultations. The draft policy was a step up from the previous Battery Waste Management Rules of 2001 which were centered around only Lead acid batteries as they recognized Lithium-ion batteries as well.

Inclination towards Battery recycling

The draft had some encouraging measures which brought dealers into the ambit of battery collection and directed them to provide invoice for batteries collected by them. But from a wider perspective, the Draft BWMR was highly skewed towards battery recycling rather than battery reuse.

The inclination of the draft rules can be gaged through the following statement for battery producers regarding extended producer responsibility (EPR):

"Extended Producer Responsibility Authorization should comprise of general scheme for collection of waste batteries and Electronic Equipment (containing battery) placed on the market earlier, such as through dealer, collection centers, Producer Responsibility Organization, through buyback arrangement, exchange scheme, etc. whether directly or through any authorized agency and channelizing the items so collected to authorized recyclers"

The statement though noble in its motive, misses a large portion of the value chain i.e., reuse which has the potential to elongate battery usage in terms of years. The sentiment was also corroborated by industry practitioners. From a dealer's perspective as well, they are not mandated to send the collected batteries to reuse players and only to authorized recyclers or the battery manufacturers. The policy needs to be inclusive of reuse to ensure that the necessary feedstock of end-of-life batteries is provided.

Presence of the unorganized players in the ecosystem

The uniqueness of Indian battery ecosystem is through the presence of unorganized players such as scrap dealers, itinerant collectors (kabadiwallas). Their role in recycling of lead acid batteries has been significant owing to the simpler handling and recycling procedures. However, lithium-ion batteries are highly flammable and require specialized competence to handle them.

Lithium-ion batteries are highly inflammable and toxic to the environment and also have a volatile electrolyte. As explained earlier, battery packs have to be dismantled in a controlled environment to prevent cathode oxidization and special tools are necessary to gage the battery state of health and determine its suitability for second life and reuse. Post assessment,

[144] Primary Interaction

Improper handling of the batteries can lead to significant loss of value and eventual contamination of environment. Thus, it is necessary to have caveats in the rules to ensure that batteries reach authorized reuse facilities only.

The coverage of unorganized players can be leveraged by the battery reuse players in the market. Collaboration amongst the unorganized players and the reuse players similar to the ones being used by recycling players can enable smooth flow of feedstock for the industry.

Enablers and incentives globally

Battery reuse, especially for lithium-ion batteries, is gradually picking up pace in multiple geographies across the world. Regions such as the European Union have included specific clauses in their Batteries Directives to ensure growth of reuse ecosystem. Other than the EU, there are some other measures being taken in countries like South Korea, USA, China which could provide the essential direction for developing policies for reuse of lithium-ion batteries. These countries are necessary reference points because of their earlier adoption of electric vehicles compared to India.

The selective policies/ measures from the said countries have been described in the upcoming segments.

European Union

In December 2020, the European Commission proposed a new Battery regulation that aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire life cycle. In particular, there's specific article related to Second Life Batteries (e.g., Article 59), that contains following key points:

Battery Management System (BMS) to store information needed for reuse and recycling value chain members

Rechargeable industrial and electric vehicle batteries must contain a battery management system that will store all the data needed and further help to determine the state of health of the battery. The data gathered through BMS can be used to test, sort, and repurpose. The details regarding the input must be shared only with the owner and any third party involved in process of the second life of batteries.

Table 144: Parameters specified by the European Commission to be stored in BMS

Parameters for determining state of health of batteries	Parameters for determining the expected lifetime of batteries
• Remaining capacity • Overall capacity fade • Remaining power capability and power fade • Remaining round trip efficiency • Actual cooling demand • Evolution of self-discharging rates • Ohmic resistance and/or electrochemical impedance	• The dates of manufacturing of the battery and putting into service • Energy throughput • Capacity throughput

Source: European Commission (Annexure VII to Battery Directive 2020)

The parameters so mentioned in the table above augment the decision making of the remanufacturers and second life operators.

Non-waste categorization of batteries after first use

Used batteries from industrial and electric vehicles are no longer considered as waste if the battery provider proves that:

- State of health checks confirm the capability to deliver the specified performance relevant for its reuse,
- the battery will be used through an invoice or sale contract
- the batteries will be protected against damage during transport

Ascertaining the reuse player as the manufacturer of the repurposed battery

Attaching the responsibility of manufacturer to reuse facilities ensures that suitable standards applicable for first use batteries are applicable for reused/ repurposed batteries. It exposes the battery to product, environmental and other requirements, including conformity assessment procedures etc., with the exception of certain sustainability rules.

Providing adequate direction and responsibility to reuse players improves the confidence of second life battery off takers

Creation of European Electronic Exchange System

The Batteries Directive has proposed to develop an electronic information exchange system which would help battery value chain players to share the necessary information for downstream players to ease battery handling and decision making with respect to reuse and recycling.

Table 145: The information to be shared on the exchange

Sl.	Category	Details
1.	**Publicly accessible part of the system**	• Battery Manufacturer • Battery type • General description of the model, sufficient for it to be unequivocally and easily identified, including the date of placing in the market • Manufacturing place and date • Battery composition, including critical raw materials • Carbon footprint information in the units indicated in the relevant implementing measure(s) • Information on responsible sourcing as indicated in the relevant implementing measure(s); • Recycled content information as indicated in the relevant implementing measure(s); • Rated capacity (in Ah); • Minimal, nominal and maximum voltage, with temperature ranges when relevant; • Original power capability (in Watts) and limits, with temperature range when relevant ; • Expected battery lifetime expressed in cycles, and reference test used ; • Capacity threshold for exhaustion (only for EV batteries); • Temperature range the battery can withstand when not in use (reference test); • Period for which the commercial warranty for the calendar life applies; • Initial round trip energy efficiency and at 50% of cycle-life; • Internal battery cell and pack resistance; • C-rate of relevant cycle-life test.

2.	**Accessible to accredited economic operators, commission**	• Detailed composition, including materials used in the cathode, anode and electrolyte;
		• Part numbers for components and contact details of sources for replacement spares;
		• Dismantling information, including at least:
		  ○ Exploded diagrams of the battery system/pack showing the location of battery cells,
		  ○ Disassembly sequences,
		  ○ Type and number of fastening techniques to be unlocked,
		  ○ Tools required for disassembly,
		  ○ Warnings if risk of damaging parts exist,
		  ○ Amount of cells used and layout;
		• Safety measures.

