REPORT

BATTERY PACK AADHAAR

UNLOCKING FINANCING, SECONDARY MARKETS, AND LIFECYCLE VALUE FOR INDIA'S EV TRANSITION

JUNE 2026

ABOUT

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ABBREVIATIONS

ACC	Advanced Chemistry Cell
AIS	Automotive Industry Standards
B2B	Business-to-business
BaaS	Battery-as-a-Service
BCF	Battery Carbon Footprint
BDD	Battery Dynamic Data
BDS	Battery Descriptor Section
BESS	Battery Energy Storage Systems
BI	Battery Identifier
BMCS	Battery Material Composition Section
BMI	Battery Manufacturer Identifier
BMS	Battery Management System
BPAN	Battery Pack Aadhaar Number
BS VI	Bharat Stage VI
CAFE	Corporate Average Fuel Efficiency
CAGR	Compound Annual Growth Rate
CATL	Contemporary Amperex Technology Company Limited
CMVR	Central Motor Vehicles Rules
CoP	Conformity of Production
DFI	Development Finance Institution
DPP	Digital Product Passport
eDAR	Electronic Detailed Accident Report
ESPR	Eco-design for Sustainable Products Regulation
EOL	End-of-Life
EPR	Extended Producer Responsibility
EU	European Union
EV	Electric Vehicle
GBA	Global Battery Alliance
GHG	Greenhouse Gas
ICE	Internal Combustion Engine
ICT	Information and Communications Technology
IoT	Internet of Things
IT	Information Technology
kWh	Kilowatt-hour
LaaS	Lending-as-a-Service
LFP	Lithium Iron Phosphate
LIB	Lithium-ion Batteries
LMT	Light Means of Transport
LTV	Loan-to-Value
MoEFCC	Ministry of Environment, Forest and Climate Change
MHI	Ministry of Heavy Industries
MoM	Ministry of Mines
MEITy	Ministry of Electronics and Information Technology
METI	Ministry of Economy, Trade and Industry
MoP	Ministry of Power
MoRTH	Ministry of Road Transport and Highways
MSME	Micro, Small, and Medium Enterprises
NEV	New Energy Vehicle
NBFCs	Non-Banking Financial Companies
NMC	Nickel Manganese Cobalt
NPAs	Non-Performing Assets
OBD	On-Board Diagnostics
OEMs	Original Equipment Manufacturers
PLI	Production Linked Incentive
PoC	Proof of Concept
RSF	Risk Sharing Facility
RUL	Remaining Useful Life
SaaS	Software as a Service
SEWA	Self Employed Women's Association
SIDBI	Small Industries Development Bank of India
SMEs	Small and Medium Enterprises
SoC	State of Charge
SoH	State of Health
TEC	The Energy Company
UIN	Unique Identification Number

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EXECUTIVE SUMMARY

India's transition to electric mobility is a critical pillar of its broader decarbonization and energy security strategy. However, despite strong policy support and increasing market momentum, the adoption of electric vehicles (EVs) continues to face structural barriers. A key constraint is the absence of a transparent and standardized battery data ecosystem. Batteries, accounting for a substantial portion of EV cost, play a decisive role in determining performance, safety, resale value, and end-of-life (EOL) potential. As a result, the EV adoption rate in India remained relatively low at just 8.24% in the financial year (FY) 2025-26.[1]

Building on the key learnings from our research, we have undertaken extensive stakeholder consultations with over 20 industry stakeholders including OEMs, financing institutions, recyclers, civil society organizations and battery service providers, to identify the key challenges across the EV ecosystem. Furthermore, we have proposed evidence-based recommendations to strengthen the ecosystem for achieving battery circularity in the country. This report highlights that limited visibility into battery health, usage patterns, and composition has cascading impacts across the EV ecosystem. It constrains access to affordable financing, limits risk assessment for insurance, weakens secondary markets, and restricts efficient reuse, repurposing, and recycling of batteries. In this context, India's proposed Battery Pack Aadhaar system guidelines present a transformative opportunity to establish a digital backbone for battery traceability and enable a circular battery economy.

India's EV adoption is constrained by uncertainty around battery performance and residual value. The absence of standardized metrics such as State of Health (SoH) and limited data transparency significantly reduce confidence among consumers, financiers, and insurers. The analysis of the financing ecosystem reveals that EV loans are less favourable compared to internal combustion engine (ICE) vehicles, with lower loan-to-value ratios, higher interest rates, and shorter tenures due to perceived technology and asset risks. Similarly, the insurance sector faces challenges in pricing EV risks, as higher repair costs, battery safety concerns, and limited claims data result in premiums that are 20–30% higher than conventional vehicles.

The report further examines end-of-life (EOL) battery management, highlighting substantial untapped potential in second-life applications and recycling. According to NITI Aayog, the demand for battery technologies would grow at a CAGR of 50% over FY 2022-30 and the total cumulative demand for EV batteries was estimated to be approximately 380 GWh by 2030. Nearly 128 GWH of lithium-ion batteries (LIBs) would be available for recycling by 2030, out of which 59 GWh (46%) would be from the EV segment alone.[2] While EV batteries retain up to 70% of their capacity after first use, the lack of traceability and standardized diagnostics prevents efficient reuse and value recovery. The chapters on roadblocks to battery circularity identify systemic challenges such as fragmented data ecosystems, lack of standardization, and weak recycling infrastructure. These limitations are further compounded by regulatory fragmentation and limited coordination across stakeholders.

Efforts to introduce battery passports are ongoing across the globe. In 2018, China launched the "Interim Provisions on the Traceability Management of Power Battery in New Energy Vehicle" regulatory framework.[3] In Japan, Ministry of Economy, Trade and Industry (METI) plans to mandate the disclosure of EV battery production emissions.[4] The European Union took a major step by including Battery Passport under the Battery Regulation (EU) 2023/1542.[5] The Battery Regulation mandates a comprehensive set of data attributes for the passport, with information selectively shared among the public, regulators, and service/end-of-life operators, each with specific permissions to balance transparency and data privacy.

In India, the Office of the Principal Advisor to the Government of India released the "E-mobility R&D Roadmap for India" which included a key initiative on Battery Pack Aadhaar system in July 2024.[6] Following this, the Ministry of Road Transport and Highways (MoRTH) constituted a committee which later released the draft "Guidelines for Implementation of Battery Pack Aadhaar System" in December 2025.[7] The Battery Pack Aadhaar is an ingenious digital identification and data storage system that will ensure end-to-end traceability of batteries throughout their entire lifecycle. This system will complement the Battery Waste Management Rules in India.

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The comparison between the EU Battery Passport and India's proposed Battery Pack Aadhaar guidelines are given in the table below.

TABLE 1. COMPARISON BETWEEN EU BATTERY PASSPORT AND BATTERY PACK AADHAAR GUIDELINES		
Dimension	**EU Battery Passport**	**Battery Pack Aadhaar (India)**
Regulatory Status	Legally mandated under EU Regulation (2023); implementation from 2027	Draft guidelines released (2025); implementation pending
Scope	Covers all batteries including EV, industrial, and imported batteries	Focuses primarily on EV batteries (2W, 3W, 4W, industrial >2 kWh)
Data Architecture	Decentralized system across economic operators	Primarily centralized server-based architecture
Data Access	Open standards with tiered access (public, regulators, stakeholders)	Public and private access defined; governance frameworks evolving
Battery Identification	Digital battery passport with QR code	Battery Pack Aadhaar Number (BPAN) with QR code
Dynamic Data Tracking	Continuous updates on SoH, lifecycle performance, and usage	Lifecycle data captured, but update protocols require clarity
Standardization	Strong emphasis on interoperability and uniform data formats	Standards under development; interoperability challenges persist
Carbon Footprint Reporting	Mandatory lifecycle carbon disclosure	Proposed adoption of EU methodology; implementation unclear
Recycling and Circularity	Strict recovery targets and recycled content mandates	Linked to EPR rules; infrastructure and enforcement gaps remain
Implementation Maturity	Advanced, supported by pilots and well-defined governance	Early-stage with significant implementation challenges

Finally, the report evaluates the Battery Pack Aadhaar system as a policy innovation designed to enable cradle-to-grave traceability. By assigning a unique digital identity to each battery and enabling data sharing across stakeholders, the system has the potential to reduce risk, unlock financing, improve safety, and strengthen circularity.

Photo: Magnific

TABLE 2. CHALLENGES AND RECOMMENDATIONS FRAMEWORK: BATTERY PACK AADHAAR GUIDELINES

Category	Challenges	Recommendations
Governance & Institutional Coordination	▪ Lacks clarity on Nodal agency ▪ Ambiguity in stakeholder roles and responsibilities ▪ Fragmented regulatory ecosystem and lack of lifecycle-wide oversight ▪ Lack of clarity on implementation timelines	▪ Establish a nodal agency with members from various relevant departments ▪ Clearly define roles, responsibilities, and accountability across stakeholders ▪ Develop a coordinated governance framework covering the full battery lifecycle ▪ Align implementation with a phased roadmap and defined timelines
Data Governance, Privacy & Access	▪ OEM reluctance to share proprietary battery data ▪ Lack of trust in centralized systems and data-sharing platforms ▪ Unclear data ownership, access rights, and liability frameworks	▪ The data of the battery pack from cradle-to-grave could be stored at OEM-level until the Battery Pack Aadhaar system gets established with right data governance structures ▪ Implement periodic regulatory audits and inspection by nodal agency to ensure OEM compliance with data storage ▪ Enable peer-to-peer data sharing mechanisms with NDAs ▪ Introduce strong data security protocols (encryption, access controls) ▪ Conduct pilot projects to test scalability and reduce implementation risk
Data Standards, Interoperability & Technical Architecture	▪ Lack of standardized SoH methodologies ▪ Inconsistent data formats and interoperability gaps ▪ Difficulty in integrating data across stakeholders and platforms ▪ Centralized architecture raises scalability and cybersecurity concerns	▪ Align with global frameworks (e.g., EU Battery Passport standards) ▪ Define common data formats and interoperability protocols ▪ Move toward a hybrid data architecture combining centralized supervision with decentralized data ownership: a centralized portal ensures visibility and traceability, while proprietary data remains with OEM
Industry Adoption & Market Readiness	▪ Resistance from OEMs due to cost and competitive concerns ▪ Lack of clear value proposition for stakeholders ▪ Limited incentives to adopt the system ▪ Low awareness and trust among ecosystem actors	▪ Build "value circularity" incentives across stakeholders (preferential financing, PLI-linked incentives, government procurement preference) ▪ Develop a clear business case demonstrating benefits (financing, resale, insurance) ▪ Promote industry consultation and co-design of guidelines
End-of-Life (EOL) Ecosystem & Traceability	▪ Weak formal collection, dismantling, and recycling systems ▪ Informal sector dominance in battery handling ▪ Lack of traceability during recycling, repurposing, and battery swapping ▪ No clear mechanism linking old and new BPANs	▪ Invest in formal EOL infrastructure (collection, dismantling, recycling) ▪ Strengthen EPR implementation and compliance systems ▪ Develop clear BPAN lifecycle protocols (linking original and new IDs) ▪ Integrate traceability with existing platforms (e.g., VAHAN database)

One of the biggest impediments holding back democratization of EVs is the uncertainty around the resale and salvage value of EVs. This has also resulted in immature and underdeveloped secondary market for electric vehicles. This lack of clarity affects not only consumers but also financial institutions, which remain hesitant to offer EV loans with competitive interest rates, high loan-to-value (LTV) ratios, and longer tenures. The uncertainty surrounding the value of used EV batteries stems from several factors, the most significant being the uncertainty in knowing their State of Health (SoH) at any given point in time. SoH is a critical metric that helps estimate the remaining useful life of a battery in mobility applications, assess its potential for second-life use cases (such as stationary energy storage), and determine the residual value of critical minerals contained within. The framework for initial rollout of Battery Pack Aadhaar system proposed in this report focuses on unlocking the SoH data to benefit the stakeholders across the EV ecosystem.

FRAMEWORK FOR INITIAL ROLLOUT OF BATTERY PACK AADHAAR SYSTEM IN INDIA

Presently, the data on SoH of the EV battery is not openly shared with either the EV user or the any other stakeholders in the EV ecosystem unless the OEMs agree to share the information. To address this challenge, we have depicted a potential governance mechanism which could focus on getting the OEM-calculated SoH data of the EV batteries. The flow diagram and the detailed steps involved in the depicted potential governance mechanism for implementation of Battery Pack Aadhaar system are given below in Figure 1.

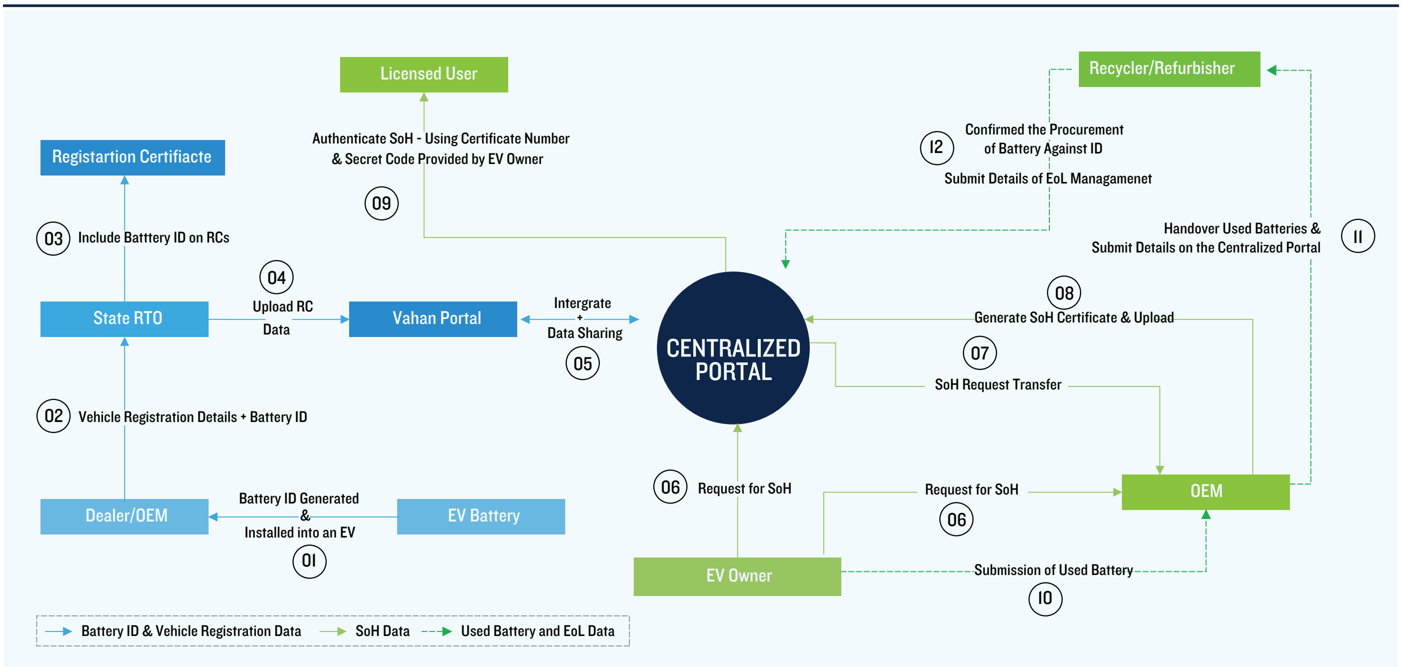
This example of governance mechanism could help in establishing formal basic traceability of the EV batteries.

The supporting guidelines and regulations to operationalize this mechanism shall be developed to enforce compliance from the OEMs and other relevant stakeholders. This basic governance mechanism can serve as the starting step for implementation and based on the pilots implemented, it will be further refined. It will help achieve the broader objective of ensuring the traceability of EV batteries for better EOL management and unlock secondhand market for EVs by providing access to the OEM-calculated SoH data.

The Battery Pack Aadhaar system has the potential to become a foundational pillar of India's clean mobility transition by enabling end-to-end battery traceability and data transparency.