Sl.	Category	Details
3.	**Accessible only to notified bodies, market surveillance authorities and the commission**	• Results of tests reports proving compliance with the requirements laid out in this Regulation, and its implementing or delegated measures

Source: European Commission (Annexures to Battery Directive 2020)

The provision of specific information and selective access to the above stated information creates a healthy ecosystem for battery reuse as players have the necessary information to make informed decisions about further steps to ensure longevity of batteries.

Provision of safety measures, disassembling steps gives the industry the necessary handbook to reuse at scale and have standardized processes in place.

Selective and controlled information sharing amongst battery manufacturers and end-of-life battery handlers is a necessary enabler for developing a battery ecosystem.

South Korea

Having commenced lithium-ion battery manufacturing in 1999, South Korea launched its program for second life program for products in 2015 with the expectation of steady flow of EV batteries ready for reuse and second life application in stationery power and backup functions.

Waste EV battery collection

The waste EV batteries in South Korea are collected by the Ministry of Environment. The collection of the batteries are done by the respective local governments when the owner intenders to deregister the motor vehicle for the purpose of scrapping. However, the caveat in the policy is that it is only applicable for subsidized EV batteries.

Similarly, the Seoul Metropolitan Area under a Special Act on the Improvement of Air Quality in the region has mandated the EV owners to return the EV batteries to the Seoul Special Metropolitan City Mayor or a person determined by the mayor.

The incompleteness of the policies was unearthed when high volumes of batteries started returning to the government but there was inadequate reuse infrastructure. There were no formal management procedures for the waste batteries which necessitated establishment of reuse centers.

Demonstration Projects

In 2017, post realizing the requirement of adequate reuse facilities, Jeju Special Self-governing province authorized Jeju Technopark to collect EV batteries and conduct research to study the performance of recovered batteries. Jeju Technopark explored solutions to reuse and disposal of batteries.

In 2019[145], a demonstration project was launched, and the Jeju Special Self-governing province invited companies to conduct the "Demonstration Project to Reuse Electric Vehicle Batteries." The invitation led to the development of South Korea's first EV battery reuse complex and has proved to be a directional body in the field.

The Reuse center was initiated by the consortium of Jeju Technopark, Jeju National University, Korea Battery Industry Association and Korea Automotive Technology Institute. The consortium is working on building battery inspection systems as well as setting up the required equipment.

[145] Jeju Province Launches Project to Reuse Electric Vehicle Batteries (access here)

Other measures

The Korea Battery Industry Association (KBIA) in 2019 developed a standard second-life battery reuse valuation method and a standard for battery grade evaluation methods is being developed. KBIA has been supported by the Ministry of Trade, Industry & Energy and KATS (Korean Agency for Technology and Standards) for battery standardization of xEVs.

The KBIA for instance has come up with categorical second life applications for batteries based on the state of health.

Table 146: Battery Second life categorization

SOH	Method to be applied	End use application
≥ 80%	Reuse	ESS, EVs
≥ 65%	Re-fabrication	ESS, UPS, Lighting
< 65%	Recycle	Material inputs for manufacturing

Source: ADB, Asia Clean Energy Forum 2021 (access here)

Such categorization enables reuse centers in South Korea to make the correct decision regarding the steps to be taken for batteries collected from electric vehicles through multiple channels.

USA

Compared to the initiatives in the EU and South Korea, USA has embarked on another route to develop a reuse ecosystem for EV batteries. California has been on the forefront of the developments and has rolled out funding for startups under the EPIC (Electric Program Investment Charge) Initiative and the MIT initiative to develop a demonstration project for reused batteries.

Startup funding for technology development

The California Energy Commission under the EPIC funding pool provided three start-ups RePurpose Energy, Smartville Energy and ReJoule with USD 2-3 million in funding in 2019[146]. The funding was provided from the CalSEED program with an objective to reuse batteries from electric vehicles to store solar energy in lower cost and more sustainable energy storage systems.

Smartville, for instance, provides end to end solution for electric vehicle battery reuse and recycling. After receiving the seed grant from CalSEED, the firm showcased their second-life battery pilot project in June 2020.

ReJoule on the other hand has developed characterization techniques to quickly and accurately grade batteries. These techniques are called electrochemical impedance spectroscopy (EIS) and hybrid pulse power characterization (HPPC). These are diagnostic tests that unlock battery parameters that track degradation.

Key takeaways

Reuse as a significant battery value chain element requires further policy push to develop. Multiple countries have taken directed measures to develop the reuse ecosystem. The policies for the effective second life usage of batteries from electric vehicles require a strong partnership between the industry players viz. battery manufacturers, vehicle OEMs, collection centers, and eventually the reuse and recycling players.

Because of the fast-changing landscape of battery technologies and lowering battery prices, the development of business case for battery reuse is challenging. The promotional measures have to be all encompassing in terms of the battery value chain and incentivizing to improve the attractiveness of the industry.

[146] Green Tech Media (access here)

8.5 Key unlocks for the battery reuse sector in India through promotional measures

Taking cue from the multiple measures taken globally and the challenges faced by the industry players in India, the following policy measures are of essence:

KEY MEASURES TO UNLOCK THE BATTERY REUSE INDUSTRY POTENTIAL IN INDIA

1. **Funding of reuse industry players to develop adequate battery handling capacity**
2. **Funding of demonstration projects with reused batteries for multiple applications**
3. **Development of safety guidelines for management of batteries for reuse**
4. **Development of standards for assessing BMS information for second use applications**
5. **Establishment of legal basis for promoting reuse of EV batteries**
6. **Electronic information exchange system for battery information and stage in lifecycle**

Each of the suggested measure and associated action items are elaborated further.

1 Funding to reuse industry players for developing adequate battery handling capacity

The present battery volumes for reuse in India are very low, however in the coming 4-5 years the batteries currently in circulation would reach their end of life and have to be either reused or recycled. There are very limited number of players in the reuse industry and most of them have been conducting their business in smaller pockets across India and are running pilot size operations in their respective regions.

The funding can be either seed funding or a grant based on a viability gap assessment of the players. Inspiration can be taken from CalSEED program which has helped develop an ecosystem for battery reuse in California, USA as stated in 0.