By addressing information asymmetry and improving lifecycle visibility, it can unlock multiple benefits, including enhanced access to finance, reduced insurance costs, improved safety, and optimized resource utilization. However, its success will depend on strong governance, stakeholder alignment, and the development of a trusted and interoperable data ecosystem. Aligning India's approach with global best practices will be essential to ensure effective implementation and long-term sustainability. A collaborative approach, where regulatory support is complemented by industry innovation, will be critical to accelerating EV adoption and establishing India as a global leader in circular and sustainable battery systems.

FIGURE 1. ILLUSTRATION OF POTENTIAL GOVERNANCE MECHANISM FOR IMPLEMENTATION OF BATTERY PACK AADHAAR SYSTEM IN INDIA



Source: NRDC Analysis

1. INTRODUCTION

The transport sector is India's third most greenhouse gas (GHG) emitting sector, accounting for 14 per cent of country's energy-related CO_2 emissions, which have increased threefold since 1990.[8] Road transport dominates energy consumption, accounting for 90% of the sector total energy use.[9] With vehicle ownership more than doubling from 159 million in 2012 to over 354 million in 2022, and projected to grow at a compound annual growth rate (CAGR) of 9.7% through 2030, the urgency to decarbonize the sector has never been greater.[10]

To address the growing emissions from the road transport sector, the Government of India came up with Corporate Average Fuel Efficiency (CAFE) standards and Bharat Stage VI (BS VI) norms to improve fuel efficiency and emission standards of vehicles.[11] In addition, a multi-tiered policy approach to accelerate electric vehicle (EV) adoption with both national and sub-national governments have introduced a mix of fiscal and non-fiscal incentives to promote EV adoption, supported localization through phased manufacturing programs, and implemented production-linked incentive (PLI) schemes to strengthen the domestic EV supply chain.[12] However, despite concerted efforts by various stakeholders in the ecosystem, several persistent challenges, such as inadequate charging infrastructure, limited EV model availability, high cost differentials, and the lack of attractive financing options, continue to impede EV adoption. As a result, the EV adoption rate remained relatively low at just 8.24% in the financial year (FY) 2025-26.[13]

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One of the biggest impediments holding back EV adoption and democratization of EVs is the uncertainty around the resale and salvage value of EVs. This has also resulted in immature and underdeveloped secondary market for electric vehicles. This lack of clarity affects not only consumers but also financial institutions, which remain hesitant to offer EV loans with competitive interest rates, high loan-to-value (LTV) ratios, and longer tenures. A major concern for financiers is the battery, often called the "elephant in the room", as it accounts for nearly 40% of an EV's total cost.[14] Compounding this issue is the limited access to user-level internet of things (IoT) data, which provides real-time insights into asset health and battery usage. Original equipment manufacturers (OEMs) are often reluctant to share this data due to privacy concerns and regulatory uncertainty around data-sharing, making it difficult for lenders to accurately assess risk. Additionally, there is a lack of standardized metrics for evaluating battery health and remaining useful life (RUL), both of which are critical for determining the value of used EVs during resale, refinancing, or buyback. This lack of transparency and standardization has effectively frozen the second-hand EV market.

Furthermore, the secondary market value of EV batteries, whether for second-life applications or recycling, remains poorly defined and unstandardized. The absence of clear valuation frameworks for end-of-life batteries significantly increases perceived risk, further restricting financing options and slowing EV market penetration.

The uncertainty surrounding the value of used EV batteries stems from several factors, the most significant being the uncertainty in knowing their State of Health (SoH) at any given point in time. SoH is a critical metric that helps estimate the remaining useful life of a battery in mobility applications, assess its potential for second-life use cases (such as stationary energy storage), and determine the residual value of critical minerals contained within. These minerals include lithium, nickel, cobalt, and graphite which are not produced domestically at scale in India, resulting in a heavy reliance on imports. Enabling regulations and infrastructure for battery circularity would help retain a significant portion of these valuable resources. Battery circularity refers to the systematic management of batteries across their lifecycle to optimize retained value, through reuse, repurposing, remanufacturing, and recycling, thereby reducing dependence on primary raw material extraction and minimizing waste generation. Establishing a closed-loop battery ecosystem is therefore crucial not only to enhance the circularity and residual value of EV batteries but also to reduce import dependency and ensure long-term resource security and resilience.

Another apprehension affecting the consumer sentiment emerges from safety-related incidents. The safety of EV batteries, whether during their life in EVs, or when the first owner intends to sell the EV, or after reaching their end-of-life in mobility use, is of critical concern. Data disclosure on remaining battery capacity, instances of harmful practices such has deep discharge events, or operation and charging in extreme temperatures, will help ascertain SoH of the battery. Deep discharge of an EV battery refers to vehicle operation in which the battery is discharged to a very low state of charge resulting in increased electrochemical, mechanical, and safety-related degradation risks. Tracking the data on batteries from cradle-to-grave will help in preventing unsafe disposal of EV batteries.

In this context, the draft "Guidelines for Implementation of Battery Pack Aadhaar System" released by the Ministry of Road Transport and Highways (MoRTH) could play a pivotal role by enabling end-to-end traceability of batteries and their components from cradle-to-grave.[15] Such a system, which along with other strategies like the EU Battery Passport Regulation, will be discussed in this report. They can facilitate access to data on sourcing and usage of batteries, help to establish standardized procedures for assessing the condition, composition, and residual value of used batteries, thereby facilitating more accurate valuation and boosting confidence among stakeholders across the EV ecosystem. In this report we have built the case for the need for battery traceability, identified the roadblocks for end-of-life (EOL) management, analyzed the global best practices including EU's battery passport regulation and China's battery regulations, and unpacked the draft guidelines for implementation of a Battery Pack Aadhaar system. Building on the key learnings from our research, we have undertaken extensive stakeholder consultations with over 20 industry stakeholders including OEMs, financing institutions, recyclers, civil society organizations and battery service providers, to identify the key challenges across the battery value chain. Furthermore, we have proposed evidence-based recommendations to strengthen the ecosystem for achieving battery circularity in the country.

In the following section, we have delved deeper into the present financing landscape for vehicles and built the case for the need of battery traceability data to achieve price parity between internal combustion engine (ICE) vehicles and EVs.

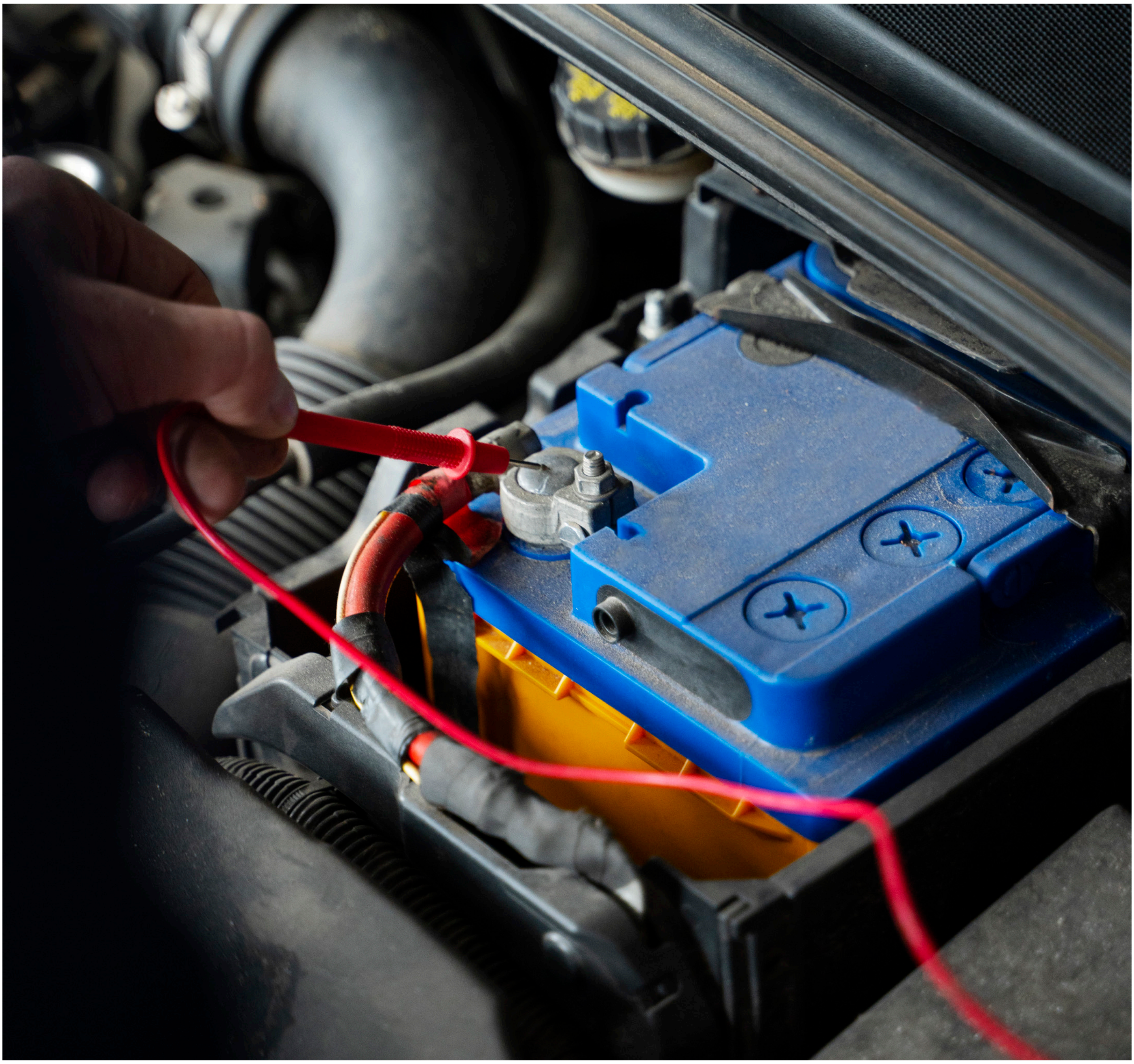


Photo: Magnific

2. STATUS QUO OF AUTOMOBILE FINANCING IN INDIA

Over time, India's automobile sector has demonstrated strong growth and is projected to expand from USD 137.06 billion in 2025 to USD 147.58 billion in 2026. It is further forecasted to reach USD 213.74 billion by 2031, registering a CAGR of 7.69% during 2026–2031.[16] Financing has consistently played a crucial role in supporting this growth, as different vehicle segments and form factors involve significant upfront costs for buyers. The availability of easy financing and the continuous development of a robust financing ecosystem have established financing as a key catalyst for the growth of automobile sales in India. As a result, auto loans account for approximately 12.4% of total personal finance lending in India, reflecting their significant role in the automotive sector.[17] Overall, nearly 77% of all vehicles in India are financed through banks and non-banking financial companies (NBFCs), though this share varies across different segments.[18]

In markets with well-established credit systems and structured lending policies, financing is more common and contributes to a higher volume of vehicle sales. Additionally, changes in economic conditions, such as rising interest rates or tighter lending standards, can shift the balance between these two modes of purchase, of financing and upfront purchase, with buyers leaning more towards upfront payments to avoid the additional cost of financing. Understanding these financing dynamics becomes essential for automakers, dealers, and financial institutions looking to optimize their strategies for vehicle sales growth.

2.1 OVERVIEW OF ICE VEHICLE FINANCING VS. EV FINANCING

In India, vehicle financing is one of the predominant modes of vehicle acquisition for both private and commercial users. Across different vehicle segments and use cases, more than 75% of privately used vehicles and over 90% of commercially used vehicles are financed through formal lending channels.[19,20,21,22]

Over the years, financing for ICE vehicles has evolved into a well-defined and mature ecosystem. This is supported by a robust second-hand market, established after-sales repair and maintenance networks, predictable insurance frameworks, and proven commercial business models. These factors provide greater confidence to financial institutions, enabling them to offer loans for ICE vehicles at competitive interest rates and with longer repayment tenures.

In contrast, the EV financing ecosystem is still at a nascent stage. Given that the technology in EVs is evolving, especially the batteries, the relatively limited market maturity, evolving resale value, and uncertainties around operations and after-sales maintenance have resulted in 10 – 30% lower loan-to-value (LTV) ratios, about 1 – 9% higher interest rates and nearly 6 – 18 months shorter loan tenures for EV loans, depending on the vehicle category.[20] Financiers also remain cautious about extending credit for EVs in commercial applications due to perceived risks related to performance, reliability, and long-term operational viability.[23]

To better understand the current landscape of EV financing in India, stakeholder consultations were conducted with a range of financial institutions. These discussions provided valuable insights into the efforts being undertaken to bridge financing gaps in the EV ecosystem. Key insights from some of the innovative financing solutions are captured below.

Innovative Financing Solutions for EVs – Insights from Financial Institutions

Small Industries Development Bank of India (SIDBI):

As a Development Financial Institution (DFI), SIDBI launched 50KEV4ECO, aimed at supporting the downstream EV value chain by enabling Micro, Small, and Medium Enterprises (MSMEs) and startups to transition to electric mobility using innovative solutions. SIDBI has also launched EWEE (Empowering Women and Enhancing their Business through E-Mobility), a collaborative initiative with Self Employed Women's Association (SEWA) and NBFC partners to empower rural women entrepreneurs by improving access to affordable finance for electric two- and three-wheelers.[24] Through NRDC's rural e-mobility pilot initiative, NRDC collaborated with SIDBI to develop a concessional financing instrument, a risk-sharing facility (RSF), to de-risk lending and enable access to EV finance for low-income women entrepreneurs.[25] For early adopters, accessing market finance has been a huge challenge. Development finance in the form of RSF and first loss guarantee schemes remains critical to build confidence among stakeholders on EV technology and thereby encouraging other public and private financing institutions to broaden their offerings for EVs.

Finayo:

Finayo is an innovative Lending-as-a-Service (LaaS) company which uses advanced business-to-business (B2B) software-as-a-service (SaaS) technology to transform the EV lending business in India, with a specific focus on Tier 2 and Tier 3 cities. While traditional banks in the EV space suffer from high non-performing assets (NPA), Finayo addressed this issue through better asset monitoring and management. The company integrated asset health monitoring to track vehicle performance and downtime, ensuring that requests for assistance were resolved within 24 hours to minimize vehicle downtime. Finayo collaborated with manufacturers to provide technology support at minimal cost, offering technological solutions to dealers as well. The company ensured that flexible payment modes were available for consumers, tailored to suit their earning cycles. Finayo emphasized that monitoring key metrics such as charging time, charger type, range, vehicle overloading, and misuse, helped in determining the vehicle's overall health at the time of resale. The company found that with proper tracking, the EVs retained 60-70% of their resale value after six months.[26]

In the case of personal EV financing, lending decisions are largely driven by the borrower's credit profile, similar to ICE vehicle financing. However, despite this similarity, the overall number of EVs financed remains significantly lower than that of ICE vehicles, reflecting broader market and institutional hesitations around technology risk and uncertainty around resale/salvage value.

2.2 FINANCING DYNAMICS IN SECOND-HAND MARKET FOR ICE VEHICLES

The second-hand market for ICE vehicles in India is rapidly expanding and is supported by a well-established ecosystem that provides financiers with reliable benchmarks for residual value. This validated framework has strengthened lender confidence by reinforcing trust in the long-term value of these assets, thereby facilitating the growth of financing options for used ICE vehicles.

In 2024, the second-hand ICE vehicle market in India was valued at approximately USD 35.1 billion and is projected to reach USD 68.32 billion by 2030, growing at a compound annual growth rate (CAGR) of 14.87%.

This robust growth reflects increasing consumer preference for pre-owned vehicles, driven by rising new vehicle prices, shorter ownership cycles, and the growing adoption of digital platforms that simplify the used-vehicle purchasing process.[27]

The determination of salvage value commonly referred to as residual value, has played a pivotal role in establishing a stable and transparent second-hand vehicle ecosystem. Residual value serves as a critical benchmark for pricing, financing, and risk assessment, thereby supporting market stability and fostering confidence among buyers, sellers, and financial institutions.

In India, the second-hand ICE vehicle market is broadly segmented into organized and unorganized sectors. The organized sector comprises OEM-affiliated subsidiaries and private digital platforms such as Mahindra First Choice, Maruti True Value, Spinny, and Cars24. These platforms conduct comprehensive vehicle inspections and diagnostics to determine standardized pricing. Their structured evaluation processes enhance transparency and reliability in pricing and quality assessment.[28] In the organized sector, financing institutions are often directly integrated with sales platforms, enabling faster loan processing and easier access to credit based on vehicle condition, assessed value, and the borrower's creditworthiness. This integrated ecosystem significantly improves the efficiency of financing for end-users.

In contrast, the unorganized sector consists of local dealerships, small-scale brokers, and individual sellers. Pricing in this segment is typically determined using less standardized and comparatively less stringent assessment parameters. Despite this, both organized and unorganized segments are supported by banks and NBFCs, which actively provide financing solutions for used vehicles.

With respect to financing, commercial used vehicles are generally subject to greater scrutiny of business models and revenue potential. As a result, they typically attract higher interest rates, shorter loan tenures, and lower LTV ratios. In comparison, private vehicles benefit from more standardized credit assessment processes, lower interest rates, longer repayment tenures, and higher LTV ratios.

2.2.1 BATTERY HEALTH: THE KEY TO UNLOCK SECOND-HAND MARKET FOR ELECTRIC VEHICLES

By understanding the concerns of financiers in EV financing, it is evident that their decisions are largely influenced by uncertainties surrounding the developing ecosystem and EV batteries. Since batteries constitute a significant portion of the overall cost, the valuation of an EV depends heavily on battery health. Therefore, it is crucial to bring greater certainty around EV battery performance throughout its lifecycle to accelerate this transition.

The consultations with industry stakeholders (see Annexure) showcased actionable recommendations and innovative solutions to address these barriers and support the development of an inclusive, sustainable, and data-driven EV transition. The SoH of an EV battery refers to ratio of actual capacity delivered by the battery to the nominal capacity or the capacity when it is new.[29] Unlike conventional vehicles where age and mileage roughly indicate engine wear, an EV's value depends largely on the battery's driving range and ability to hold a charge. The battery SoH assessment requires a series of battery performance and usage datasets, which are typically held by vehicle OEMs. To accurately estimate the EV battery SoH, startups in India are providing novel solutions and a couple of examples are given below.

The Energy Company (TEC):

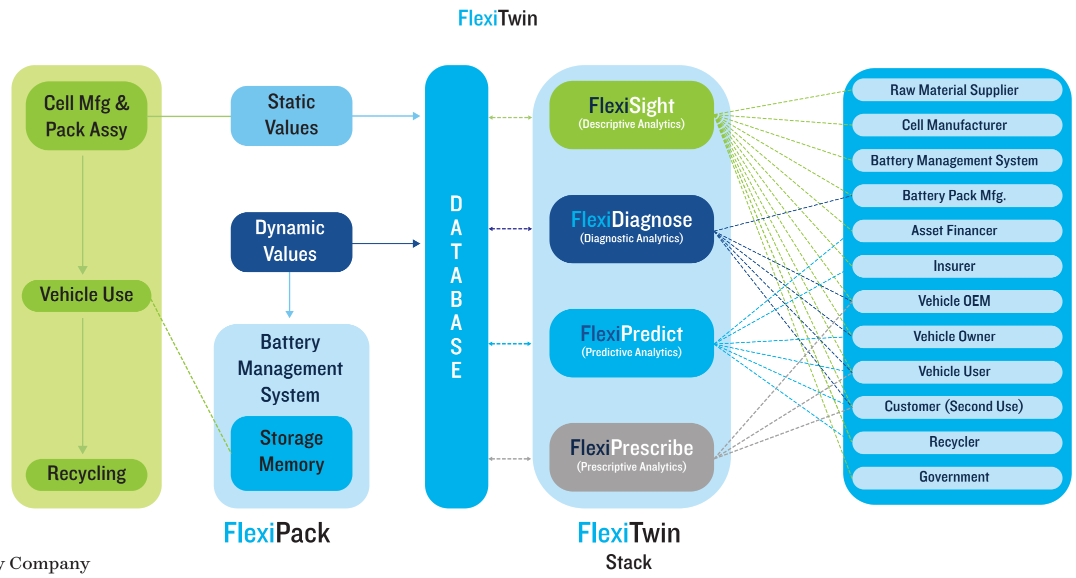
TEC has developed a first-of-its-kind Hardware (FlexiPack) paired with Digital Twin Battery Platform (FlexiTwin) that is both physically and digitally integrated with electric vehicles. FlexiTwin, is built on a unique framework conceptualized by TEC for battery traceability and they named it "Battery Pack Aadhaar".[30] FlexiTwin is the database layer which provides advanced monitoring and analytics capabilities, enabling smarter battery management. The hardware, which houses the battery management system (BMS) in the battery pack, enables flexible charging at any location, while the tamper-proof Digital Battery Pack Aadhaar serves as a digital identity for each battery, capturing its performance, lifecycle, and environmental impact.

The raw telematics from the BMS will be complex to inform the financiers on the battery condition. To help the financiers, the platform provides refined, actionable metrics such as battery uptime and SoH, using conservative models updated every 500–600 cycles to ensure accuracy and improve lender confidence by simplifying asset evaluation and minimize financial risk. Battery Pack Aadhaar ensures end-to-end lifecycle traceability by recording usage data, swapping history, and vehicle associations. This is crucial for determining the remaining useful life of each pack and supports informed decisions on recycling, refurbishing, and repurposing EV batteries for second-life applications such as battery energy storage systems.

"At The Energy Company, we've seen first-hand that battery traceability isn't just a compliance exercise, it's the foundation for unlocking a new financial architecture around energy assets. When a financier can see real-time state-of-health data, charge cycle history, and anomaly flags for every battery in a fleet, the risk premium embedded in EV loans begins to dissolve. Equally, batteries designed from the ground up for data transparency and modular second-life deployment can reduce repurposing costs dramatically, transforming end-of-life from a liability into a recoverable asset. Battery Pack Aadhaar, once implemented well, could be the single most powerful lever for India to build a financially self-sustaining battery circular economy."

– **Mr. Rahul Lamba, CEO & Co-Founder, The Energy Company**

FIGURE 2. AN EXAMPLE OF BATTERY DIGITAL TWIN AND SERVICE PROVIDED BY TEC'S FLEXITWIN STACK



Source: The Energy Company

Battery-OK Technologies:

EV DOCTOR is a Bluetooth-enabled, plug-and-play testing device that connects the battery and charger during charging. It communicates with the cloud to perform AI-driven battery diagnostics, and leverages 25+ machine learning-based models; results are displayed through a dedicated app. It helps OEMs, fleet operators, insurers, and service providers accurately assess battery health, safety, faults, and performance in real time. It supports E-2W/E-3W LFP, NMC and Lead Acid batteries.

By offering fast, reliable, and standardized battery diagnostics, Battery-OK Technologies addresses one of the biggest barriers to EV resale, uncertainty about battery health. This transparency enables fair pricing, boosts consumer confidence, and helps establish a more robust second-hand market for electric vehicles, ultimately supporting affordability and wider EV adoption. Presently, there are over 3000 active EV DOCTOR devices across 30 countries and compatible with more than 120 EV brands.[31]

Furthermore, due to the lack of credible data on battery SoH, the safety of used EV batteries remains a key concern. The next sections delves deeper into this topic and explains how data transparency could mitigate the fire safety risk for EV batteries.

FIGURE 3. EV DOCTOR DEVICE

Source: Battery-OK Technologies

3. ENABLING EV INSURANCE AND MITIGATING FIRE SAFETY RISK OF EV BATTERIES WITH DATA TRANSPARENCY

Research data from 2024-25 states that globally on an average about 25 EVs per 100,000 EVs were involved in fires accidents as compared to 1,530 fires per 100,000 ICE vehicles.[32] Although the chances of fire in an EV are significantly less than those in ICE vehicles, the nature of fire varies significantly.

Due to thermal runaway in lithium-ion batteries, fire in an EV lasts longer, it is complex to manage and requires extended cooling and monitoring to prevent reignition. The battery cells can release toxic gases and heavy metal particles, and this will require larger control and evacuation zones. As a result, the EV batteries, even after reaching end-of-life, pose significant fire risk during storage and transportation. To understand further, the causes of fire in EVs are listed in the table given below in Table 3.

TABLE 3. CAUSES OF FIRES IN ELECTRIC VEHICLES AND THEIR DESCRIPTION

Cause	Description
Thermal Runaway	When batteries are exposed to extremely high temperatures, they get overheated due to unwanted chemical reactions. When the heat dissipation ability of the battery is poor, it will lead to a self-sustaining chain reaction called the thermal runaway.
Faulty Charging	EV batteries are manufactured to receive a pre-determined amount of energy in a set time duration. Due to faulty charging equipment, if the energy supplied exceeds this limit, then it could lead to overheating or electrical faults such as internal short circuit or overcharging. With a properly designed battery management system (BMS), fire due to electrical abuse could be prevented.
Collision	When an EV is involved in a collision with another vehicle or object, it could lead to internal short circuits.
Manufacturing Defects	EVs with faulty batteries and wiring flaws increase fire risk. However, with the evolution of standards and certification, the probability of manufacturing defect is very low in present day EVs.

The fire in an ICE vehicle is dependent on external fuel and oxygen while in an EV, the lithium battery can generate oxygen internally which can prolong combustion. Therefore, only carbon dioxide or other chemicals will not suffice because they will put out the fire but will not be able to cool down the battery pack or prevent reignition. While using copious amount of water is the most effective solution, it could sometimes result in electrical faults and water could react with lithium to release hydrogen gas.[33] Therefore, specialized training for first responders is essential for controlling EV fires.

It is observed that electric bikes and electric scooters with smaller batteries have been involved in more EV fire incidents than other bigger EVs. For example in China, there were about 350 million e-bicycles in circulation by end of 2022 and nearly 21,000 e-bicycles were involved in fire accidents, which was less than 0.01% of total e-bicycles.[34] In London, there were 155 e-bike fires and 28 e-scooter fires recorded in the year 2023 which was an increase of 78% as compared to 2022.[35] In India, the Ministry of Road Transport and Highways (MoRTH) has implemented the eDAR (Electronic Detailed Accident Report), which began capturing a dedicated field for motorized electric vehicles from November 2022. This data revealed that there were about 23,865 accidents involving EVs reported over 3 years from 2023 to 2025. Of these, only 26 accidents involved fire in EVs, which was a meagre 0.1%.[36]

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Based on the recommendations of an investigating team of independent experts, safety amendments were formulated for battery, its components and the BMS through the Automotive Industry Standards (AIS) for 2-wheelers, 3-wheelers, quadricycles, 4-wheeler passenger and goods vehicles. To ensure the quality of EVs produced in the country, MoRTH issued the Conformity of Production (CoP) for all categories of EVs. With these regulations, the Ministry of Heavy Industries (MHI) in India has clarified that the national government supports the manufacturing and use of EVs by strengthening the safety ecosystem through rigorous testing standards and certification.[36]

EVs not only attract higher interest rates but also have higher insurance premiums because of the key factors explained in the below section.

3.1 DATA-DRIVEN APPROACH FOR EV INSURANCE

The underwriting models used for ICE vehicles fail to fully capture the risk profile of an EV. Some of the key factors that influence the underwriting of an EV insurance are given below:

1. **High Repair Cost**: It was estimated that an average EV repair claim costed 25% more than a similar ICE vehicle due to specialized components and skills required for the repair.[37]
2. **Battery Fire Risk**: High-voltage EV batteries pose the risk of potential fire hazards which will require specialized knowledge and equipment, thereby increasing the cost of repair. Battery replacement can be expensive as it constitutes nearly 40% of the EV cost.
3. **User Behaviour Impact**: As the EV user's driving behaviour bears a significant impact on the battery performance, some insurance companies are known to adjust premiums based on telematics data.[38]
4. **Technology & Market Impact**: The technology in the EV sector is fast evolving and this makes it difficult for the insurers to understand and formulate policies that can match the advancement speed. The insurers are expected to adapt to the changing technological, regulatory and market environments of the EV market which is challenging.

Research estimates that on an average, EV insurance costs 20-30% higher than an ICE vehicle due to high repair costs, battery-related hazards and specialised maintenance requirements.

Research estimates that on an average, EV insurance costs 20-30% higher than an ICE vehicle due to high repair costs, battery-related hazards and specialised maintenance requirements.[39] The repair costs of EVs are higher because economies of scale have not yet been realised, due to the requirement of high infrastructure investment as opposed to the low volumes of EVs on road. Notably high-priced EVs are more energy-efficient, have enhanced safety features, and low accident rates; insurance companies are required to account for these distinctions in their underwriting strategies. In this direction, a data-driven approach would be important to tailor insurance based on driver behaviour and battery performance.

It is evident that the data on downstream process and life of the battery in an EV is crucial to devise monitoring and control strategies to prevent an EV fire. For EV insurance risk underwriting, the data on EV battery performance during the use of an EV will prove beneficial in adjusting the premiums accordingly. However, when the EV battery reaches its end-of-life in the mobility application, its management becomes essential to enable a circular battery value chain.

The next chapter provides detailed insights into the utilization of second-hand EV batteries, along with their end-of-life management and potential applications.

4. END-OF-LIFE MANAGEMENT OF EV BATTERIES: SECOND-LIFE APPLICATIONS & RECYCLING

Electric vehicle batteries retain significant usable capacity after their mobility use and that can be harnessed through second-life application. Recent study demonstrated that EV batteries could retain around 80% of their full capacity even after 2,00,000 kilometres.[40] This retained capacity represents not just technical potential but also untapped economic value.

At the end of their second life, batteries remain valuable for recycling as essential materials such as lithium, nickel, and copper can be recovered and reused, reducing reliance on new resources and supporting the circular economy. However, the absence of robust battery traceability systems and standards in India significantly constrains the realisation of this potential.

Realising the economic and environmental value of EV batteries therefore requires clearly defined pathways for end-of-life (EOL) management, supported by robust traceability mechanisms.

4.1 OVERVIEW OF PATHWAYS FOR END-OF-LIFE MANAGEMENT OF EV BATTERIES

The EOL management pathways for EV batteries are commonly categorised into reuse, refurbishment, repurposing, and recycling, each representing a distinct level of technical intervention and value recovery.

Reuse involves continued deployment of batteries in their original application with minimal intervention and is typically limited to niche cases where degradation is marginal.

Refurbishment entails repair or replacement of degraded cells or modules to restore functional performance, enabling continued use in mobility or in less demanding applications.

Repurposing refers to the reconfiguration of retired EV batteries for non-mobility uses such as stationary energy storage, renewable energy integration, telecom tower backup, or commercial power systems.

Recycling marks the final stage of the lifecycle and focuses on recovering critical materials such as lithium, nickel, and cobalt.

Among these pathways, refurbishment and repurposing form the core of second-life utilisation, as they allow batteries to deliver additional years of service while deferring energy- and capital-intensive recycling processes. Evidence from international deployments indicates that a lithium-ion battery used in an EV has an approximate lifespan of 8 years but using it in a stationary second-life application can extend it by 10 years.[41]

In the Indian context, projections indicate a growing volume of EV batteries entering these second-life pathways. NITI Aayog estimated that the cumulative potential for reuse and repurposing of lithium-ion batteries from EVs could reach nearly 49.2 GWh by 2030, driven by increasing EV adoption, especially for four-wheel vehicles and buses.[42]

Second-life utilisation not only harnesses residual capacity but also contributes to India's broader energy system priorities. It was estimated that repurposed EV batteries could service a substantial share of future renewable energy storage needs, with potential to support between 17% and 39% of average daily solar and wind generation by 2038, thereby promoting grid stability and higher renewable penetration.[43]

After the end of first life, batteries typically retain capacity and maintain value for second-life applications and mineral recovery. Repurposing EV batteries for second-life use in stationary storage offers optimal utilisation of remaining capacity before final recycling, thereby extending the functional life of battery systems and delaying entry into the waste stream. This improves overall material efficiency and reduces the need for premature recycling of batteries that are not yet truly at their end-of-life.

Repurposing of EV Batteries in India

India's EV ecosystem, while still developing, has started to produce examples of second-life battery applications.