The action items for the measures are shown below:

Table 147: Action Items for Funding reuse industry players

Sl. No.	Suggested Action Items	Suggested Body
1.	Formation of committee with authorities from MoEF&CC, CPCB, SPCB, MeiTY, MAIT, NITI Aayog	MoEF&CC
2.	• Launch of innovation challenge for reuse industry players to showcase • Selection of industry players	Committee formed by MoEF&CC
3.	Financial Economic viability assessment of selected industry players and decision on seed grant or viability gap funding	Committee formed by MoEF&CC
4.	Constant monitoring of capacity development and progress	Committee formed by MoEF&CC

2 Funding of demonstration projects with reused batteries for multiple applications

Development of confidence especially downstream in the offtake part of reused batteries is important to enable reuse industry players. Present industry players have highlighted that the EV batteries reused in EV applications are usually a step down from their first use. A step down refers to the usage of the EV batteries in segments which use smaller batteries compared to the first use. For example, an EV 4W or E-bus battery can be reused in E-3Ws or in E-2Ws which have lower load requirements compared to their first use.

Energy storage systems also can utilize reused EV batteries as it has been seen in the MIT initiative for a 2.5 MW solar farm from EV batteries[147].

Table 148: Action Items for initiating demonstration projects

Sl. No.	Suggested Action Items	Suggested Body
1.	Formation of committee with authorities from MNRE, MoP, SECI, NITI Aayog, select state government	MoP
2.	Selection of an upcoming project or past project to use BESS having reused batteries	Committee formed by MoP
3.	State run EV battery reuse program for EV-2Ws and 3Ws in a select city	Committee formed by MoP
4.	Constant monitoring of the program and awareness development	Committee formed by MoP

3 Development of safety guidelines for management of batteries for reuse

Handling of end-of-life EV batteries is very different compared to lead acid batteries. As stated in 0, specialized manpower and setup is necessitated for dismantling EV battery packs and repurpose them for second life usage.

A cross functional team of experts is required to develop safety guidelines for battery end use management covering all safety aspects for industry practitioners. The safety guidelines would be inclusive of safety measures for personnel, facilities which can be a foundation stone for the slowly rising industry.

Table 149: Action Items for developing safety guidelines for management of waste EV batteries

Sl. No.	Suggested Action Items	Suggested Body
1.	Formation of committee with authorities from MoRTH, MoEF&CC, CPCB, NITI Aayog	MoEF&CC
2.	Development of draft safety guidelines for battery reuse and comments acceptance	Committee formed by MoEF&CC
3.	Addressing comments from industry stakeholders by committee	Committee formed by MoEF&CC
4.	Launch of safety guidelines for battery reuse and selection of implementation authority	Committee formed by MoEF&CC

4 Development of standards for assessing BMS information for second use applications

[147] MIT News (access here)

At present, there is no standardized method for determination of State of Health of batteries for 2nd life applications. However, the data from Battery Management system is key to understanding the maximum value that can be derived from an EV battery.

The set of descriptors of the life of the battery to be stored and retrieved from the BMS to assess the SoH are as follows:

1. BMS specifications
2. remaining capacity for each module in the battery pack, and for each individual cell (if feasible)
3. history of storage conditions (temperature/duration)
4. overall kilometers in e-mobility or overall cycles in stationary applications (system level)
5. total number of charges and discharges (system level)
6. information on battery use, including load charge and discharge profiles or the time spent at certain SoC (system level)
7. internal resistance increases for each module in a pack/system
8. remaining power or power fade in a pack/system
9. remaining round-trip efficiency or efficiency fade in a pack/system
10. actual cooling demand
11. self-discharge rates
12. negative events during lifetime (below/above temperature limit, voltage spikes, overcharge and over-discharge, previous repairs)
13. any error messages and faults occurring in the BMS itself

Additional information on the battery can be obtained as shown in Table 145. Cues can be taken from ANSI/CAL/UL 1974: 2018 which deals with the sorting and grading process (via SoH determination) by BIS.

Guidance can also be taken from CENELEC standards:

- EN 45553:2020 (General method for the assessment of the ability to remanufacture energy-related products)
- EN 45554:2020 General methods for the assessment of the ability to repair, reuse and upgrade energy-related products
- EN 45556:2019 General method for assessing the proportion of reused components in energy-related products

Table 150: Action Items for developing standards for assessing end-of-life batteries

Sl. No.	Suggested Action Items	Suggested Body
1.	Formation of committee with authorities from BIS, ARAI, ICAT	BIS
2.	Benchmarking of global standards in the field of battery state of health determination	BIS
3.	Development of standard for SoH determination of end-of-life batteries	BIS
4.	Launch of standard	BIS

5 Establishment of legal basis for promoting reuse of EV batteries

As stated in the policy side challenges in 0, the battery waste management rules have to more inclusive for reuse. Certain caveats can be added to the Draft Battery Waste Management Rules 2020. The EPR guidelines must include the collection of batteries to reuse/ refurbish centers and recyclers.

The Draft BWMR must provide guidance on the specific route that the end-of-life waste batteries must be put into based on their state of health assessment. The lead for these caveats has to be taken by the **MoEF&CC**. Since the draft has been in circulation since 2020, it is high time that the clauses specific to reuse are included in the rules by the end of FY23.

6 Electronic information exchange system for battery information and stages in lifecycle

An electronic platform for battery manufacturers, battery collection centers, battery reuse players, battery recycling facilities with adequate security measures and selective authorization needs to be developed in the long-term. The non-standard design features are a major impediment to the reuse and recycling players who have to customize their processes as per their feedstock of used batteries in regular intervals.

The exchange system can have two levels of information. The first being the general battery specifications and the second level being detailed battery specifications which can only be accessed through authorization.

The data segregation suggested by the European Commission, as shown in 0, can be applied in India. Since the industry is in the initial phases of development, onboarding of the battery value chain players would be comparatively easy at present than in the future with larger number of players.

Table 151: Action items for developing electronic exchange system for batteries

Sl. No.	Suggested Action Items	Suggested Body
1.	Formation of committee with authorities from MoEF&CC, CPCB, SPCB, MeiTY	MoEF&CC
2.	Devising the functional requirements for the Electronic exchange system through industry consultations	Committee formed by MoEF&CC
3.	Floating RfP for development of Electronic Exchange system	MoEF&CC
4.	Selection of exchange system developer	MoEF&CC
5.	Development of exchange system	Selected Vendor
6.	Acceptance testing of exchange system	Selected Vendor, MoEF&CC
7.	Onboarding of Battery Value chain stakeholders	MoEF&CC

Side by side to the development of the electronic information exchange platform, a QR code based system can also be developed to ensure that the tracking of batteries is seamless. After reaching their end-of-life after first use, the batteries can be scanned in the collection centers and then the reuse or recycling center where they are sent.