Vision Mechatronics:

In collaboration with MG Motors, Vision Mechatronics has launched ReLive – India's first high-voltage second-life battery system.[44] This 36 kWh BESS, built from repurposed MG ZS EV batteries, is equipped with an ingeniously developed active balancing Battery Management System (BMS), designed, developed, and manufactured entirely in India. ReLive enables the reuse of EV batteries in stationary applications such as grid support and energy storage across residential, commercial, and industrial sectors. It offers high performance, safety, and durability, supporting the transition to cleaner energy while minimizing carbon emissions and electronic waste. This second-life battery can be purchased from Vision Mechatronics, and its modular design allows for easy scalability and customization.[44]

According to NITI Aayog, the demand for battery technologies would grow at a CAGR of 50% over FY 2022-30 and the total cumulative demand for EV batteries was estimated to be approximately 380 GWh by 2030. Nearly 128 GWh of lithium-ion batteries (LIBs) would be available for recycling by 2030, out of which 59 GWh (46%) would be from the EV segment alone.[45] Furthermore, a recent study also estimated that the battery waste from the EV sector could increase six times by 2040, and it would be ten times more by 2050.[46] As a widespread practice, the end-of-life (EOL) LiBs are discharged, dismantled, shredded and the components are further separated to convert them into black mass. The black mass is the fine, dark powder-like material that is obtained after mechanical processing of EOL lithium batteries. Presently, less than 1% of LiBs are recycled in India and many recycling companies convert them into black mass but are unable to extract battery grade raw material from it, due to the lack of domestic refining capacity.[45] A few companies extract recycled lithium, and export it to battery manufacturers abroad, as the domestic market for recycled material is almost non-existent in India.

Recycling of EV Batteries in India

Despite being a relatively growing market for EV lithium-ion batteries, India already boasts of the increasing number of companies focused on battery recycling.

Lohum:

Lohum operates a hydrometallurgical plant (NEETM technology) that can process 2 GWh of batteries annually. This technology can recover 95% of materials and produce battery-grade lithium, nickel, and cobalt salts locally.[47]

Attero:

Attero specializes in processing EOL batteries, and it has recycled a total of 9,998 metric tons of lithium-ion batteries. Attero has established strategic partnerships with nearly 80% of electric car OEMs in India, enabling old EV batteries to be submitted to service centres for proper recycling, fostering a more circular approach to battery life cycles. Attero's advanced extraction process involves mechanical pre-processing, which shreds and separates metals and 'black mass' containing lithium, cobalt, and nickel. This is followed by hydrometallurgical extraction, which recovers battery-grade materials through chemical leaching and solvent extraction. The process achieves more than 98% recovery efficiency and purity exceeding 99.9%, allowing the recovered materials to be reused in the production of new batteries.[48]

Recycling costs of lithium-ion batteries can vary from USD 1.64/kg to USD 22.4/kg depending on the route, feedstock and scale. Profit margins can vary from USD 0.4–3.3 per kg (hydrometallurgy) and USD 0.5–4.0 per kg (pyrometallurgy) to USD 2.0–14.4 per kg (direct recycling), depending on the process conditions, the cost categories considered and the number and type of recovered products.[49]

The revenue side of battery recycling comes from value recovery – extracting materials like cobalt, nickel, lithium, copper, aluminium, and graphite that can be sold back into the supply chain. The chemical composition of the battery largely determines the potential revenues. Lithium Ferro Phosphate (LFP) and Nickel Manganese Cobalt (NMC) are by far the two most predominant lithium-ion battery chemistries used in Indian EVs. Until now, most EVs have used NMC batteries due to their higher energy density, offering longer ranges in compact formats. However, in recent times major EV OEMs in India are switching to LFP batteries due to lower cost, longer lifespan and wider range of optimal operating temperatures. However, NMC batteries fetch higher economic value after recycling as opposed to LFP batteries. In India, the recyclers purchase used NMC batteries at approximately INR 100-200/kg and the revenue from recycling of these batteries could be as high as INR 350/kg. Whereas the recyclers pay as low as INR 40/kg for purchasing LFP batteries and sometimes the OEMs pay the recyclers to collect LFP batteries.[48] As more number of LFP batteries reach the end of their first life in mobility applications, policies around second-life applications are essential to prevent early retirement of LFP batteries for recycling. The next section delves deeper into the market dynamics and applications of lithium-ion battery packs, including LFP and NMC chemistries.

4.2 GLOBAL TRENDS: LITHIUM BATTERIES FOR MOBILITY AND ENERGY STORAGE SYSTEMS

The demand for lithium batteries across the world, reached 1.6 TWh in 2025 with mobility use cases accounting for 84% of the demand, followed by battery energy storage systems (BESS) and consumer electronics.[50] Over the past decade, lithium-ion battery technologies have undergone significant maturation, driven by innovations in materials, manufacturing processes, and economies of scale. Average lithium-ion battery pack prices in 2025 fell to a record low of USD 108 per kilowatt-hour (kWh), less than half the price in 2018. The global battery market size is estimated to touch 6.8 TWh by 2035 and nearly 85% of this demand will be for LiBs, driven by the increase in EV adoption and energy storage.[42]

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Notably, battery manufacturers in Asia, specifically in China, produce 75% of the batteries sold globally. The Chinese battery ecosystem is well equipped with presence of actors along all the steps of the supply chain from mineral refining to recycling. As a result, the battery pack prices in China were reportedly the cheapest, while the battery pack costs in the US and Europe were approximately 31% and 48% higher.[51] This has prompted other governments to introduce incentives for localized industries to produce batteries and decentralise manufacturing.[52] Some of the key global examples for second-life application of EV batteries are given below.

Case Study: Second-Life Application of EV Batteries

- **Enel X** constructed an energy storage solution at its thermal power plant from 78 second-life battery packs provided by auto manufacturer Nissan, which reduced the risk of power cuts in the autonomous city of Melilla. The system can deliver power of up to 4 MW and a maximum stored energy of 1.7 MWh.

  Key outcomes:

  - Reduced grid outage risks by providing fast-response backup power
  - Extended the functional life of EV battery packs by approximately six years, delaying recycling
  - Lower system costs compared to equivalent new battery installations
  - Demonstrated a circular economy model, integrating EV battery reuse into critical energy infrastructure.[53]
- **Redwood Materials (United States):** Redwood Materials' division Redwood Energy repurposes retired EV batteries into modular energy storage systems. Its first commercial installation, a 12 MW/63 MWh microgrid in Nevada, used refurbished batteries to support a datacentre power system capable of displacing fossil fuel power generation while providing grid-interactive services. This project represents one of the largest second-life battery deployments worldwide.[54]
- **Jaguar Land Rover (United Kingdom):** In partnership with Allye Energy, Jaguar developed a mobile 270 kWh energy storage unit using second-life batteries from Range Rover plugin hybrids. This energy storage unit is intended to replace diesel generators and support electric vehicle ecosystems during product testing and deployment.[55]

While countries are building regionalized supply chains, it is still a long drawn-out process to achieve energy security with regard to supply of LiBs. In this regard, the second-life EV market holds significant potential, though it remains at a nascent stage. Globally, it was estimated that 100-200 GWh of EV batteries could be available of second-life applications by 2030.[56] As India is in the early stages of developing cell manufacturing facilities and recycling of LiBs, parallelly developing innovative solutions to establish a second-life application market for EVs would result in optimal utilization of the batteries. This could complement the efforts to develop a robust recycling industry to secure battery-grade minerals from urban mining of EV batteries.

The second-life EV batteries could lower the capital cost of stationary storage by 30–70% compared to new batteries, improving project viability and returns.[57] When batteries are repurposed instead of discarded, substantial environmental benefits are gained, such as 15–70% reduction in lifecycle emissions depending on the battery capacity and the second-life application.[58]

Given the economic and environmental benefits of recycling and repurposing EV batteries, countries worldwide have introduced policies and action plans to strengthen end-of-life management. The following section examines these global policy approaches in greater detail.

4.3 OVERVIEW OF GLOBAL POLICIES ON END-OF-LIFE MANAGEMENT OF EV BATTERIES

Policymakers around the world have recognized the importance of managing EV batteries at end-of-life, both to prevent environmental harm and to secure critical materials. Regulations and mandates are evolving to ensure safe recycling practices and given below are battery regulations in a few key countries and regions.

TABLE 4. BATTERY REGULATIONS ON END-OF-LIFE MANAGEMENT OF USED BATTERIES FROM THE EUROPEAN UNION, CHINA AND INDIA

European Union (EU) - Regulation (EU) 2023/1542 (2023)	Manufacturers are responsible for the collection and recycling of EV batteries and must meet the increasing targets.
	Key requirements include:
	■ High recycling efficiencies
	  ■ by end of 2027, recyclers must recover at least 90% of the cobalt, nickel, copper, and lead in battery waste, rising to 95% by end of 2031.
	  ■ For lithium, at least 50% must be recovered by 2027 and 80% by 2031.[59]
	■ In addition, the EU will impose minimum recycled content in new batteries – by 2031, EV batteries must contain at least 16% recycled cobalt, 6% recycled lithium, and 6% recycled nickel (by weight).[60]
	■ The regulation also covers battery passports and transparency – by 2026, batteries must carry a label and by 2027 a QR code giving detailed information on the battery's composition, capacity, and carbon footprint.

China - Interim Measures for the Management of Recycling and Utilization of Power Batteries for New Energy Vehicles (2018)	In China, battery recycling is heavily incentivized through financial and regulatory frameworks.[61] The manufacturer has responsibility of the manufacturing process of batteries and its entire lifecycle, including its recycling and waste disposal. The new EV manufacturers must establish a recording system for tracing all the information on sold vehicles and their owners. To achieve this, the manufacturers must work with scrap vehicle collection entities, to share relevant information that facilitates scrap collection procedures. The regulation also encouraged standardization of battery design, production and verification to improve the assembly and dismantling of used batteries. In addition, this provided provision for repairing and repackaging for second-life utilization.
India - Battery Waste Management Rules 2022	The Government of India introduced the Battery Waste Management Rules 2022, along with the Extended Producer Responsibility (EPR) mandates, to promote circularity in the battery supply chain.[62] These regulations aim to establish a standardized mechanism for the collection, recycling, and reuse of used batteries, ensuring environmentally responsible end-of-life battery management and reducing dependency on raw material imports. The rules mandate that ■ by FY 2027-28, producers must collect at least 70% of the EV batteries they put on the market (cumulatively). ■ Phased material recovery targets – 70% recovery by FY 2024-25, 80% by FY 2025-26, and 90% recovery from FY 2026-27 onwards.[63] ■ Producers must incorporate minimum percentages of domestical y recycled materials, starting at 5% in FY 2027-2028 and increasing to 20% by FY 2030-31.

The current rules do not adequately address key aspects such as labelling requirements for lithium-ion batteries, tracking of materials used within the batteries, regulatory standards for testing and classifying used batteries suitable for second-life applications, and the standardization of battery design for easier repurposing and recycling.

In India, while regulations for battery recycling have been established, effective implementation remains a significant challenge. The current rules do not adequately address key aspects such as labelling requirements for lithium-ion batteries, tracking of materials used within the batteries, regulatory standards for testing and classifying used batteries suitable for second-life applications, and the standardization of battery design for easier repurposing and recycling.[64] Although the central government is responsible for formulating overarching strategies, goals, and mandates, the state governments play a critical role in ensuring these policies are effectively executed at the ground level.

Effective data sharing and management are critical for the efficient handling, repurposing, and recycling of batteries. While labelling remains the most widely used method for conveying basic battery information, it is no longer sufficient given the increasing complexity, material richness, and recyclability of modern batteries. To enable informed decision-making at every stage of a battery's life cycle, from production to second-life applications to end-of-life recycling, the storage and accessibility of detailed technical data are essential.

5. ROADBLOCKS TO ACHIEVE BATTERY CIRCULARITY

Battery circularity can be holistically achieved when there is visibility over the different stages in the battery supply chain, useful life of the battery and end-use management. However, as discussed in the previous sections, data transparency on battery remains a key challenge for unlocking the benefits of battery circularity. We have undertaken detailed consultations with over 20 industry stakeholders, including OEMs, financing institutions, recyclers and civil society organizations, to identify the key challenges across the battery value chain. To achieve low cost financing for EVs, establish a second-hand market for EVs, create value proposition for second-life applications and to achieve better recycling rates, we have to first identify the roadblocks across the battery ecosystem.

5.1 CHALLENGES IN FINANCING, INSURANCE AND SECOND-HAND MARKET DEVELOPMENT FOR EVS

The key challenges that continue to hinder financing and second-hand market evolution for EVs are outlined below:

- **Rapid Advancement in Technology:** Due to the lack of data visibility and transparency, financing institutions and insurers often have limited understanding of EV and battery technologies. Concerns persist around battery safety, lifecycle, and performance, including range, maintenance requirements, and load capacity. These uncertainties are amplified by rapid technological advancements, which raise fears that vehicles could quickly become outdated or lose resale value. Inadequate after-sales service networks, limited availability of spare parts, and the absence of long-term warranties further reduce the confidence of both insurers and financiers. Fragmented data ecosystems limit traceability and transparency, leaving most OEMs without a comprehensive view of battery condition or performance over time.[65]
- **Uncertain Resale and Residual Value:** The secondary market for EVs in India is still very nascent, with unstructured resale processes and no institutionalized buyback or warranty-backed schemes. This makes it difficult for financiers to estimate asset recovery in case of borrower default.[66] The battery poses significant residual value concerns due to limited repurposing and recycling infrastructure in the country.[67] Also the OEMs are adopting varied data storage mechanisms and therefore standardized data on value of residual battery life is not available.
- **Policy and Regulatory Risk:** Both national and subnational governments have introduced various policies and schemes to support transport decarbonization. However, the emergence of multiple fuel and propulsion technologies has led to frequent policy changes, creating uncertainty for consumers and OEMs. This is particularly challenging given the significant investments required for developing and expanding manufacturing facilities to support the EV transition.[68] Moreover, geopolitical disruptions in global EV supply chains, especially in the post-COVID period, have increased concerns over the availability and cost of critical components. These uncertainties have heightened investor and lender apprehensions, thereby limiting proactive financing and slowing sectoral growth.[69]

Case Study: Battery-as-a-Service (BaaS) Model to Reduce High Upfront Cost

To address the challenge of high upfront cost of EVs, several OEMs have introduced Battery-as-a-Service (BaaS) models. For instance, MG, Tata Motors and Maruti Suzuki in the passenger car segment and Honda in the two-wheeler segment have adopted this approach. Under the BaaS model, the battery cost is decoupled from the vehicle price, thereby reducing the upfront purchase cost of the EV.[70,71] Instead, battery usage is converted into an operational expense through subscription or pay-per-use arrangements. This model helps improve affordability, reduces residual value risks for financiers, and enhances the overall bankability of EV assets.

- **Manufacturer Risk:** Many new-age OEMs are still in the early stages of establishing their presence in the EV market. At the same time, some of the two-wheeler and three-wheeler manufacturers face challenges in sustaining advanced technologies. These manufacturers often lack adequate scale, quality assurance systems, and after-sales service capabilities required to meet formal lending standards. As a result, financial institutions remain cautious in extending credit for products from lesser-known or unreliable OEMs, perceiving them as high-risk assets.[72]
- **Utilisation and Operations Risk:** EVs have higher upfront costs and lower operating expenses, making their financial viability dependent on high utilization. Downtime due to technical issues, poor maintenance, or charging constraints can reduce revenues, especially for commercial operators, affecting loan repayment and increasing default risk.[73] Limited awareness of EV maintenance needs, shortage of trained technicians, and improper upkeep practices further impact vehicle

performance, lifespan, and resale value. These factors heighten asset risk and contribute to higher NPAs in EV financing portfolios.[74]

5.2 CHALLENGES FOR END-OF-LIFE MANAGEMENT OF EV BATTERIES

Deployment of EOL batteries involves the following technical challenges that arise from variability in battery condition, limited data availability, safety risks, and system integration constraints:

- **Battery Heterogeneity:** Second-life batteries originate from diverse vehicle models, manufacturers, and operating environments, resulting in substantial heterogeneity across chemistries, cell and module formats, and degradation patterns. Studies indicate that even battery packs retired from similar vehicle models can exhibit capacity variations of 10–30% and materially different internal resistance levels, depending on driving behaviour, charging frequency, and thermal exposure during first life.[75] Batteries with mismatched capacities, internal resistances, and ageing trajectories do not perform uniformly when combined in a single system. As a result, second-life deployments require additional sorting, grading, and system-level controls that are not necessary for new batteries manufactured to standardized specifications.[76]

Studies indicate that even battery packs retired from similar vehicle models can exhibit capacity variations of 10–30% and materially different internal resistance levels, depending on driving behaviour, charging frequency, and thermal exposure during first life.