The electronic exchange system can be utilized to keep track of the battery whereabouts throughout its lifecycle and multiple uses. The QR code formation can be advocated through the standards which would be developed by BIS in the future.

8.6 Policy note conclusion

The Indian EV battery reuse industry is in stages of infancy and would require significant capacity in the next 5-10 years to cater to the high volume of EV batteries reaching their end-of-life. Globally multiple countries have taken unique paths directly or indirectly to develop their reuse ecosystem.

The Indian policy makers need to have a clear vision of the existing market which is highly fragmented and has significant involvement of unorganized sector in the value chain. Suitable measures and policies have to be brought forward to address the issues stated in this report and the measures suggested can be implemented in the short to medium term.

Short Term	Medium Term	Long term
• **Funding assistance** to reuse industry players to develop adequate battery handling capacity • **Establishment of legal basis** for promoting reuse of EV batteries	• **Funding of demonstration projects** with reused batteries for multiple applications • **Development of safety guidelines** for management of waste EV batteries	• **Development of standards** for assessing BMS information for second use applications • **Electronic information exchange system** for battery information and stage in lifecycle

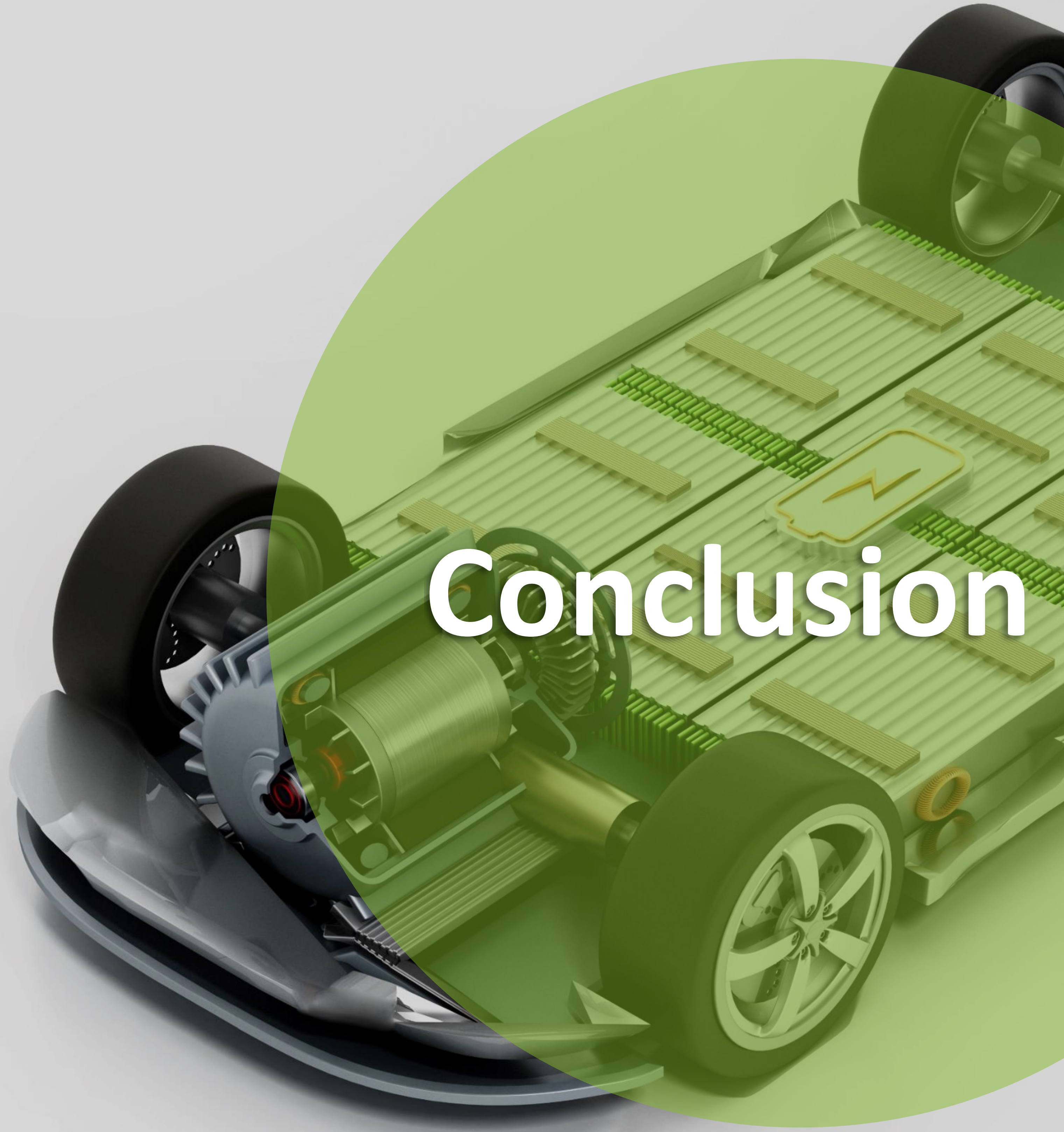
The development of the reuse ecosystem would need improvement in both the upstream and downstream activities of battery reuse. The feedstock of batteries can be enhanced through the Battery Waste Management rules and the processes of reuse can be enhanced through funding, demonstration projects, and standard development. In the long term the industry would benefit largely through the electronic exchange system for battery information as well.

8.7 Recommendations

As illustrated in previous sections, there are certain barriers in the battery reuse market in India which should be addressed to ensure an enabling ecosystem for battery reuse. The table below presents various recommendations for different stakeholders which could act as a catalyst to boost battery reuse in India:

Sl. No.	Stakeholder/Intervention area	Detail
1.	Policy makers & Regulators	The lack of guidelines and management rules for battery reuse needs to be addressed. The guidelines for battery reuse and associated standards should be prepared. Simultaneously, subsidies should be rolled out to promote the growth of infrastructure for battery reuse. Policies should be directed towards encouraging the use of BESS or other applications to increase the demand of repurposed batteries.
2.	Automotive and Battery OEMs	OEMs must include onboard diagnostic to accurately track the capacity, and various characteristics to determine the viability of battery for reuse. This would lead to reduction of cost of reuse, thereby ensuring better adoption.
3.	Research & development	R&D should be directed towards examining battery degradation, newer methods or technologies of battery reuse, SOH estimation, effect of battery complexity and variability of battery chemistries for different processes. As an industry led approach, growth centers could be set up to promote battery reuse by current players. This could drive innovation, productivity, and competitiveness in the market.

Conclusion

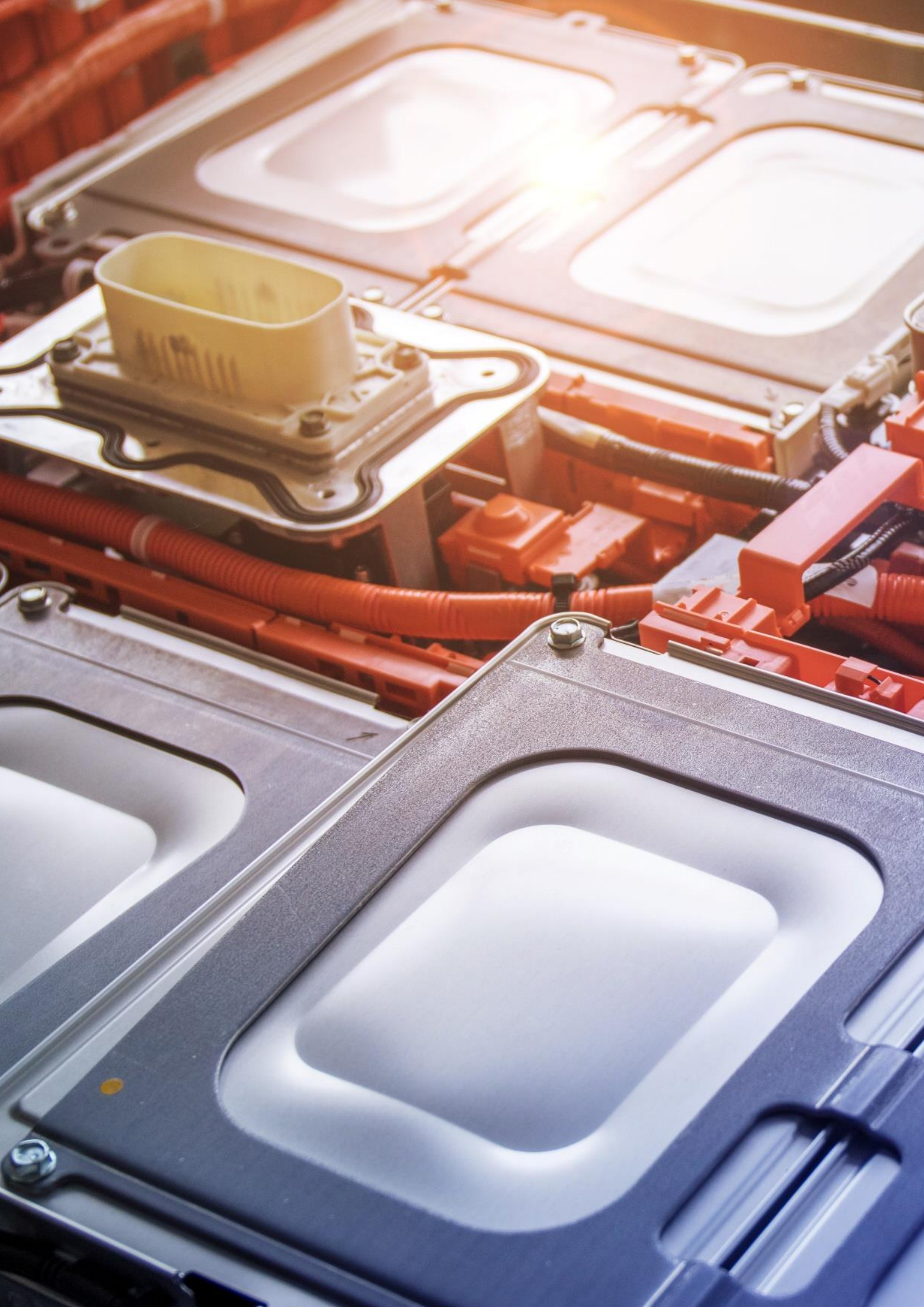


Chapter 9. Conclusion

With favorable policies viz. FAME II, ACC PLI, large scale adoption of electric vehicles can be envisaged in the medium to long term in India. Battery demand in 2025 is expected to be in the range of 5 – 15 GWh which is further expected to rise to 30 – 112 GWh in 2030. From a supply side, 50 GWh of battery capacity has been awarded under the ACC PLI Scheme. Assuming the commissioning of the capacity by 2025, the industry is expected to experience shortages in meeting battery demand from 2029. The scope of shortages implies towards the requirement of a robust circular economy of batteries used in electric vehicles and development of a healthy battery ecosystem.

Sl. No.	Area	Remarks
1.	**Battery technology**	• Lithium-ion batteries with their **higher energy density** (leading to compact size), **longer service life, faster charging rate, lower discharging rate** and no **memory effects** are best suited for electric vehicle applications. • Within lithium-ion batteries, three chemistries are fundamentally used for EVs – **LFP, NMC, and NCA.** • From an Indian context, **LFP batteries** are better suited than NMC or NCA due to the climatic conditions being hotter than Europe or USA.
2.	**Battery standards**	• Indian standards lag international standards such as IEC, ISO, QC/T, etc. when it comes to coverage of the entire battery value chain and extensive testing of batteries in certain aspects. • Special focus must be given to battery standards for **transportation and recycling** which would are necessitated for ensuring a healthy battery ecosystem. • Basis the detailed study of battery standards, suitable recommendations on the existing battery standards in India especially AIS-048 have been suggested to widen the scope of testing prescribed in the standards and to make them more suitable for Indian conditions. • One of the encouraging signs for the Indian battery ecosystem is that the country is one of the **contracting parties of the UN GTR No.20** and this helps in guiding the policy makers to develop the standards and legislations accordingly.
3.	**Policy & regulatory landscape**	• Indian government has identified the need of developing a supply chain for battery minerals to feed the battery manufacturing facilities in pipeline. • Compared to countries like China, Australia, Brazil, South Korea, Japan, and USA, the **R&D investment by India is lagging** and the country lacks uniform regulations for battery reuse and recycling. • Significant policy push and incentives for consumers are required to make the switch to e-mobility and drive battery demand. Measures such as **EV credits** for auto companies and tax credits for EV manufacturers on investments could drive battery manufacturing in the country. • **Financial assistance for R&D and supply chain development** through tax offsets, exemptions on capital gain taxes, setting up growth centers could prove to be necessary enablers for the ecosystem. • Setting up of waste **recycling rates** as well as recovery rates with **timeline-based monitoring** through policies can help in developing a robust reuse and recycling value chain. At the same time, standards focused on battery swapping and financial incentives for them would be necessary enablers in the envisaged electrification of E-2W and E-3W segment in the country.
4.	**Battery manufacturing**	• When it comes to presence of battery minerals, India fares well only for Manganese and Graphite. Reserves of Lithium, Nickel, and Cobalt are not abundant in India and the country is highly dependent on imports. • The development of **economical supply chains** is important because **material cost** is the highest contributor to a cell's cost **(53 – 60%)** followed by overheads (23 – 30%) and cost of manufacturing.
5.	**Battery swapping**	• Battery swapping presents an opportunity to reduce upfront cost of electric vehicles and a solution for tackling longer charging durations.