- **Battery Dismantling:** Diverse battery designs and the way they are integrated into the EVs, make battery dismantling complex and labour intensive process. Due to the absence of universal safety guidelines and stricter protocols for battery dismantling, there is a potential risk of fire, electrocution and exposure to hazardous materials. Moreover the lack of standardized processes for dismantling leads to dependency on manual labour which hampers scalability.
- **Standardisation of SoH calculation:** A core technical limitation in second-life deployment is the absence of standardised and universally accepted methods to assess State-of-Health (SoH). SoH estimation for aged lithium-ion batteries is inherently complex, as degradation mechanisms are non-linear and chemistry-specific. SoH estimation methods for second-life lithium-ion batteries face significant uncertainty due to variability in chemistry, cycling history, and usage protocols; this uncertainty arises because there are no universally accepted SoH testing standards or protocols. Accurate SoH assessment is critical for operational sizing, warranty design, and risk evaluation, yet it still remains an open research problem.[77]
- **Data Gaps from First-Life Usage:** Second-life evaluation is further constrained by incomplete or missing first-life usage data. Detailed records on charge-discharge cycles, depth of discharge, temperature exposure, and fast-charging frequency are often proprietary and not transferred when batteries exit vehicle service. Notably, limited access to battery usage data is one of the key barriers to scaling reuse markets, as it undermines confidence in remaining life estimates and safety margins. In the absence of historical data, second-life operators must rely on conservative assumptions and costly diagnostic testing, reducing economic viability.[78]
- **Safety Risks:** Safety considerations represent a critical obstacle in large-scale applications and second-life battery systems. Aging batteries may be more susceptible to thermal runaway, particularly if latent defects or internal damage accumulated during the first life go undetected. A review of lithium-ion battery safety mechanisms shows that degraded cells are more susceptible to failures like thermal runaway under abuse conditions, requiring advanced monitoring and mitigation.[79] Uneven degradation across cells and modules, can lead to overcharging or overheating if not carefully managed. Compared to new batteries, second-life systems therefore require more sophisticated battery management systems, enhanced monitoring, and conservative operating envelopes to mitigate safety risks. In BaaS model, the safety risk becomes prominent as the EV user may not know the SoH of the swapped battery as these batteries are floating entities in the business model.

Uneven degradation across cells and modules, can lead to overcharging or overheating if not carefully managed. Compared to new batteries, second-life systems therefore require more sophisticated battery management systems, enhanced monitoring, and conservative operating envelopes to mitigate safety risks.

- **Challenges in Battery Collection and System Integration:** The collection of used batteries in the current system are mostly handled by the informal sector until they reach the EOL management companies. There is lack of responsible agencies to collect, segregate, store and safely transport the used EV batteries. Deploying second-life batteries at scale requires the aggregation of multiple used battery units into coherent systems, which introduces additional integration challenges. Differences in voltage profiles, module architectures, communication protocols, and thermal behaviour often necessitate customised power electronics and control strategies. Moreover, performance uncertainty complicates forecasting, dispatch optimisation, and maintenance planning in grid-connected or commercial energy storage applications. These integration challenges reinforce the fact that second-life batteries cannot be treated as modular, interchangeable components without additional technical intervention.

These technical challenges have direct implications for downstream stakeholders:

- **Insurers** face difficulty in pricing risk due to the absence of standardised safety benchmarks and predictable failure profiles.
- **Financiers** face heightened uncertainty about asset life, performance, and residual value, which can raise the cost of capital or limit access to finance.
- **Second-life operators** must absorb higher testing, sorting, and system integration costs, reducing margins and slowing scale-up.

Collectively, these challenges indicate that EOL management requires additional technical and compliance costs, directly influencing its economic viability, which depends on supporting systems and institutional frameworks. The data transparency across the battery value chain is critical for efficient EOL management of batteries. The next sections provides a detailed explanation of how battery traceability regulations play a key role in enabling a circular battery value chain.

Photo: Magnific

6. BATTERY PACK AADHAAR – UNLOCKING THE POTENTIAL FOR INDIA

The adoption of EVs in India received a major push with the introduction of schemes such as Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) I & II, Electric Mobility Promotion Scheme (EMPS) and PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE). The growing adoption of EVs increased the demand for critical minerals. For example, an electric car would require nearly six times more minerals as compared to an ICE car due to the presence of a large battery, motor and other components.[80] Although India has around 18 GWh of announced lithium-ion batteries (LiBs) manufacturing capacity, if the current trends persist, by 2030, only 13% of the battery cell demand could be sourced domestically.[81,82] This implies that still most of the lithium cells would be imported, which defies the country's goal to achieve energy security.

To develop a battery circular economy, it is critical to first have visibility across the entire EV battery supply chain:

- Upstream (mining, processing and refining),
- Midstream (cathode and anode material production, electrolyte manufacturing),
- Downstream (cell manufacturing and assembly of battery pack),
- EV usage (battery life and health), and
- End-of-Life Management (repurposing/refurbishing and recycling).

Presently, OEMs are disclosing limited information from their battery suppliers, which is hampering visibility on the upstream, midstream and downstream processes. Furthermore, during the life of an EV, crucial information on EV usage and battery performance is not readily disclosed by the EV OEMs. Without proper data from stakeholders across the EV value chain, the EOL management for an EV battery is a herculean task. Adding to this, non-disclosure of the materials used in the battery pack makes it difficult to design fire control strategies for different battery chemistries.

To improve EOL management of EV batteries, key policies were introduced in the following countries: China, the European Union, Japan, South Korea, the United States of America, Latin America, South Africa and India.[83] While these policies were aimed only at providing the guidelines for EOL management, they were not sufficient to address the other challenges faced by stakeholders such as financing institutions and insurers, and had minimal impact on fostering a second-hand EV market or achieving battery circularity. This led to an increased need for battery circularity and subsequently China, the European Union and India have announced initiatives in this direction.

In India, the Office of the Principal Advisor to the Government of India released the "E-mobility R&D Roadmap for India" which included a key initiative on Battery Pack Aadhaar system in July 2024.[84] Following this, the Ministry of Road Transport and Highways (MoRTH) constituted a committee which later released the draft "Guidelines for Implementation of Battery Pack Aadhaar System" in December 2025.[85]

The Battery Pack Aadhaar is an ingenious digital identification and data storage system developed to ensure end-to-end traceability of batteries throughout their entire lifecycle. This system would complement the Battery Waste Management Rules in India and the potential benefits of the Battery Pack Aadhaar system are detailed in the following section.

> "The Battery Pack Adhaar initiative comes at the right time and represents a pivotal step towards integrating India-first digital identity centering energy security and resilience. More than a compliance framework, it can enable lifecycle transparency for both data custodian and data user; catalyze value-addition for domestic industry and demonstrate the nation's leadership in responsible battery governance."
>
> **– Ms. Anannya Das Banerjee, Associate Director, Global South Center for Clean Transportation (GSC), ITS – UC Davis**

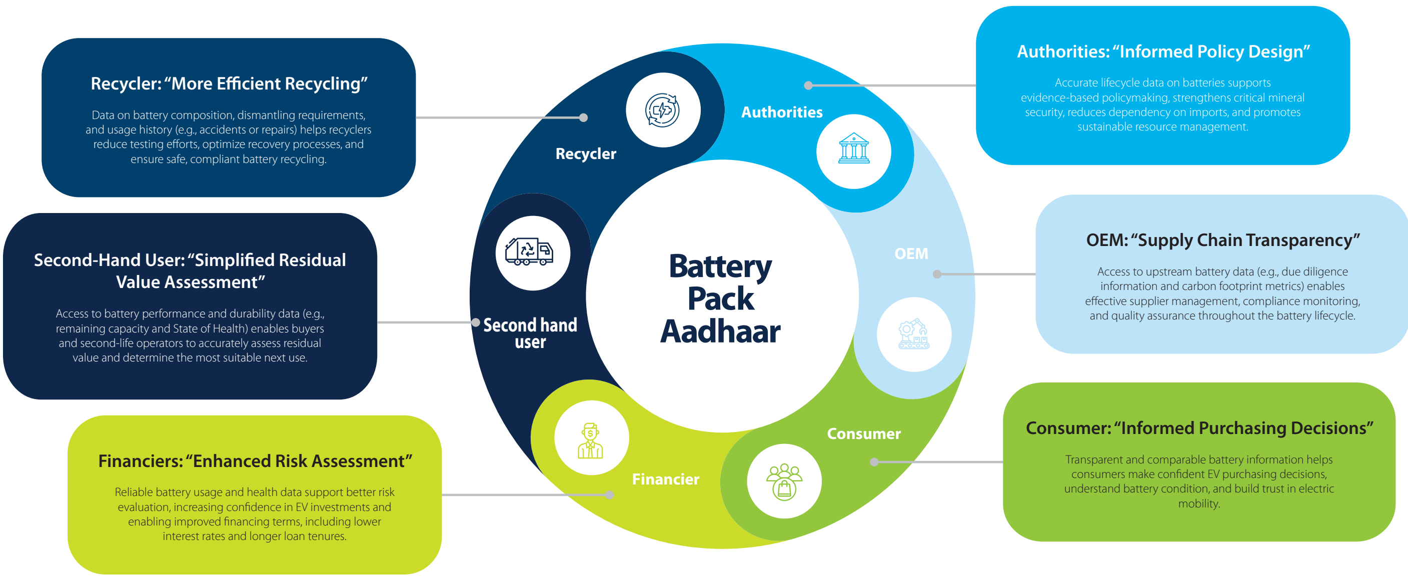
6.1 POTENTIAL BENEFITS OF BATTERY PACK AADHAAR SYSTEM

A well-established Battery Pack Aadhaar system could address the following key concerns:

- **Traceability and Safety:** This system is aimed at providing end-to-end traceability to batteries and their components from cradle to grave. This will help in knowing whether the battery is currently in use or whether the EOL management was undertaken adhering to the regulations. In the event of an EV battery mishap or fire, the data sharing through Battery Pack Aadhaar system enables root-cause traceability down to the battery's composition, cell manufacturer batch number and details of importer. This level of transparency helps in identifying defects, assigning liability to the responsible entity, and implementing corrective measures to prevent future incidents. This transparency helps OEMs diagnose product issues, assign liability, implement corrective actions, and build greater consumer trust in EVs.

- **Critical Mineral Security and Import Reduction:** India is expected to retire around 128 GWh of batteries annually by 2030, up from just 2 GWh in 2023.[86] This could represent a market opportunity of approximately INR 8,300 crore (USD 1 billion) per year.[87] Battery Pack Aadhaar system could enable efficient recovery of critical minerals from used batteries, potentially reducing import dependency.[88] Additionally, it can provide authorities with accurate data to support fact-based policy design for resource security.
- **Improved Low-Cost Financing and Insurance:** By enabling standardized valuation of used batteries based on their SoH, chemistry, and potential second-life use, this system could instil greater confidence among financial institutions. This could lead to more low-cost financing options with longer tenures, which would further accelerate EV adoption. The Battery Pack Aadhaar system can enable standardized diagnostics and traceability which could reduce risk uncertainty, allowing insurers to rationalize premiums and design affordable EV-specific products.
- **Optimized Second-Life Utilization:** Since EV batteries are made up of critical materials, the data sharing provisions under the Battery Pack Aadhaar system could allow stakeholders to evaluate battery health and conduct detailed diagnostics at both the cell and pack levels. This enables informed decision-making regarding second-life applications, whether through repurposing, partial refurbishment, or recycling for mineral recovery. Such insights help determine the most appropriate post-mobility use case, ensuring optimal resource utilization.[89]

FIGURE 4. POTENTIAL BENEFITS FROM IMPLEMENTATION OF BATTERY PACK AADHAAR



Source: AEEE-NRDC Analysis

The proposed Battery Pack Aadhaar guidelines benefit stakeholders by supporting traceability, informed decision-making, risk assessment, and efficient EOL management. Building on this multi-stakeholder framework, the next section examines global best practices in battery traceability.

6.2 INTERNATIONAL INITIATIVES ON BATTERY TRACEABILITY

Efforts to introduce battery passports, digital records uniquely linked to an individual battery that store standardized, verifiable data describing the battery's composition, provenance, performance, environmental footprint, and lifecycle history, are ongoing across the globe. In 2018, China launched the "Interim Provisions on the Traceability Management of Power Battery in New Energy Vehicle" regulatory framework.[90] The regulations cover the entire battery lifecycle, from manufacturing through to recycling, and apply to all relevant stakeholders in the mainland Chinese market, as well as Hong Kong, Macau, and Chinese Taipei.[91,92] It mandates that all EV batteries are assigned a Unique Identification Number (UIN), registered on the National Monitoring and Comprehensive Management Platform for Power Battery Traceability, and updated within 10 working days following key events like sales, servicing, repurposing, or recycling. As of December 2022, reporting statistics show that over 14.6 million new energy vehicles (NEVs) and 18.6 million battery packs were logged.[93] To ensure accountability across the battery value chain, these regulations clearly assign recycling responsibilities to battery and automobile manufacturers.

In Japan, Ministry of Economy, Trade and Industry (METI) plans to mandate the disclosure of EV battery production emissions.[94] This will require manufacturers to report emissions data directly to METI, initially as a prerequisite for subsidies and later for consumer transparency, with plans for third-party verification mechanisms. At present, this policy does not use the term "battery passport;" instead, it mandates emissions disclosure, but it sets the groundwork for a digital battery passport system.

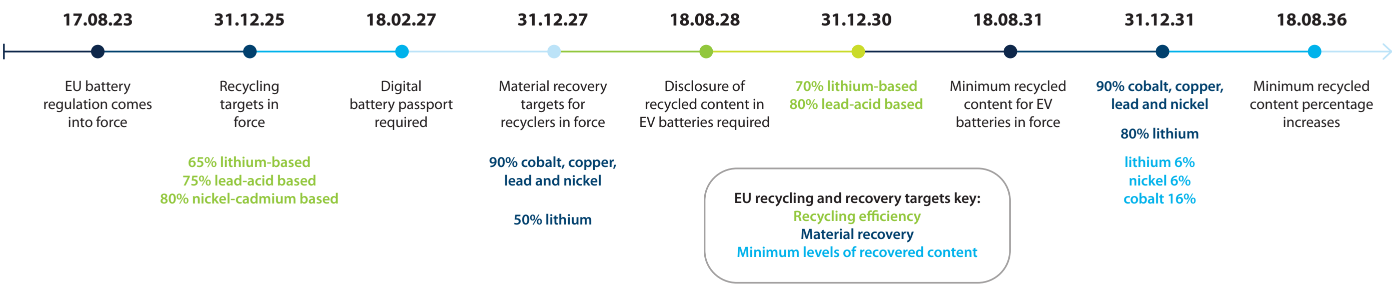
The European Union took a major step by including Battery Passport under the Battery Regulation (EU) 2023/1542.[59] The Battery Regulation mandates a comprehensive set of data attributes for the passport, with information selectively shared among the public, regulators, and service/end-of-life operators, each with specific permissions to balance transparency and data privacy. The details on the EU Battery Passport is provided in the following section.

6.2.1 THE EU BATTERY PASSPORT: DECENTRALIZED APPROACH FOR BATTERY TRACEABILITY

By 2030, it is estimated that the European Union (EU) would need 5 times more cobalt and 18 times more lithium compared to the demand in 2018, and an exponential increase in the demand is expected by 2050.[95] To ensure a sustainable transition to transport electrification, a system-level approach is needed, focusing on responsible material sourcing, efficient battery production, and effective end-of-life processing.

To support the EU's shift towards a circular economy, Regulation (EU) 2023/1542 was developed to ensure that future batteries have a lower carbon footprint and minimal use of harmful substances. It aimed at enabling effective collection, reuse and recycling of batteries within the EU.[59] Building on the 2023 regulation, the EU enforced the Eco-design for Sustainable Products Regulation (ESPR) in 2024, and it was aimed at improving the circularity, recyclability, energy performance and durability of products entering the EU market.[96] The ESPR introduced the Digital Product Passport (DPP) as a tool that will electronically register, process and share product-related information amongst supply chain businesses and authorities. DPPs are standardized digital records linked to a physical product, and they aim to enhance transparency and sustainability by providing access to data on materials, manufacturing, usage, and end-of-life management. Batteries are the first product group for which the use of a DPP will be a legal requirement as of 2027, through the EU Batteries Regulation.

FIGURE 5. TIMELINE OF THE EU BATTERY REGULATIONS



Source: The Advanced Propulsion Centre UK[97]

The key highlights from the EU Regulation concerning batteries and waste batteries is detailed in the table given below.[98]

TABLE 5. KEY HIGHLIGHTS FROM THE EU REGULATION ON BATTERIES AND WASTE BATTERIES (2023)

Key Parameter	Description
Battery Passport is mandated	■ February 2027
Battery Type	■ Any battery sold or used in the EU whether produced within the EU or outside ■ Light Means of Transport Battery (LMT battery, battery weight ≤ 25 kg): e-bicycles, e-bikes, e-scooters ■ Electric Vehicle Battery (weight > 25 kg): 2,3,4-wheeled vehicles (both passenger and goods transport) ■ Industrial battery (weight > 5 kg): any battery that is not an SLI, LMT or EV battery
Battery Labelling	■ Label on the battery with following details: ■ Manufacturer identification, battery identification, date of manufacture ■ Weight, Capacity, Chemistry ■ Presence of hazardous substance, usable extinguishing agent ■ Presence of critical raw minerals ■ Battery passport to be accessible through QR Code in compliance with ISO/IEC standards ■ CE marking (mark of European Conformity) which ensures that the battery meets the EU requirements and it can be marketed freely in the EU regardless of manufacturing location

TABLE 5. KEY HIGHLIGHTS FROM THE EU REGULATION ON BATTERIES AND WASTE BATTERIES (2023)

<table>
<tr><th>Key Parameter</th><th>Description</th></tr>
<tr><td>Battery Passport Data Storage</td><td>The battery passport data will be stored by the economic operators[i] across multiple interconnected locations</td></tr>
<tr><td>Dynamic Data Storage</td><td>Decentralized: Data on SoH and expected lifetime of batteries is locally stored in the BMS of the battery, mandatory from August 2024
Applicable for stationary battery storage systems, LMT and EV batteries</td></tr>
<tr><td>Data Access</td><td>End-user or any third party acting on behalf of the end-user
Read-only access to be provided through the QR Code
Consumers, economic operators and relevant actors to have access to battery passport free of charge
All information to be based on open standards and in an interoperable format</td></tr>
<tr><td>Data Update Frequency</td><td>At least daily or more frequently depending on the purpose</td></tr>
<tr><td>SoH estimation</td><td>Technical specification from the informal UNECE Working Group on Electric Vehicles on data access in EVs must be considered as benchmark for SoH and expected lifetime estimation of EV batteries
EV batteries: Only one parameter, the State of Certified Energy (SOCE) - percentage of usable battery energy retained as the battery ages
LMT & Industrial batteries (BESS): Multiple parameters such as remaining power capacity, capacity fade, energy throughput, tracking of harmful events, no. of charge-discharge cycles and so on.</td></tr>
<tr><td>Carbon Footprint Declaration</td><td>Rechargeable industrial batteries more than 2 kWh, LMT batteries and EV batteries must draw up a carbon footprint declaration for each battery model per manufacturing plant
The carbon footprint must be calculated for 4 stages of battery lifecycle:
Raw material acquisition and pre-processing
Manufacturing
Distribution
End-of-Life & Recycling
The calculation of carbon footprint during the useful life of the battery is excluded from the scope of this regulation.
The date from which the carbon footprint declaration shall apply from is summarized in the table given below.
<table>
<tr><th>Type of Battery</th><th>Date</th><th>Guidelines</th></tr>
<tr><td>EV Batteries</td><td>18 February 2025</td><td>- Adopted a Delegated Act and published the methodology for calculation and verification of carbon footprint of EV batteries[99]
- Unit: kg CO_2-equivalent per kWh</td></tr>
<tr><td>Rechargeable Industrial Batteries without external storage</td><td>18 February 2026</td><td>- Published Rules for the calculation of Carbon Footprint of Industrial Batteries without external storage[100]
- Unit:
(a) Repetitive Energy Supply Batteries: kg CO_2-equivalent per kilowatt-hour
(b) On-Demand Batteries: kg CO_2-equivalent per kilowatt-minute-year</td></tr>
<tr><td>LMT Batteries</td><td>18 August 2028</td><td>To be notified</td></tr>
<tr><td>Rechargeable Industrial Batteries without external storage (BESS)</td><td>18 August 2030</td><td>To be notified</td></tr>
</table>
</td></tr>
</table>

i Economic Operator includes the manufacturer, authorized representative, the importer, the distributer, the service provider who has legal obligation towards manufacturing, repurposing, remanufacturing of batteries or placing batteries on the market.

<table>
<tr><th colspan="2">TABLE 5. KEY HIGHLIGHTS FROM THE EU REGULATION ON BATTERIES AND WASTE BATTERIES (2023)</th></tr>
<tr><th>Key Parameter</th><th>Description</th></tr>
<tr><td>Recycling Targets</td><td>
Targets for recycling efficiency
<table>
<tr><th>Type of Batteries</th><th>By 31 December 2025</th><th>By 31 December 2030</th></tr>
<tr><td>Lead-Acid</td><td>75%</td><td>80%</td></tr>
<tr><td>Lithium</td><td>65%</td><td>70%</td></tr>
<tr><td>Nickel-Cadmium</td><td>80%</td><td>Not Specified</td></tr>
<tr><td>Others</td><td>50%</td><td>Not Specified</td></tr>
</table>
Targets for recovery of materials
<table>
<tr><th>Material</th><th>By 31 December 2027</th><th>By 31 December 2031</th></tr>
<tr><td>Cobalt</td><td>90%</td><td>95%</td></tr>
<tr><td>Copper</td><td>90%</td><td>95%</td></tr>
<tr><td>Lead</td><td>90%</td><td>95%</td></tr>
<tr><td>Lithium</td><td>50%</td><td>80%</td></tr>
<tr><td>Nickel</td><td>90%</td><td>95%</td></tr>
</table>
</td></tr>
<tr><td>Battery Due Diligence Policy</td><td>

Initially applicable to economic operators with turnover more than EUR 40 million in a financial year, scheduled for August 2025
To allow more time to prepare for battery makers, postponed by two years to August 2027 and applicable to economic operators with turnover more than EUR 150 million in a financial year; exempting Small and Medium Enterprises (SMEs)[101]
Not applicable to economic operator involved in battery reuse, refurbishing, repurposing or remanufacturing
Communicate the company battery due diligence policy to the suppliers and public regarding raw materials and associated social and environmental risk categories
Design and implement strategy for risk management across the supply chain
Carry out third-party verification of battery due diligence policies

</td></tr>
<tr><td>Transfer of Battery Passport for EOL Management</td><td>

BMS to have software reset function which will be used to upload different BMS software by economic operators involved in reuse, repurposing or remanufacturing of batteries
Battery subjected to reuse, repurposing or remanufacturing will have new battery passport linked to the original battery passport
The battery passport of recycled battery will cease to exist

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

The roles and responsibilities of key stakeholders to implement the EU battery regulations are described in the table given below.

<table>
<tr><th colspan="2">TABLE 6. ROLES AND RESPONSIBILITIES OF KEY STAKEHOLDERS AS DESCRIBED IN THE EU BATTERY REGULATION</th></tr>
<tr><th>Key Stakeholder</th><th>Roles & Responsibilities</th></tr>
<tr><td>Economic Operator includes the Manufacturer, authorized representative, the importer, the distributer, the service provider</td><td>

Ensure only those batteries in conformity with the regulation are made available in the market
Carry out conformity assessment & affix the CE marking where applicable
Draw up the EU declaration of conformity for each battery model & retain it with technical documentation for at least 10 years after the last battery of the respective battery model is in the market
Ensure that the information in battery passport is accurate
Store the data on battery passport
Ensure that corrective action is taken for non-compliant batteries
Extended producer responsibility for EOL management of batteries
Finance the cost of collecting, treating, recycling all collected batteries, providing information to end-users and waste operators about the batteries, their re-use and management of waste batteries.
Proactively inform end-users on mandatory separate collection of waste batteries and the collection schemes
Report to Competent Authorities on the collection and treatment of waste batteries

</td></tr>
<tr><td>Conformity Assessment Body</td><td>
Perform conformity assessment activities including calibration, testing, certification and inspection
</td></tr>
</table>

TABLE 6. ROLES AND RESPONSIBILITIES OF KEY STAKEHOLDERS AS DESCRIBED IN THE EU BATTERY REGULATION	
Key Stakeholder	**Roles & Responsibilities**
Notified Body	■ Conformity assessment body notified by the Member States ■ Chosen by the manufacturer to carry out examinations, measurements and tests ■ Issue a certificate of conformity
Competent Authority	■ Monitor & verify the obligations for producer and producer responsibility organizations ■ Grant registrations to producers and collect fees from producers for registration
Member States	■ Establish a register of producers ■ For each calendar year, provide information to the EU Commission on number of batteries supplied within their territory and the amount of waste batteries collected, by category and chemistry. ■ Information must be accompanied by a quality check report. ■ Report on rates for recycling efficiency and recovery of materials achieved ■ Lay down rules on applicable penalties for non-compliance

The access to data under the EU Battery Passport are granted among stakeholder at two levels: battery model and individual battery. The battery model refers to all battery units which share same technical characteristics and belong to the same model identifier. By August 2026, the EU will adopt implementing acts which will specify the persons who are to be considered of legitimate interest. While the development of supporting guidelines and acts for the full implementation of EU Battery Passport are underway, there are a range of initiatives carried out in the EU, which led to the development of proof of concepts or pilots to enable data transparency and circularity across battery supply chains.

6.2.2 PROOF-OF-CONCEPTS AND PILOTS: INDUSTRY-DRIVEN BATTERY PASSPORT INITIATIVES

In the wake of battery traceability programs announced across countries, there were industry-led consortiums which participated in proof-of-concepts and pilots on battery passport in the European Union region. The Global Battery Alliance (GBA), through a multi-stakeholder approach, conducted two rounds of pilots which brought together mining companies, battery manufacturers, vehicle OEMs and IT providers who provided services such as tracking and tracing of batteries.[102] The GBA established 11 separate pilot consortia which was led by key battery manufacturers such as Contemporary Amperex Technology Co., Limited (CATL), EVE Energy Co., Ltd , Farasis Energy, FinDreams Battery, LG Energy Solution, Samsung SDI, Sunwoda and CALB Group Co. Ltd. And together they represented nearly 80% of global EV battery market share. The pilots also involved seven independent IT providers such as Circularise, Circulor, Glassdome, Nanjing Fuchuang Intelligent Manufacturing Technology Co., Ltd., RCS Global - an SLR company, Shenzhen Dianlian Technology, and Shenzhen Precise Testing Technology Co., Ltd.[103] These pilots were conducted in a pre-competitive environment and through the Battery Passport initiative, GBA aims to build a transparency and accountability framework of globally harmonized, traceable, and comparable performance metrics at the product level.

The major learnings from the second wave of pilots carried out in 2024 are given below.[104]

- A full governance structure was required for data disclosures, which would provide an assurance for the participating companies on how and where their data would be shared. Furthermore, it would provide a clear pathway for incentivisation of progressive data disclosure, beyond the minimum requirement.
- In order to scale up the Battery Passport initiative, the next pilots would explore a decentralised model for data exchange and aggregation. When a centralized model was implemented in the 2024 pilots, the challenges evident were around disclosure of sensitive data to third parties and the administrative burden of centralisation. These challenges could be mitigated by developing a detailed digital data exchange framework to allow information technology (IT) providers to work bilaterally with supply chain companies.
- It was important to build a diverse third-party verifiers' ecosystem to avoid potential conflict-of-interest issues. To help the verification process, suitable recognition framework for verifiers and a detailed guidance rulebook of the verification system must be developed going forward.

Another key project, BATRAW, on battery sustainability and circularity, was funded by the EU with participation from 17 partners across 7 countries, including OEMs such as the Renault group and Ford Otosan.[105] The participants included a range of stakeholders across EV battery value chain such as battery manufacturer, EV manufacturer and companies responsible for dismantling, repair, disassembly, recycling and so on. The key objective of this pilot was to develop and demonstrate two innovative pilot systems: (a) sustainable recycling and EOL management of EV batteries; and (b) generate secondary streams of strategically important raw materials from domestic batteries and battery scraps. One of the deliverables was the demonstration of a blockchain platform for data sharing and QR code to enable access (battery passport) for raw material tracking and supply chain transparency. As the results of this project, certain key documents were developed, which included a detailed study on the implementation of the EU Battery Passport, guidelines on manual deactivation and dismantling of battery packs and a report on compliance with the EU's carbon footprint requirements.

From the pilots, it was observed that the battery passport significantly benefitted recycling and second-life application of batteries.[106] However, critical challenges were noted, particularly with regard to data collection and sharing. Many of these companies were accustomed to sharing data where non-disclosure agreements were in place, because this provided an assurance to them that data confidentiality would be maintained with sensitive information. As a result, there was a general reluctance to share data for battery passport without these protective measures in place. The competitive nature of the market also led to lack of trust between the supply chain actors. There were concerns raised around providing full access to data to third parties, and it was crucial to establish data security measures and ensure clarity in the system. Interoperability standards must be in place to ensure that the battery-related data from different global supply chains were provided in defined format. Since most of the guidelines and standards were still not in place, some of the company experts evinced concerns that 2027 timeline for implementation of Battery Passport might be ambitious.

6.3 DECODING DRAFT BATTERY PACK AADHAAR GUIDELINES FOR INDIA

The Government of India announced the national program on Advanced Chemistry Cell Battery Storage to build domestic manufacturing capacity and reduce India's reliance on the import of lithium-ion cells, primarily from China. This production linked incentive (PLI) scheme has a budgetary outlay of INR 18,100 crore.[107] The scheme set an ambitious target of achieving 50 GWh of advanced battery manufacturing capacity in India by 2026. However, by October 2025, only 2.8% of the targeted capacity was commissioned.[108] To support the domestic manufacturing ecosystem, the draft guidelines issued by MoRTH (in 2025) on implementation of the Battery Pack Aadhaar system, are a welcome step. While it is inspired partially from the EU Battery Passport, it has been customized to be relevant to the Indian EV market, which is largely dominated by 2-wheelers and 3-wheelers. These guidelines are intended to complement the 2022 Battery Waste Management Rules, which outline the rules for EOL management of all types of batteries excluding the batteries in equipment used for military purposes or sent to space.