Sl. No.	Area	Remarks
		• Owing to it ease of use and technological simplicity, **manual swapping** technology is **generally adopted for e-2W and e-3Ws**. This is quite visible in various 2W and 3W swapping players globally as well as in India. • For commercial **e-4W and e-buses**, typically **robotic / automatic swapping** is preferred owing the larger battery sizes and less appetite for a longer waiting time. • Different business models viz. **fleet operated, swapping service provider driven, and OEM driven** are present for the segment participants. • Since it has been understood that battery swapping is technically most feasible for commercial vehicles in the 2W, 3W and 4W segment, the **fleet operators** may choose to set up and operate the swapping stations themselves • The **battery sizing** decided at the beginning of the business and the **optimal balance** between the customers opting for fixed swapping rate against the customers paying on usage basis are two of the major factors to be kept in mind while operating the stations.
6.	**Battery disposal**	• India has a high presence of itinerant collectors who collect batteries from end users and sell off to scrap dealers. These scrap dealers then divert the batteries to collection centers which then directs them to recyclers. • **Lack of monitoring system** for battery disposal, absence of national level collection schemes, high presence of unorganized sector are some of the barriers to effective battery disposal in the country. • The challenges can be addressed through **national level battery collection schemes**, **disposal responsibility attribution** to manufacturers and vehicle OEMs, developing a repository for battery end of life configuration, and inclusion of municipalities in the collection process.
7.	**Battery recycling**	• There are two major recycling technologies namely, pyrometallurgy and hydrometallurgy. • **Hydrometallurgy** is environmentally friendly, less capital intensive, has higher recovery rates and can accommodate multiple chemistries making it the **go-to technology** for lithium-ion battery recycling. • The industry could be supported through **design to reuse and recyce** initiatives, **mandatory recovery rates**, to name a few. • From a financial perspective, **hydrometallurgical** recycling plant for lithium-ion battery recycling provides **better profitability** and has a **wider operating window** for costs.
8.	**Battery reuse**	• With low volume of feedstock (used batteries), the reuse industry in India is still in early stages of development and has certain barriers which need to be addressed. • There is **lack of guidelines** and rules for battery reuse which need to be addressed through **standards and state level EV policies**. Appropriate subsidies could help in improving the demand for repurposed batteries. • Battery OEMs have to include **onboard diagnostics** for tracking the capacity and other battery characteristics to determine the viability of battery reuse. • **R&D directed towards examining battery degradation**, **newer methods or technologies** of battery reuse, SOH estimation, effect of battery complexity and variability of battery chemistries for different processes could lead to improved battery management and improved reuse potential.



Chapter 10. Annexure

10.1 Annexure for battery technologies

Table 152 Technical characteristics of battery technologies

Sl. No.s	Parameter	Lead acid Battery	Advanced lead acid Battery	Lithium-Ion Battery	Flow Battery	High temperature Battery	Nickel Cadmium Battery	Nickel Metal Hydride Battery	Metal Air Batteries	Solid State Battery	Sodium-ion battery
1.	Energy Density (Wh/Kg)	30-50	30-50	100-325	10-70	150-240	45-80	60-120	350-500	>1000	160
2.	Power Density (W/Kg)	30-50	180	4000-6500	0.5-2	120-160	150	250-1000	100	N/A	N/A
3.	Cycle life (cycles)	500-1000	2500-4000	1000-4000	12000-14000	2500-4000	2000	700-1000	>1000	Up to 10 years	>3000
4.	Round trip efficiency	79-90%	79-90%	85-95%	60-85%	70-90%	70%	66-92%	<60%	N/A	90-95%
5.	C-rate	0.05C – 0.2C	0.05C – 0.2C	1C-10C	N/A	1/6C	1C	0.5 C		0.2C-100C	0.1 – 2 C
7.	Self-Discharge	10%		5%	~0		10-20%	10-15%	2% per year	<5%	<10%
6.	Safety & Reliability	Serious environmental concerns. Tolerant to overcharging (flooded) and high temperature (sealed)	Reduction in sulfation makes them reliable. But they still have serious environmental concerns	Overcharging and overheating can lead to thermal runaways. Lithium-ion batteries tend to explode in certain scenarios	Nonflammable, nontoxic and no risk of exploding	Very safe. Thermal runaway can only happen if the battery is pierced but that also won't lead to explosion	Tolerant to overcharging and reduced sensitivity to low temperatures. Toxic to the environment	Much safer to operate as compared to NiCd batteries. Environment friendly	Very safe. Only risk associated with possible leakage of hydroxide electrolyte and formation of hydrogen by metal electrode	No risk of explosion or fire	Very low risk of explosion or fire

Source 2 Analyst reports, Research publications, Deloitte analysis

10.2 Annexure for battery standards

Performance standards of Lead Acid Batteries

Table 153: Performance standards for Lead Acid Traction Batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	SAE	J2758	Global	• Describes a test procedure for rating peak power of the Rechargeable Energy Storage System (RESS) used in a combustion engine Hybrid Electric Vehicle (HEV).
2.	SAE	J1634	Global	• Battery Electric Vehicle Energy Consumption and Range Test Procedure are illustrated in this document. The standard looks forward to determine energy

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
				consumption and range of light duty vehicles (LDVs) based on federal emission test procedure (FTP). An urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) are used to provide a flexible testing methodology that is capable of accommodating additional test cycles as needed.
3.	IEC, CENELEC	IEC 60254-1:2005	Global	• Titled as general requirements and methods of tests, the standard defines tests relevant to all traction battery applications which include road vehicles, locomotives, industrial trucks and mechanical handling equipment. The objective of the standard is to specify characteristics such as capacity, charge retention, high rate discharge performance, cyclic endurance.
4.	IEC, CENELEC	IEC 63193:2020	Global	• The standard is applicable to lead acid batteries powering **electric two-wheelers** (mopeds) and **three-wheelers** (e-rickshaws and delivery vehicles) and also to golf cars and similar **light utility** and **multi-passenger vehicles**. The methods of tests are tailored to ensure satisfactory and safe battery performance in the intended application. The test methods cover capacity, cycle life, dynamic driving range, charge retention. The standard also specifies requirements for vibration resistance, flammability rating of materials, thermal protection against ignition from external sparks, durability, and identification of materials. • The tests are not applicable for vehicle engine starting applications, traction applications, stationery applications and general-purpose applications.
5.	BIS	IS 5154: Part 1: 2013	Indian	• The standard follows the IEC 60254-1: 2005 standard. The objective of this standard is to specify certain essential characteristics of traction batteries or cells, together with the relevant test methods of those characteristics. Tests such as capacity test, charge retention test, high-rate discharge performance test, cyclic endurance test and their sequence are provided in the standard.