The key highlights from the draft guidelines for implementation of Battery Pack Aadhaar are described in the table given below.[109]

TABLE 7. KEY HIGHLIGHTS FROM THE GUIDELINES FOR IMPLEMENTATION OF THE BATTERY PACK AADHAAR SYSTEM

Key Parameter	Description
Battery Type	■ Categories of batteries as covered by the Battery Waste Management Rules, 2022 ■ EV Batteries for L Category: 2-wheeler, 3 wheeler and quadricycle ■ EV Batteries for M and N Category: all types of 4-wheeler passenger and goods vehicles ■ Industrial Batteries with capacity > 2 kWh ■ Guidelines focuses exclusively on EV applications
Battery Labelling	■ Battery Pack Aadhaar Number (BPAN) consisting of 21 alphanumeric characters ■ QR code allows access to data such as battery material and carbon footprint parameters
Data Type	■ Static Data: Information established when battery pack is manufactured or assembled ■ Dynamic Data: Information captured consistently throughout the battery's lifecycle, influenced by battery usage patterns
Dynamic Data Storage	■ Centralized: Dynamic data is maintained and updated through a centralized server. ■ Internet-based method ■ Suitable storage and access mechanism to be designed to allow interoperability across software platforms
Data Access	■ Public Access: Information publicly accessible ■ Private Access: Authorized entities such as service providers, recyclers, producers or other approved stakeholders
SoH Validation	■ Supports both OEM-calculated SoH and regulator-validated SoH checks ■ Government to develop detailed methodology for validation of SoH

Battery Carbon Footprint	■ The carbon footprint to be calculated as outlined under the EU Battery Passport regulation
	■ The carbon footprint must be calculated for 4 stages of battery lifecycle:
	  ■ Raw material acquisition and pre-processing
	  ■ Manufacturing
	  ■ Distribution
	  ■ End-of-Life & Recycling
	■ The calculation of carbon footprint during the useful life of the battery is excluded from the scope of this regulation.

Transfer of Battery Passport for EOL Management	■ New BPAN must be created for change in attributes of BPAN due to recycling and repurposing by same or new producer/importer

The roles and responsibilities of key stakeholders to implement the Battery Pack Aadhaar System are described in the table given below.

TABLE 8. ROLES AND RESPONSIBILITIES OF KEY STAKEHOLDERS AS DESCRIBED IN THE GUIDELINES FOR IMPLEMENTATION OF THE BATTERY PACK AADHAAR SYSTEM

Key Stakeholder	Roles & Responsibilities
Battery Producer/ Manufacturer/ Importer	■ Register the Battery Manufacturer Identifier and Factory Code with the National Agency (One-Time) ■ Collect relevant information from the suppliers ■ Obtain Technical conformity assessment or Type Approval from Authorized Test Agency ■ Assign the BPAN number to each battery ■ Mark the BPAN on the battery, alphanumeric code and QR code ■ Upload dynamic data of battery pack onto the Government BPAN portal ■ Create a new BPAN for batteries undergoing recycling and repurposing
Supplier of Battery cells/modules	■ Provide information and documentation to comply with requirements
Vehicle Manufacturer	■ Update the BPAN onto VAHAN Database ■ Print alphanumeric code and QR code on the vehicle ■ Change BPAN with new BPAN if the battery pack is replaced with a new one
Authorized stakeholder/ Recycler	■ Provide read-only access to identity and battery data through public access interface ■ Gain access to information such as material composition, carbon footprint and dynamic data through private access interface
Producer/ Service Provider/ Authorized stakeholder/ Recycler	■ Upload the event-based updates during the usage of the battery
Government Authority	■ Audit the premises of battery manufacturers/producers for BPAN number generation capabilities

While the roles and responsibilities are assigned to the relevant stakeholders, there is ambiguity about who would qualify as an authorized stakeholder to access the private data interface. Furthermore, there are 58 data parameters that are included in the Battery Pack Aadhaar guidelines with clear distinction on which parameters can be accessed through the alphanumeric code, the QR code and the server. The public and private categorization specifies the access level for each data parameter; however the dynamic data access and storage mechanism is not detailed.

The guidelines recommend a phased approach for implementation:

- **Phase 1:** Implement Battery Manufacturer Identifier (BMI), Battery Descriptor Section (BDS) and Battery Identifier (BI) in the alphanumeric and the QR Code
- **Phase 2:** Implement Battery Material Composition Section (BMCS) in the QR code and Battery Dynamic Data (BDD) for lifecycle events such as status, SoH and EOL reporting with timestamp in the server
- **Phase 3:** Implement Battery Carbon Footprint (BCF) as an advanced requirement in the QR Code

However, the tentative timeline for the implementation of each phase is not yet specified. The following section delves deeper into the key challenges for the implementation of Battery Pack Aadhaar system in India.

6.3.1 KEY CHALLENGES FOR IMPLEMENTATION OF BATTERY PACK AADHAAR SYSTEM

After the draft guidelines were issued, we undertook detailed bilateral consultations with stakeholders from the industry including electric vehicle manufacturer and battery service providers who had developed products to support battery traceability. The key challenges identified for the implementation of Battery Pack Aadhaar system are discussed below.

- **Identification of Nodal Agency:** MoRTH has released the draft guidelines with a focus on EV batteries and notably MoRTH also manages the vehicle database platform VAHAN in India. However, once the battery reaches the end of its mobility application, then MoRTH would not be well-suited to perform the function of a nodal agency to implement these guidelines for the EOL management of the battery. The Battery Pack Aadhaar system intends to complement the Battery Waste Management Rules, 2022 that come under the purview of Ministry of Environment, Forest and Climate Change (MoEFCC). However, the data on battery sourcing would be of critical concern for the Ministry of Mines (MoM) and the present guidelines do not specify as to which government department would be the nodal agency for the implementation of the Battery Pack Aadhaar system.
- **Limited Access to Upstream Data:** As the battery cells are manufactured outside India, the OEMs which import the cells/batteries may not have access to information on the cell-level data of the battery. The documentation provided by the foreign suppliers to the battery importers may not be in standardized format and the data reporting may not fully comply with the requirements for generating the entire BPAN. Without suitable international data frameworks in place, it will be difficult to access this data and then get it integrated into the Battery Pack Aadhaar system.
- **Dual Reporting of Data:** Some of the parameters listed in the BPAN such as type of construction of the module, type of cooling system are included in the Central Motor

Vehicles Rules (CMVR) Type approval process. Including these parameters once again in the BPAN would increase the administrative burden for the manufacturer.

- **Inclusion of Power Capability Information:** The inclusion of parameters such as original power capability at 80% SOC and 20% SOC, usable capacity between 80% and 20% SOC are derivable values from the battery capacity data. Therefore, inclusion of these as separate parameters is not necessary. Also, the BPAN does not specify to capture the data on temperature range along with the battery capacity when relevant.
- **Updating Dynamic Data:** The responsibility of updating the dynamic data of a battery into the BPAN portal, during its useful life, lies with the battery manufacturer, the producer, or the vehicle manufacturer. For advanced EVs with IoT systems, the data from the battery is regularly collected through onboard diagnostic systems and BMS by the OEM. However, it is not clear as to how the manufacturer will upload the data on the dynamic server and what will be the frequency of uploading this data to maintain the accuracy of the SoH data.
- **Data Security Concerns:** Competitive concerns, even when mitigated through non-disclosure agreements, discourage transparency. Furthermore, a lack of trust between supply chain actors and insufficient awareness of regulatory requirements further hinder data transparency.[110] Relatedly, security and centralization risks arise when a single entity or third-party provider is entrusted with full access to valuable data. Without robust safeguards, such as encryption, and strict access controls, there is a heightened risk of data breaches and misuse.[111] Therefore, the manufacturers are sceptical about storing the data in a centralized server.
- **Lack of Data Standards and Interoperability:** Incompatible data formats make it difficult to integrate information across diverse platforms, complicating both regulatory compliance and operational efficiency. Additionally, ensuring data reliability and verification remains a persistent challenge, especially across global supply chains involving small and medium-sized enterprises (SMEs) that often lack adequate documentation systems. This raises concerns about the credibility of consolidated battery data.

Incompatible data formats make it difficult to integrate information across diverse platforms, complicating both regulatory compliance and operational efficiency.

- **SoH Validation:** Although the guidelines accept OEM-calculated SoH, they prescribe regulator-validated SoH checks. It is challenging to standardize SoH validation methodology across all battery types and use cases in India. Battery chemistries and degradation behavior continue to evolve, and methodology that works well for a few categories of batteries and manufacturers may not be suitable for others.
- **Policy and regulatory challenges:** These include the absence of clear guidelines on stakeholder responsibilities across the battery lifecycle and a lack of harmonized global standards for interoperability. Additionally, concerns persist regarding data privacy, defining access rights, and liability in case of data errors. High compliance costs may disproportionately impact SMEs, highlighting the need for supportive measures such as subsidies or shared infrastructure. Without coordinated regulatory clarity, the widespread and effective deployment of Battery Pack Aadhaar remains difficult.
- **Information and Communications Technology (ICT) infrastructure Setup and Cost:** Ensuring reliable, secure, and interoperable digital systems requires substantial investment in software development, cloud hosting, IoT integration, QR-code tagging, and maintenance. The collection of dynamic data and maintenance of a centralized server will incur certain costs, and it is not clear about who will bear these costs in the EV ecosystem. Also, keeping the data on Battery Pack Aadhaar alive for extended periods will incur additional costs.
- **Cost Burden for Smaller OEMs:** Introduction of this data-oriented solution could result in a cost burden for smaller EV OEMs (2-wheelers and 3-wheelers). Without articulating tangible benefits for these OEMs, they will not be willing to incur the additional costs for Battery Pack Aadhaar as their focus will be primarily on market penetration and growth. Furthermore, they may not have sufficient leverage to get the data from the key players across the battery supply chain.
- **Ambiguity on BPAN during EOL Management:** When a battery gets recycled, the old BPAN must cease to exist as the recycled materials will be used to manufacture a new battery pack. When a battery is refurbished or repurposed, then the a new BPAN would be required to exclude the original manufacturer from any liability arising from these second-life applications of the battery. Presently, the guidelines suggests the creation of a new BPAN for both recycling and repurposing. The mechanism to link the new BPAN to the old BPAN during the EOL management is not mentioned. The BPAN of the first battery will be affixed on the EV body by the vehicle manufacturer and the same will be updated on the VAHAN portal. However, if the battery in the EV gets replaced or if the EV has a swappable battery then there is no clarity on how the BPAN will be transferred across EVs and simultaneously updated on the VAHAN portal.
- **Inclusion of Extinguisher Class Data:** From Section 3, it is evident that control and monitoring strategies for EV battery fires are complex because battery fires are self-sustaining due to thermal runaway. By mentioning the extinguisher class, it could give a false sense of security

or lead to deployment of ineffective emergency strategies by the first responders. Unsuitable action by the first responders could be potentially hazardous.

- **Carbon Footprint Declaration:** While it is mentioned that the methodology followed by the EU Battery Passport for carbon footprint declaration can be adopted by the manufacturers, it is to be noted that the collection of primary data is a challenge in itself. Even in the EU, complexity in the battery supply chain and data confidentiality among the suppliers make it difficult to access the data parameters required for the calculation of carbon footprint. Using secondary data might result in underestimation of the carbon footprint values. If the manufacturers declare non-accurate values, it will be challenging for the notified authorities to have the resources for data verification.

The identification of key challenges has helped us propose recommendations in the following section to strengthen the guidelines for the implementation of the Battery Pack Aadhaar system.

6.3.2 RECOMMENDATIONS TO STRENGTHEN THE BATTERY PACK AADHAAR SYSTEM

There are multiple stakeholders across the battery value chain and ensuring data transparency and compliance across the different stages of the battery lifecycle will be essential for the successful implementation of the Battery Pack Aadhaar system. Based on the challenges identified in the previous section, key recommendations are presented below, along with examples of global practices, where applicable.

- **Nodal Agency with Members from key Departments:** The nodal agency to implement the Battery Pack Aadhaar system could be an independent body established by the Government of India with representatives from all the key departments such as Ministry of Road Transport and Highways (MoRTH), Ministry of Environment, Forest and Climate Change (MoEFCC), Ministry of Mines (MoM), Ministry of Heavy Industries (MHI), Ministry of Power (MoP) and Ministry of Electronics and Information Technology (MEITy). This will help in ensuring the right validation of data from all the actors across all stages of the battery lifecycle. The nodal agency could host the portal with the repository of BPANs for all the applicable batteries.
- **Harmonize Relevant Policies and Regulations:** Most of the static data required for the BPAN are already submitted by the OEM during the CMVR Type Approval certification, and the Automotive Industry Standard (AIS) compliance includes specific requirements for battery safety and performance. Under the Battery Waste Management Rules 2022, the responsibility of different actors for EOL management of batteries is detailed, which can help in collection of data to help close the loop for circularity. Therefore, it is important to harmonize the regulations relevant to the battery ecosystem to streamline the compliance process for the manufacturers.

EU Battery Regulation concerning Batteries and Waste Batteries[98]

The battery passport initiative in the EU is housed within the EU battery regulation. This regulation outlines roles and responsibilities for all the actors and data requirements across the battery value chain. It establishes the guidelines on the processes from conformity assessment to EOL management, including battery carbon footprint declaration.

- **Data Storage at OEMs with Regulatory Audits:** To ensure digital continuity and data transparency from cradle-to-grave for EV batteries, it is recommended to implement the Battery Pack Aadhaar system on a peer-to-peer data sharing model. This will allow the manufacturers and other key actors to first identify the challenges for data transparency across the battery value chain in a pre-competitive environment and build trust for data collection. OEMs have evinced significant concerns around hosting sensitive battery data on a third-party server due to the fear of losing the competitive edge in the market. It is recommended to host the Battery Pack Aadhaar data at the OEM level to promote acceptance among the manufacturers and allay fears of data security. Periodic audits and inspection by the nodal agency must be undertaken to ensure that the OEMs are maintaining the relevant cradle-to-grave data of the batteries that have been deployed.

The OEMs could share data with select actors through on-board diagnostics (OBD) port or any other means of bilateral data sharing. This would entail signing of non-disclosure agreements between OEMs and suppliers, plus OEMs and other stakeholders such as financing institutions, battery service providers, refurbishing companies and recyclers. Furthermore, detailed guidelines could be prepared by the nodal agency for governing the decentralized data sharing process.

EU Battery Regulation concerning Batteries and Waste Batteries[98]

The economic operator is tasked with the responsibility to store the battery passport data at module level and individual battery level. There are no clear pathways defining how the restricted data will be shared among the key actors such as notified bodies, market surveillance authorities, the European Union commission and persons with legitimate interest. The persons with legitimate interest are yet to be defined for this regulation and they could include financing institutions, refurbishing companies, recyclers and second-hand vehicle sellers. Presently, it is left to the market forces to decide on the modality of data sharing between the key actors, through a peer-to-peer system. However, the downside to this approach is that there is no clarity on how the data on battery passports will be available for the concerned parties in the event of the economic operator exiting the business.

- **Develop Supporting Guidelines in Consensus with the Industry:** It is important to involve the industry stakeholders such as battery manufacturers, vehicle OEMs, financing institutions, battery service providers and recyclers while developing the supporting guidelines to implement Battery Pack Aadhaar system. This could include recommending open standards[ii] for data sharing, methodology for SoH benchmarking, methodology for carbon footprint calculation, or developing standards for data collection and access mechanisms.
- **Implement Pre-Competitive Pilots:** The government must encourage multi-stakeholder consortiums to undertake pilots to test the performance of the Battery Pack Aadhaar system for different use-cases. It is important to implement these pilots in an operational environment and collect real-world data which can help test different components of the Battery Pack Aadhaar system. Given that there is a global trend toward digital supply chain transparency, the participating organizations would benefit by staying ahead of the curve and preparing their operations, management systems and reporting structures to be ready for the evolving compliance requirements.

The government must encourage multi-stakeholder consortiums to undertake pilots to test the performance of the Battery Pack Aadhaar system for different use-cases.

Global Battery Alliance's Battery Passport Pilots (2023)[102]

In 2023, the world's first Battery Passport proof-of-concept (PoC) was led by Audi and Tesla, and involved Contemporary Amperex Technology Limited (CATL), LG Energy Solution, Samsung SDI, Eurasian Resources Group (ERG) and others. These pilots led to the development of the Greenhouse Gas Rulebook, and the Child Labor and Human Rights Indices. This exercise helped unlock new fields of competition, evaluate technology readiness, find balance between interoperability and data privacy, and most importantly establish trust in the ecosystem.