Source: IEC, CENELEC, SAE, BIS

Safety standards of Lead acid batteries

Table 154: Safety standards for Lead Acid Traction Batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	IEC	IEC 62485-3:2014	Global	Applies to secondary batteries and battery installations used for electric vehicles (e.g. goods vehicles, golf carts, bicycles, wheelchairs), and does not cover the design of such vehicles. It provides requirements on safety aspects associated with the installation, use, inspection, maintenance, and disposal of batteries. Outlines for battery containers and enclosures, battery peripheral equipment, transportation, storage, disposal and environmental aspects are provided along with guidelines for: • Protection against electric shock by the battery and charger • Prevention of short circuits and protection from other effects of current • Provisions against explosion hazards by ventilation • Provisions against electrolyte hazard
2.	CENELEC	EN 61982-4:2016	Global	• Applies to secondary batteries and battery installations used for electric vehicles, e.g. in electric industrial trucks (including lift trucks, tow trucks, cleaning machines, automatic guided vehicles), in battery powered locomotives, in electric vehicles (e.g. goods vehicles, golf carts, bicycles, wheelchairs). • It provides requirements on safety aspects associated with the installation, use, inspection, maintenance and disposal of batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
3.	ISO	ISO 6469-1:2019	Global	• Specifies safety requirements for rechargeable energy storage systems (RESS) of electrically propelled road vehicles for the protection of persons. The standard covers technical requirements and test procedures related of varied nature such as mechanical, climatic, simulated vehicle accident, electrical, and functional.
4.	SAE	J2289	Global	• Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. Also covers termination, retention, venting system, thermal management, and other features necessary for battery systems.
5.	SAE	J1495	Global	• The standard details procedures for testing lead-acid SLI (starting, lighting, and ignition), heavy-duty, EV (electric vehicle), and RV (recreational vehicle) batteries, to determine the effectiveness of the battery venting system to retard the propagation of an externally ignited flame of battery gas into the interior of the battery under sustained overcharge conditions
6.	QC/T	QC/T 989-2014	Global	• The standard specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles. Applicable to vehicle charging battery enclosure and swapping battery enclosure.
7.	UL	UL 2271	Global	• This standard covers electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in **light electric-powered vehicles** (LEVs) as defined in this standard. • To be compliant with the standard, the batteries must withstand overcharging, over-discharging, short circuit, imbalanced charging, and operation at maximum specified temperature in addition to withstand vibration, shock, crushing, drops, and roll overs. The batteries must also pass environmental tests such as immersion test and exposure test to stated IP67 rating and rapid thermal cycling from extremes of hot to cold and cold to hot.

Source: IEC, CENELEC, ISO, SAE, QC/T, UL

Performance standards of Lithium-ion batteries

Table 155: Performance and lifecycle standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	CENELEC	EN IEC 62660-1:2019	Global	• Specifies the test procedures to obtain the essential characteristics of lithium-ion cells for vehicle propulsion applications regarding capacity, power density, energy density, storage life and cycle life. This document provides the standard test procedures and conditions for testing basic performance characteristics of lithium-ion cells for vehicle propulsion applications, which are indispensable for securing a basic level of performance and obtaining essential data on cells for various designs of battery systems and battery packs.
2.	SAE	J2758	Global	• Determination of the Maximum Available Power from a Rechargeable Energy Storage System on a Hybrid Electric Vehicle: Describes a test procedure for rating peak power of the Rechargeable Energy Storage System (RESS) used in a combustion engine Hybrid Electric Vehicle (HEV).

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
3.	SAE	J1634	Global	• Battery Electric Vehicle Energy Consumption and Range Test Procedure are illustrated in this document. The standard looks forward to determine energy consumption and range of light duty vehicles (LDVs) based on federal emission test procedure (FTP). An urban dynamometer driving schedule (UDDS) and the highway fuel economy driving schedule (HFEDS) are used to provide a flexible testing methodology that is capable of accommodating additional test cycles as needed.

Source: CENELEC, SAE

Safety standards of Lithium-ion batteries

Table 156: Safety standards for Lithium-ion Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC, CENELEC**	**IEC 62485-3:2014**	**Global**	• Applies to secondary batteries and battery installations used for electric vehicles, e.g. in electric industrial trucks (including lift trucks, tow trucks, cleaning machines, automatic guided vehicles), in battery powered locomotives, in electric vehicles (e.g. goods vehicles, golf carts, bicycles, wheelchairs), and does not cover the design of such vehicles. • It provides requirements on **safety aspects** associated with the **installation, use, inspection, maintenance and disposal** of batteries.
2.	**IEC, CENELEC**	**IEC 62485-6:2021**	**Global**	• Applies to battery installations used for electric off-road vehicles; it does not cover the design of such vehicles. Main applications include industrial, cleaning machines, trucks for material handling, electrically propelled lifting platforms, electric powered boats and ships.
3.	**IEC, CENELEC**	**IEC TR 62660-4:2017**	**Global**	• Provides the test data on the candidate alternative test methods for the internal short circuit test according to 6.4.4.2.2 of IEC 62660-3:2016. • The internal short circuit test in this document is intended to simulate an internal short circuit of a cell caused by the contamination of conductive particle, and to verify the safety performance of the cell under such conditions. • Applicable to the secondary lithium-ion cells and cell blocks used for propulsion of electric vehicles (EV) including battery electric vehicles (BEV) and hybrid electric vehicles (HEV).
4.	**IEC**	**IEC 62281:2019+AMD1:2021**	**Global**	• Specifies test methods and requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal.
5.	**CENELEC**	**EN 50604-1:2016/A1:2021**	**Global**	• General safety requirements and test methods for secondary lithium batteries for light EV (electric vehicle) applications: • Specifies test procedures and provides acceptable safety requirements for voltage class A and voltage class B removable lithium-ion battery (packs and) systems, to be used as traction batteries of or for electrically propelled road vehicles. • Related to the testing of safety performance of battery packs and systems for their intended use for a vehicle.
6.	**SAE**	**J2289**	**Global**	• Functional guidelines for Electric-Drive Battery Pack System • Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • Also covers termination, retention, venting system, thermal management, and other features

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
7.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles. • Applicable to vehicle charging battery enclosure and swapping battery enclosure.
8.	**UL**	**UL 2271**	**Global**	• Covers electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in **light electric-powered vehicles** (LEVs) as defined in this standard. • To be compliant with the standard, the batteries must withstand overcharging, over-discharging, short circuit, imbalanced charging, and operation at maximum specified temperature in addition to withstand vibration, shock, crushing, drops, and roll overs. The batteries must also pass environmental tests such as immersion test and exposure test to stated IP67 rating and rapid thermal cycling from extremes of hot to cold and cold to hot.

Source: IEC, CENELEC, SAE, QC/T, UL

Safety standards for Nickel metal hydride batteries

Table 157: Safety standards for Nickel Metal Hydride Traction batteries

Sl. No.	Organization	Standard	Type	Standard Description and Coverage
1.	**IEC, CENELEC**	**IEC 62485-3:2014**	**Global**	• Applies to secondary batteries and battery installations used for electric vehicles, e.g. in electric industrial trucks (including lift trucks, tow trucks, cleaning machines, automatic guided vehicles), in battery powered locomotives, in electric vehicles (e.g. goods vehicles, golf carts, bicycles, wheelchairs), and does not cover the design of such vehicles. • It provides requirements on **safety aspects** associated with the **installation, use, inspection, maintenance and disposal** of batteries.
2.	**SAE**	**J2289**	**Global**	• Functional guidelines for Electric-Drive Battery Pack System • Describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. Includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. • Also covers termination, retention, venting system, thermal management, and other features
3.	**QC/T**	**QC/T 989-2014**	**Global**	• Specifies the general requirements, safety requirements, mechanical strength, appearance and dimension, environmental resistance requirements, assembly requirements, test methods, identification and mark, transportation and storage and package of battery enclosure in the traction battery system of electric vehicles. • Applicable to vehicle charging battery enclosure and swapping battery enclosure.
4.	**UL**	**UL 2271**	**Global**	• This covers electrical energy storage assemblies (EESAs) such as battery packs and combination battery pack-electrochemical capacitor assemblies and the subassembly/modules that make up these assemblies for use in light electric-powered vehicles (LEVs) as defined in this standard. • The batteries must withstand overcharging, over-discharging, short circuit, imbalanced charging, and operation at maximum specified temperature in addition to withstand vibration, shock, crushing, drops, and roll overs. The batteries must also pass environmental tests such as immersion test and exposure test to stated IP67 rating and rapid thermal cycling from extremes of hot to cold and cold to hot.

Source: IEC, CENELEC, SAE, QC/T, UL

10.3 Annexure for battery swapping

South Korea Clean Provision Act Clause 5, Article 58 (Operation etc., of Low-Emission Motor Vehicles

"Where an owner intends to cancel the registration of his/her motor vehicle for the purposes of scrapping, exporting, etc., of the motor vehicle, he/she shall return the following devices, parts, etc., to the head of the relevant local government, as prescribed by Ordinance of the Ministry of Environment:

Provided, that this shall not apply where the registration of a motor vehicle is canceled to export electric vehicles:

1. Installed or replaced exhaust gas reduction device;
2. Converted or replaced low emission engine;
3. **Battery** and other devices and parts of the motor vehicles prescribed by Ordinance of the Ministry of Environment which were subsidized for expenses under paragraph (3) (excluding motor vehicles that use natural gas as their fuel which were subsidized for expenses under paragraph (3) 1, 4 or 6).

Notwithstanding paragraph (5), an owner may pay the amount equivalent to the residual value of the devices or parts referred to in subparagraphs 1 and 2 of the same paragraph in cash as prescribed by Ordinance of the Ministry of Environment."

10.4 Annexure for battery recycling

Assumptions for recycling capacity requirement

To reach at the overall EV sales from 2021 to 2030, assumptions have been taken at two levels viz. overall Indian automobiles industry growth and EV adoption rate.

The category wise automobile sales growth for the said period is shown below.

Table 158: Automobile Industry Growth Rate (2021-30)

Category	Growth Rate (2021 – 30)
Passenger Vehicles	3.4%
Commercial vehicles	3.9%
Buses	1.1%
Three Wheelers	3.8%
Two Wheelers	6.4%

After projecting the automobile sales from 2021 to 2030, the EV sales figures are reached through assumptions taken for EV adoption rates for 2025 and 2030 for each of the categories. There are three scenarios considered for reaching at EV numbers viz. high growth, medium growth, and low growth. The table below shows the growth rates for each of the scenarios.

Table 159: EV adoption rate (as a percentage of total sales)

CATEGORY	Low Growth		Medium Growth		High Growth	
	2025	2030	2025	2030	2025	2030
Passenger Vehicle	1.3%	10.0%	1.4%	15.0%	1.5%	20.0%

CATEGORY	Low Growth		Medium Growth		High Growth	
	2025	2030	2025	2030	2025	2030
Commercial Vehicle (w/o bus)	0.8%	6.5%	0.9%	8.0%	1.0%	10.0%
Buses	0.8%	8.5%	0.9%	10.0%	1.0%	12.0%
Three-wheeler	12.5%	32.5%	13.5%	40.0%	15.0%	50.0%
Two-wheeler	6.5%	21.0%	8.0%	32.0%	10.0%	43.0%

Basis the number of electric vehicles in each category, from 2021 to 2030, the battery requirement for each of the category is determined using the battery sizing through the years. The table shown below captures the battery sizes (in kWh) considered for each of the vehicle categories.

Table 160: Segment Wise battery capacity (kWh)

Category/Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
E-2W	2.5	2.5	3	3	4	4	4.5	4.5	5	5
E-3W	4.5	4.5	5	6	6	7	8	8	9	10
E-4W (Passenger)	25	25	30	30	35	35	40	40	50	55
E-4W (Commercial)	35	35	40	40	45	50	55	65	70	75
E-Buses	150	150	160	170	180	200	220	220	240	250

As per the assumptions mentioned in 0, the required recycling capacities for 2031 and 2036 are computed.

Notes

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