- **Building Value Circularity:** Through our consultations, we realize that it is important to develop the value proposition for each key stakeholder across the battery value chain, and to share data with the relevant actors. For example:
  - The incentives under the PLI scheme for National Programme on Advanced Chemistry Cell (ACC) Battery Storage scheme could be linked to data transparency compliance by the battery manufacturer, as an additional eligibility parameter along with domestic value addition percentage and the investment by the manufacturer.
  - Financing institutions could offer preferential financing or offer lower interest rates to the EV models which are compliant with the Battery Pack Aadhaar data requirements.
  - Manufacturers who disclose required data for their batteries could certify these batteries as "responsibly sourced" or "low carbon", allowing them to charge a premium and providing them an opportunity to sell into markets with stringent regulations.
  - Government procurement of EVs could offer preference to those manufacturers with transparent, traceable, and ethical sourcing data for the batteries.
  - While the publicly accessible data could be provided for free, the data parameters with private access could be made available to authorized stakeholders by charging a nominal fee. When the authorized stakeholders realize that the data from the Battery Pack Aadhaar will unlock the bottlenecks in their business, they could be willing to pay the fee.

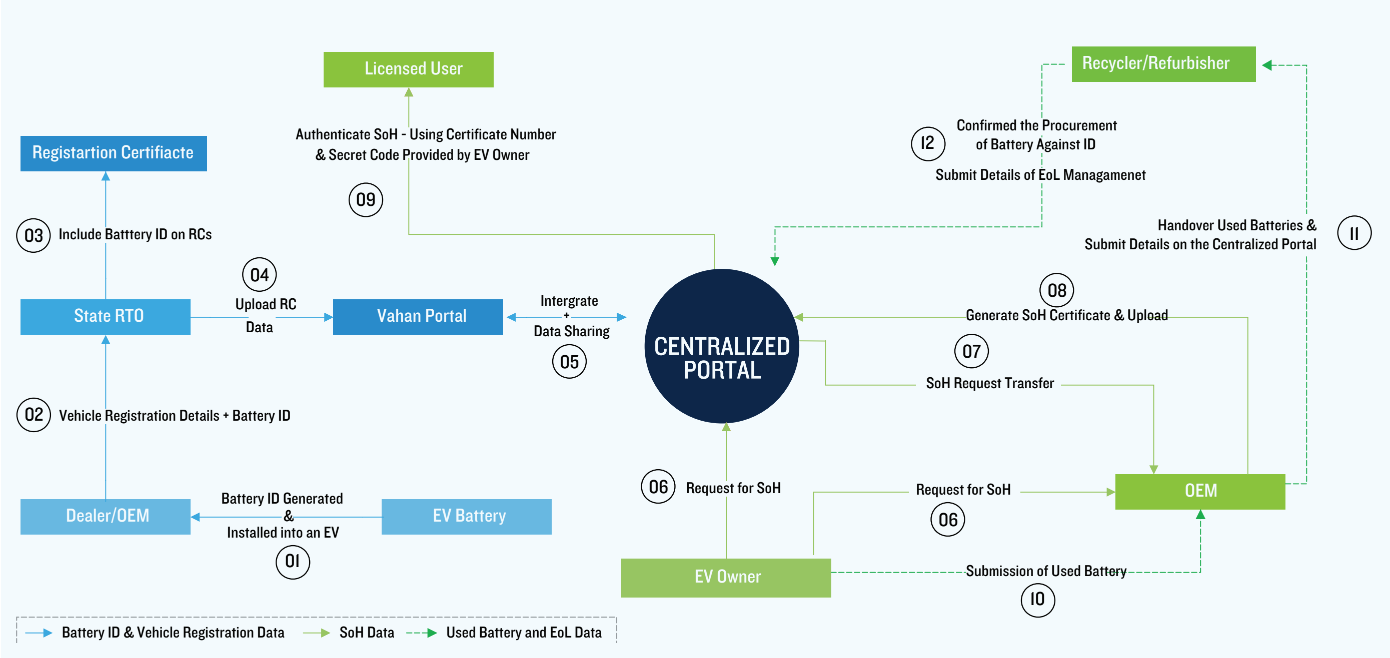
As discussed in the above examples, there is a need to build "value circularity" into the battery ecosystem to encourage compliance among all the concerned stakeholders and ensure battery traceability across the value chain. To unlock the benefits of data sharing on battery SOH for EVs, we have proposed an example of a preliminary governance mechanism for implementation of Battery Pack Aadhaar guidelines. This mechanism is explained in detail in the following section.

6.3.3 FRAMEWORK FOR INITIAL ROLLOUT OF BATTERY PACK AADHAAR SYSTEM IN INDIA

Presently, the data on SoH of the EV battery is not openly shared with either the EV user or the any other stakeholders in the EV ecosystem unless the OEMs agree to share the information. The SoH data of an EV battery can help estimate the residual value of an EV and unlock the second-hand market, improve financing and EV insurance risk underwriting. To address this challenge, we have depicted a potential governance mechanism which could focus on getting the OEM-calculated SoH data of the EV batteries. The flow diagram and the detailed steps involved in the depicted governance mechanism for implementation of Battery Pack Aadhaar system are given below.

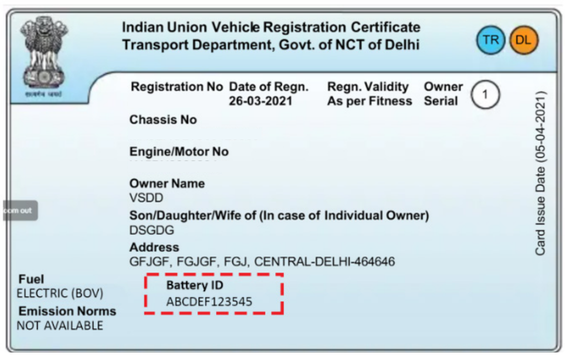
ii Open standards for data sharing are publicly documented, royalty-free and non-discriminatory specifications that enable interoperable, reusable, and secure exchange of data across systems and organisations.

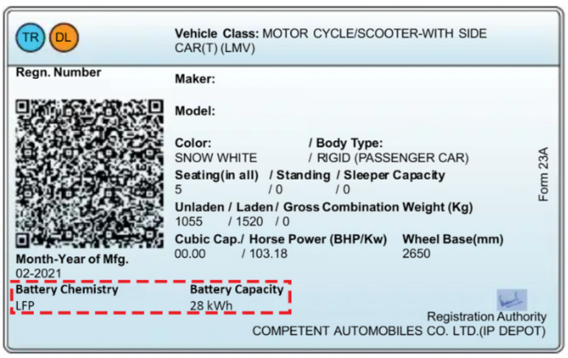
FIGURE 6. ILLUSTRATION OF POTENTIAL GOVERNANCE MECHANISM FOR INITIAL ROLLOUT OF BATTERY PACK AADHAAR SYSTEM IN INDIA



Source: NRDC Analysis

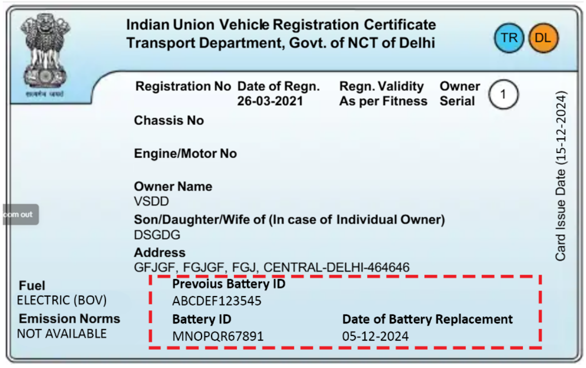
1. The EV Battery Manufacturer or Battery Assembler shall generate a unique Battery ID for every battery pack in accordance with the guidelines prescribed by MoRTH.
2. The dealer or OEM shall mention the Battery ID, battery chemistry, and battery capacity along with the existing vehicle registration details in the RTO registration application form of the EV.
3. The Registration Certificate (RC) shall include the Battery ID, battery chemistry, and battery capacity as part of the EV registration details.





4. Presently the State RTOs are uploading the EV registration details on the Vahan portal. Along with this the specific information on the battery such as the identification number (ID), chemistry and capacity of the EV battery shall be uploaded to the portal.
5. The battery ID could have the following must-have data parameters as depicted in the guidelines.
   Country Code, Manufacturer Identifier, Battery Capacity, Battery Chemistry, Nominal Voltage, Cell Origin, Date of Manufacturing, Factory Code and Sequential Production Number.
6. The Government could establish a Centralized Portal for the Battery Pack Aadhaar initiative or integrate the framework with the existing Vahan Portal to minimize duplication of databases and reduce system complexity. Integration through an additional dedicated webpage/ module within the Vahan ecosystem may also be considered.
7. The EV Owner may request a State of Health (SoH) Certificate through either of the following channels:
   - Directly from the OEM through its website, customer support, authorized dealership, or authorized service center (subject to OEM processes); or
   - Through the Centralized Portal.
8. In cases where the SoH request is initiated through the Centralized Portal, the request shall be forwarded to the respective OEM. Upon receiving the request, the OEM shall generate the SoH Certificate based on the EV data available with the OEM.
9. After generation of the SoH Certificate, the OEM shall upload the certificate to the Centralized Portal. The EV Owner shall be able to access the certificate using an OTP or secure authentication code shared on the registered mobile number and/or email address.

10. The EV owner could share the SoH certificate with the Licensed Users such as financiers, insurers, second-hand vehicle dealers, recyclers, refurbishers, and other authorized stakeholders. The Licensed user shall be able to authenticate the SoH Certificate through the Centralized Portal using the certificate number and OTP provided by the EV Owner.
    - This process shall continue for the duration in which the battery remains in its first mobility application.
    - In case of battery replacement, the OEM shall update the new Battery ID along with the date of battery replacement in the Registration Certificate (RC) and associated records.



11. Upon completion of the battery's mobility application life, the EV Owner shall submit the used battery only to the respective OEM or an OEM-authorized collection channel.
12. After receiving the used battery, the OEM shall hand over the battery only to an authorized Recycler or Refurbisher and upload the relevant details on the Centralized Portal, including:
    - Battery ID
    - Name of the Recycler/Refurbisher
    - Date of battery handover
13. Upon receipt of the battery, the authorized Recycler or Refurbisher shall confirm procurement of the battery on the Centralized Portal within the prescribed timeline and subsequently upload the required EOL management details of the battery onto the portal. This system could complement the Battery Waste Management Rules, 2022, in helping the regulatory authorities to track EPR compliance.

This example of governance mechanism could help in establishing formal basic traceability of the EV batteries. The supporting guidelines and regulations to operationalize this mechanism must be developed to enforce compliance from the OEMs and other relevant stakeholders. While this mechanism has limitations on collecting all the data required for Battery Pack Aadhaar, it could serve as an initial step to ensure the traceability of EV batteries for better EOL management and unlock second-hand market for EVs by providing access to the OEM-calculated SoH data.

> "The report captures emerging perspectives with thoughtful interpretation. It connects current realities with future-oriented insights. Observations are relevant, timely, and well contextualized. The work encourages informed thinking and progressive action." – **Mr. Anil Radhakrishnan, Chief Product Officer, Tata Elxsi**

7. CONCLUSION

India is at the cusp of transport decarbonisation and EV adoption has played a key role in this transition. In 2019, there were only about 350 EV registrations per day and in 2025, this number increased by 18 times to approximately 6,300 EV registrations per day nationally. Through March 2026, the cumulative number of EV registrations stands at around 8.17 million.[112] From these on-road EVs, it is expected that the first generation of EV batteries will reach their end-of-life between 2026 and 2030. An estimate suggests that India could generate nearly 50,000 tonnes of EOL EV batteries annually by 2030.[113] While the country currently still imports 80% of its lithium-cells, establishment in India of a circular economy for batteries depends not only on secure access to raw materials but also on our ability to recover critical minerals from these used batteries.

The draft guidelines released by MoRTH for the implementation of a Battery Pack Aadhaar system in the country is a significant step towards acknowledging that maintaining digital data continuity in the battery ecosystem is essential to track and trace batteries. As shown in the proposed governance mechanism, the OEM-calculated SoH data in the initial stages can help unlock the second-hand market, improve financing and EV insurance risk underwriting. A phased approach for implementation with supporting guidelines and interoperable standards, developed in close consultation with industry stakeholders, could result in a robust battery ecosystem. In this direction, it is essential for the concerned government departments to support industry-led consortia to carry out multiple pilots that can test the implementation of the Battery Pack Aadhaar system.

Building battery circularity will be truly possible only if the system can demonstrate a "value circularity" to all the relevant actors across the battery value chain. The benefit of sharing data must trickle down from the mining companies to the recyclers, for an organic evolution of battery track and trace systems. The successful implementation of a Battery Pack Aadhaar system will be possible when it is led by industry volition and supported by regulatory governance.

Photo: Magnific

8. ANNEXURE

List of Organizations Consulted for this Study

1	AMU Leasing
2	Ather Energy
3	Attero
4	Axis Bank
5	Battery-OK Technologies
6	Department of Science & Technology (DST)
7	Evate Technologies
8	Finayo
9	Housing Development Finance Corporation Limited (HDFC) Bank
10	IIT Bombay
11	LetsEV
12	Lohum
13	OHM
14	Small Industries Development Bank of India (SIDBI)
15	Sun Mobility
16	Tata Elxsi
17	Tata Motors
18	The Energy and Resources Institute (TERI)
19	The Energy Company
20	Transport and Environment
21	Ujjivan Small Finance Bank
22	Vision Mechatronics
23	World Resources Institute (WRI) India
24	Zenfinity
25	Ziptrax
26	Zypp

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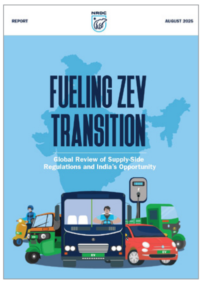
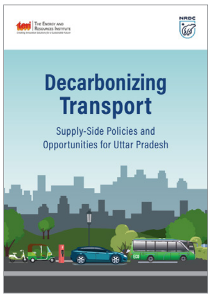
Highlighted Reports



Fueling ZEV Transition: Global Review of Supply-Side Regulations and India's Opportunity



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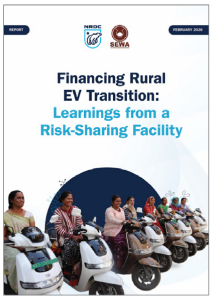
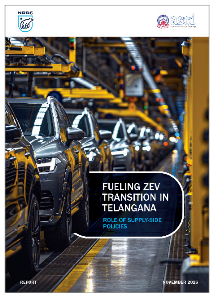


Financing Rural EV Transition: Learnings from a Risk-Sharing Facility



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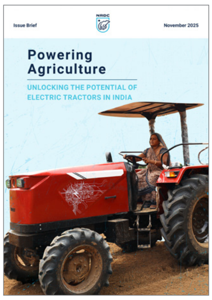
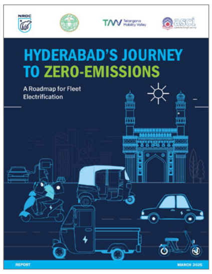
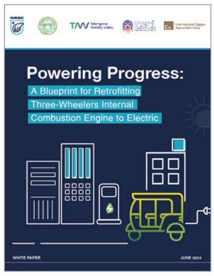


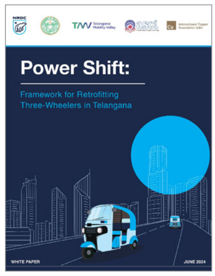
Powering Agriculture: Unlocking the potential of Electric Tractors in India



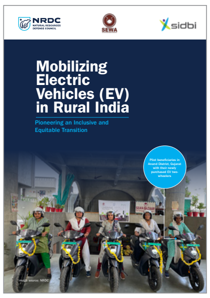
Hyderabad's Journey to Zero-Emissions: A Roadmap for Fleet Electrification



Powering Progress: A Blueprint for Retrofitting Three-Wheelers Internal Combustion Engine to Electric

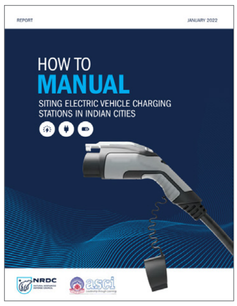


Power Shift: Framework for Retrofitting Three-Wheelers in Telangana



Mobilizing Electric Vehicles (EV) in Rural India

Energizing Freight: Policy Toolkit for Medium and Heavy Duty Truck Electrification in India



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